



**RML UT2300249 – CONDITION 35
COMPLIANCE REPORT
- Revision 2**

JULY 8, 2014





**UTAH RADIOACTIVE MATERIAL
LICENSE - CONDITION 35 (RML UT2300249)
COMPLIANCE REPORT
(Revision 2)**

July 8, 2014

**For
Utah Department of Environmental Quality
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Salt Lake City, UT 84114-4850**

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EXECUTIVE SUMMARY

In 2010, the Utah Board of Radiation Control initiated rulemaking to require a site-specific analysis for disposal of large quantities of depleted uranium. Since that time, EnergySolutions has received (and intends to dispose) 3,577 metric tons of depleted uranium waste that has been declared surplus from the Savannah River Site. However, Utah Administrative Code (UAC) Section R313-25-9(5) prohibits disposal of significant quantities of concentrated depleted uranium after June 1, 2010, until the Utah Division of Radiation Control Director approves a performance assessment that demonstrates that EnergySolutions will, following the disposal of large quantities of depleted uranium, continue to meet the performance standards specified in UAC R313-25-9.

As required by UAC R313-25-9(5), EnergySolutions has completed and hereby submits to the Division for Director approval an in-depth site-specific performance assessment for disposal of depleted uranium. Once approved, it is EnergySolutions' intention to begin disposal of significant quantities of depleted uranium in a Federal Cell using the currently-approved Class A West Embankment cover design. The Federal Cell was initially submitted for DRC approval as the "Class A South" cell, with a revised application and completeness review response package dated June 9, 2009. EnergySolutions' records show that DRC indicated interrogatories on this design were under preparation but not received at the time the application was withdrawn on May 2, 2011.

Because of the legacy processes, depleted uranium from the Savannah River Site contains small quantities of waste fission products and transuranic elements, in addition to depleted uranium. The estimated mass of depleted uranium from the Savannah River Site proposed for disposal in EnergySolutions' Federal Cell is 3,577 metric tons (5,408 drums). This depleted uranium Performance Assessment also evaluates acceptance and disposal of up to 700,000 metric tons of similar depleted uranium waste from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky.

On June 1, 2011, (in compliance with Condition 35.B of its Radioactive Material License UT2300249), EnergySolutions submitted to the Division the Report, "Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report," documenting the depleted uranium Performance Assessment. In response, EnergySolutions received from the Utah Department of Environmental Quality "Task 1: Preliminary Completeness Review" (on October 25, 2013). Following examination of the Preliminary Completeness Review, EnergySolutions submitted revision 1 of its depleted uranium Performance Assessment Report titled, "Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report," (EnergySolutions, 2013a).

On February 28, 2014, EnergySolutions received Round 1 Interrogatories from the Division, requesting clarification and additional information to support the Division's continued review of EnergySolutions' depleted uranium Performance Assessment. Version 1.199 of the depleted uranium Performance Assessment GoldSim model was provided to DEQ reviewers on May 2, 2014. As a result of ongoing research EnergySolutions has conducted regarding cover design and in review of the Round 1 Interrogatories, EnergySolutions revised the initial design of the Federal Cell to include an evapotranspirative cover similar to that currently under review by the Division for construction on the Class A West Embankment. As a result, EnergySolutions created version 1.2 of its depleted uranium Performance Assessment GoldSim model (provided the Division on May 15, 2014). In parallel to constructing the revised GoldSim model to address the performance of the evapotranspirative cover, EnergySolutions submitted responses on March 31, 2014 to the Round 1 Interrogatories.



On May 27, 2014, EnergySolutions received Round 2 Interrogatories from the Division, requesting additional clarification from some of the responses provided to the Round 1 Interrogatories. EnergySolutions submitted responses on June 17, 2014 to the Round 2 Interrogatories. On July 1, 2014, EnergySolutions received Round 3 Interrogatories from the Division, requesting additional clarification for version 1.2 of the Modeling Report (and its associated appendices). EnergySolutions has prepared responses to the Round 3 Interrogatories, attached hereto as Appendix E.

License Condition 35.B of EnergySolutions' Radioactive Material License (UT 2300249) states,

“Performance assessment: A performance assessment, in general conformance with the approach used by the Nuclear Regulatory Commission (NRC) in SECY-08-0147, shall be submitted for Director review and approval no later than June 1, 2011. The performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period will be a minimum of 10,000 years. Additional simulations will be performed for a minimum 1,000,000-year time frame for qualitative analysis.”

EnergySolutions demonstrates compliance with license condition 35 through the development and execution of the detailed, site-specific, probabilistic performance assessment using the GoldSim model. This model and the resulting findings demonstrate that EnergySolutions' proposed methods for disposal of large volumes of depleted uranium will ensure that ongoing operations, safe institutional control, and stable site closure can be conducted, and that the Federal Cell will comply with the Division's radiological criteria contained in the Radioactive Material License.

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ACRONYMS AND ABBREVIATIONS

Term	Definition
11e.(2)	Section 11e.(2) of the Atomic Energy Act of 1954, as amended
Ac	actinium
Act	Utah Radiation Control Act
ALARA	As Low As Reasonably Achievable
Am	americium
AMEC	AMEC Earth and Environmental, formerly AGRA Earth and
ASCE	American Society of Civil Engineers
ASTM	ASTM International, formerly American Society for Testing and
BLM	Bureau of Land Management
Bq	Becquerel
BWF	Bulk Waste Facility
CCE	certified cost engineer
CEDE	committed effective dose equivalent
CFR	U.S. Code of Federal Regulations
Ci	curie
cm/sec	centimeters per second
cm/yr	centimeters per year
CQA/QC	Construction Quality Assurance/Quality Control
CSF	cancer slope factor
CSLM	Controlled Low Strength Material
CSM	conceptual site model
CTC	Cover Test Cell
CWF	Containerized Waste Facility
DCF	dose conversion factor
DDE	deep dose equivalent
Division	Utah Division of Radiation Control
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DRC	Utah Division of Radiation Control
DU	depleted uranium
EDIS	electronic document imaging system
EIS	environmental impact statement

ACRONYMS AND ABBREVIATIONS (continued)

Term	Definition
EPA	U.S. Environmental Protection Agency
ETTP	East Tennessee Technology Park
EWIS	Electronic Waste Information System
FEIS	Final Environmental Impact Statement
FEP	features, events, and processes
FR	Federal Register
ft	foot/feet
Ft	feet; foot
ft/ft	feet per foot
ft-lbf/ft ³	foot-pound force per cubic foot (unit of energy density)
g	gram
GDP	gaseous diffusion plant
GTCC	greater than Class C waste
GWPL	groundwater protection limit(s)
GWQDP	groundwater quality discharge permit
ha	hectare
hr	hour; hours
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiation Protection
in	inch; inches
in/yr	inches per year
ka	thousand years ago
K _d	soil/water partition coefficient
kg	kilogram
km	kilometer
ky	thousand years
L	liter
LARW	low-activity radioactive waste
LLRW	low-level radioactive waste
LRA	License Renewal Application
m	meter
Ma	million years ago
MCL	maximum contaminant level(s)
Mg	megagram (one metric ton)
mg	milligram

ACRONYMS AND ABBREVIATIONS (continued)

Term	Definition
MLLW	mixed [hazardous and] low-level radioactive waste
mm	millimeters
MPa	megapascal
mrem	millirem
mrem/yr	millirem/yr
My	million years
NORM	Naturally-Occurring Radioactive Materials
NQA	Nuclear Quality Assurance
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NUREG	an NRC publication
PA	performance assessment
Pa	protactinium
PAWG	Performance Assessment Working Group (DOE)
pCi	picocurie
pCi/g	picocuries per gram
pCi/m ² -s	picocuries per square meter-second
Po	polonium
ppm	part per million
Pu	plutonium
QA	quality assurance
QAM	Quality Assurance Manual
QAP	Quality Assurance Program
R	Roentgen
Ra	radium
RfD	reference dose
RML	Radioactive Material License (UT2300249), as amended May 10, 2011.
Rn	radon
S&H	safety and health
SLB&M	Salt Lake Baseline and Meridian
SNM	Special Nuclear Material
SRS	Savannah River Site
Tc	technetium
TDS	total dissolved solids

ACRONYMS AND ABBREVIATIONS (continued)

Term	Definition
TEDE	total effective dose equivalent
TF	Treatment Facility
Th	thorium
TSD	Treatment, Storage and Disposal
U	uranium
UAC	Utah Administrative Code
UDOGM	Utah Division of Oil, Gas and Mining
UDSHW	Utah Division of Solid and Hazardous Waste
UDWQ	Utah Division of Water Quality
UMTRA	Uranium Mill Tailing Remedial Action
UNF	used nuclear fuel
URCA	Utah Radiation Control Act
URCB	Utah Radiation Control Board
UAC	Utah Radiation Control Rules
USACE	US Army Corps of Engineers
USGS	United States Geologic Survey
UWQB	Utah Water Quality Board
yr	year

1. INTRODUCTION

EnergySolutions, headquartered in Salt Lake City, Utah is a worldwide leader in the safe recycling, processing and disposal of nuclear material, providing innovations and technologies to the U.S. Department of Energy (DOE), commercial utilities, and medical and research facilities. At its Clive Facility, located 75 highway miles west of Salt Lake City, EnergySolutions operates a commercial treatment, storage and disposal facility for Class A low-level radioactive waste and Class A low-level mixed waste.

Historically, authorization for disposal of depleted uranium was approved by the Division at a concentration of 110,000 pCi/g beginning with License amendment 2, approved December 3, 1990. This activity was increased to the specific activity of depleted uranium; i.e., pure form; with approval of the Performance Assessment submitted in support of the October 22, 1998 License renewal (limiting the depleted uranium within a container to no greater than 370,000 pCi/g, upon receipt). Under this License authorization, approximately 18,400 Ci of depleted uranium were safely disposed in the at Clive between 1990 and 2010.

In 2010, the Utah Radiation Control Board initiated rulemaking to require a site-specific analysis before authorizing the disposal of large quantities of depleted uranium (DU). This rulemaking also applies to 3,577 metric tons (5,408 drums) of uranium trioxide (DUO₃) waste received from the Savannah River Site (SRS) in December, 2009. In compliance with the depleted uranium Performance Assessment prerequisite, EnergySolutions is temporarily holding these drums in storage (awaiting Director approval of this depleted uranium Performance Assessment). In the future, EnergySolutions is also considering disposal of depleted uranium from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky.

As is illustrated in Figure 1-1, EnergySolutions has evaluated a new Federal Cell, using either the Division-approved and licensed Class A West Embankment cover or an evapotranspirative cover design (also under review by the Division for the Class A West Embankment), as the ultimate destination for the large volumes of depleted uranium. The Federal Cell was initially submitted for DRC approval as the “Class A South” cell, with a revised application and completeness review response package dated June 9, 2009. EnergySolutions’ records show that DRC indicated interrogatories on this design were under preparation but not received at the time the application was withdrawn on May 2, 2011. Reviewers should note that the former Class A South cell included an isolation barrier between Class A and 11e.(2) wastes as well as a proposed system for monitoring groundwater beneath this barrier; in order to differentiate the source of any potential groundwater contamination as being from Class A or 11e.(2) wastes. Depending on the terms of a DOE agreement to take stewardship of a Federal Cell, these features may not be required.



Figure 1-1, EnergySolutions' Proposed Federal Cell Location

On June 1, 2011, (in compliance with Condition 35.B of its Radioactive Material License UT2300249), EnergySolutions submitted to the Division the Report, “Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report,” documenting the depleted uranium Performance Assessment. In response, EnergySolutions received from the Utah Department of Environmental Quality “Task 1: Preliminary Completeness Review” (on October 25, 2013). Following examination of the Preliminary Completeness Review, EnergySolutions submitted Responses to the review (included in Appendix B) and revision 1 of its depleted uranium Performance Assessment Report titled, “Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report,” (EnergySolutions, 2013a).

On February 28, 2014, EnergySolutions received Round 1 Interrogatories from the Division, requesting clarification and additional information to support the Division’s continued review of EnergySolutions’ depleted uranium Performance Assessment. Version 1.199 of the depleted uranium Performance Assessment GoldSim model was provided to DEQ reviewers on May 2, 2014. As a result of ongoing research EnergySolutions has conducted regarding cover design and in review of the Round 1 Interrogatories, EnergySolutions revised the initial design of the Federal Cell to include an evapotranspirative cover similar to that currently under review by the Division for construction on the Class A West Embankment. As a result, EnergySolutions created version 1.2 of its depleted uranium Performance Assessment GoldSim model (documented in Appendix A and provided the Division on May 15, 2014). In parallel to constructing the revised GoldSim model to address the performance of the evapotranspirative cover, EnergySolutions submitted responses on March 31, 2014 to the Round 1 Interrogatories (included in Appendix C).

On May 27, 2014, EnergySolutions received Round 2 Interrogatories from the Division, requesting additional clarification from some of the responses provided to the Round 1 Interrogatories. EnergySolutions submitted responses on June 17, 2014 to the Round 2 Interrogatories (see Appendix D). On July 1, 2014, EnergySolutions received Round 3 Interrogatories from the Division, requesting additional clarification for version 1.2 of the Modeling Report (and its associated appendices). EnergySolutions has prepared responses to the Round 3 Interrogatories, attached hereto as Appendix E.

In accordance with Utah Administrative Code (UAC) R313-25-9(5)(a), EnergySolutions is submitting for Director approval this in-depth site-specific performance assessment for the disposal of significant volumes of depleted uranium. However, even after this technical analysis is approved, EnergySolutions recognizes the following policy issues that must be resolved before disposing of concentrated depleted uranium in the Federal Cell.

1. NRC confirmation of the decision captured in NRC Order CLI-05-20 that depleted uranium is properly classified in accordance with 10 CFR 61 as Class A LLRW.
2. Completion of a Memorandum of Agreement with DOE assuming long-term stewardship of the Federal Cell.
3. Although the Performance Assessment evaluates disposal both above- and below-grade, future depleted uranium will only be disposed below grade to enhance assurance of continued isolation under geologic-time events such as the return of a large lake inundating Clive. Figure 1-2 below demonstrates that the entire depleted uranium inventory evaluated can be disposed in such a manner.
4. Even though groundwater beneath the Federal Cell is not potable, EnergySolutions will still be required to protect the groundwater, under the conditions of its Ground Water Quality Discharge Permit – based on the 4 mrem/year groundwater dose standard.
5. Policymakers must resolve how the Federal Cell capacity relates to the Agreement signed between former Utah Governor Jon Huntsman and former EnergySolutions CEO Steve Creamer on March 15, 2007.

These policy-level issues are acknowledged to be relevant to any ultimate approval to dispose of depleted uranium; yet outside of the technical matters relating to environmental fate and transport evaluated under the Performance Assessment.

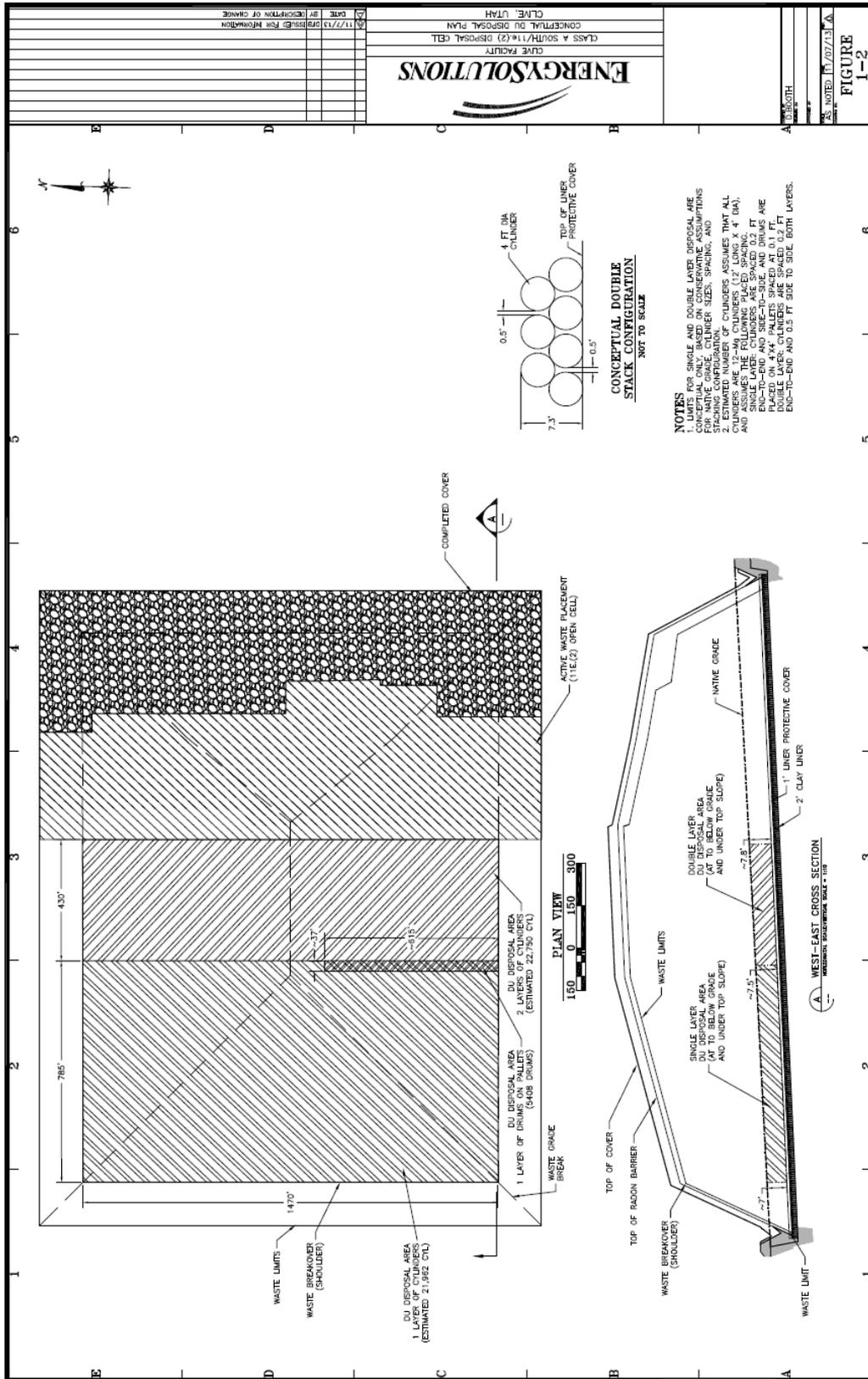


Figure 1-2, Federal Cell Below-Grade Depleted Uranium Capacity

1.1 Licensing Overview

DOE remedial activities began for the Salt Lake City Vitro mill site in February 1985 and activities were completed in May 1989. Contaminated materials that remained at the site were excavated and relocated by the State of Utah to a newly acquired site, located 75 highway miles west of Salt Lake City at a location known as Clive, Utah. Adjacent to this operation, EnergySolutions (then known as Envirocare of Utah) began disposal operations at its Clive facility in 1988 under a State license (RML UT 2300249) to dispose of Naturally-Occurring Radioactive Materials (NORM). In 1990, EnergySolutions submitted a license application to modify its license to allow disposal of low-activity radioactive waste (LARW). In 1991, the Division granted this amendment request by issuing a license for LARW disposal. From time to time, the LARW disposal license has been amended to address EnergySolutions' changing needs and those of the public interest. Eventually, the license permitted disposal of Class A low-level radioactive waste (LLRW). In 2008, the Division renewed EnergySolutions' license (EnergySolutions, 2008).

In 2012, the Division amended EnergySolutions' Radioactive Material License # UT 2300249 and Ground Water Quality Discharge Permit No. UGW450005 to combine the Class A and Class A North disposal embankments into one embankment (termed *Class A West*), (McCandless, 2012). Since then, EnergySolutions has filed an additional application with the Division to again renew its Class A Radioactive Material License (EnergySolutions, 2012b).

EnergySolutions conducts other treatment and disposal operations in areas adjacent to its Class A West Embankment. These activities include mixed hazardous waste treatment and disposal under a Treatment, Storage and Disposal (TSD) State-issued Part B RCRA Solid Waste Permit (re-issued by the Executive Secretary of the Utah Solid and Hazardous Waste Control Board on April 4, 2003). The nature of mixed waste managed at the facility includes contaminated soils, process waste, debris and sludges. The mixed waste portion of the facility consists of a disposal cell, a treatment building, a storage building and an operations building.

EnergySolutions also disposes of uranium and thorium by-product material {11e.(2)} under a license originally issued by the U.S. Nuclear Regulatory Commission (NRC) as Byproduct Material License SMC-1559. EnergySolutions' 11e.(2) license is now administered by the Division (RML UT2300478).

In conjunction with licensed activities, EnergySolutions' operations are also subject to the provisions of Ground Water Quality Discharge Permit (GWQDP) UGW450005, issued by the Utah Division of Water Quality (UDWQ). In 2008, EnergySolutions was awarded a renewal for this permit. This permit specifies that groundwater quality protection levels for radioactive constituents must be met for no fewer than 500 years following facility closure. EnergySolutions has filed an application with the Division to renew its Ground Water Quality Discharge Permit (EnergySolutions, 2013). Similarly, EnergySolutions also operates under Air Quality Approval Order DAQE-AN0107170019-11, issued by the Utah Division of Air Quality (UDAW).

1.2 Other Associated Performance Assessments

To support the Division's approval of the Class A West amendment of Radioactive Material License UT2300249 (Class A West Amendment Application), EnergySolutions submitted a performance assessment that utilized the same PATHRAE, UNSAT-H, and HELP methodology employed for previous embankment licensing efforts, updating it to reflect the new Class A West geometry and cover design. Potential groundwater impacts from the Class A West Embankment with a traditional rock-armored cover system were demonstrated therein to be minimal (Whetstone, 2011).

On February 14, 2011, EnergySolutions requested concurrence from the Division that previous licensing activities allowed for the receipt and disposal of processed ion-exchange resin waste on a large-scale in the Class A West Embankment (Shrum, 2011a; Shrum, 2011b). The Division reviewed EnergySolutions' analysis supporting this request and determined that EnergySolutions could dispose in its Class A West Embankment up to 40,000 cubic feet per year of processed ion-exchange resin waste. However, in order to manage processed ion-exchange resin waste at volumes greater than 40,000 cubic feet per year, EnergySolutions would be required to conduct a new performance assessment analyses that include *“prediction of nuclide concentration and peak dose (at the time peak dose would occur) using updated dose conversion factors, and a suggested model time frame of 10,000 years, as well as any need to revisit/update the waste source term, receptor and exposure pathways”* (Lundberg, 2011).

In compliance with these requirements and in demonstration of the performance of an alternative evapotranspirative cover design, EnergySolutions submitted to the Division on October 8, 2012 an updated, site-specific Performance Assessment (Shrum, 2012). While not yet formally approved by the Division, this updated, site-specific Performance Assessment demonstrates the alternate evapotranspirative cover and Class A West Embankment's ability to protect the general public during operations, protect the general public after closure, protect the inadvertent intruder, and to be stable over time. In fact, the model demonstrates that the alternative evapotranspirative cover design significantly reduces infiltration of precipitation into waste (Shrum, 2012), as compared to infiltration projected through the originally-approved traditional rock armored cover's top and side slope (Whetstone, 2011). In fact, the alternative cover design performance demonstrates *“. . . that no radionuclides [at concentrations up to Class A limits] have the potential to reach the groundwater point of compliance within 10,000 years.”* (page 60 of Appendix A of Shrum, 2012). Given its improved ability to protect the groundwater resources and exposed general public, EnergySolutions has also evaluated the alternative evapotranspirative cover design for the proposed Federal Cell in version 1.2 of the depleted uranium Performance Assessment.

1.3 Regulatory Context

In the context of disposal of radioactive waste, a performance assessment is a quantitative evaluation of potential releases of radioactivity from a disposal facility into the environment and assessment of the resultant radiological doses. EnergySolutions commonly conducts performance assessments to demonstrate that its various embankments meet the required performance objectives throughout the required Period of Performance.

UAC R313-25-9(5)(a) requires that a performance assessment be performed and approved by the Director prior to the disposal of significant quantities of depleted uranium. The required performance assessment must meet the provisions of section 5(a) of R313-25-9 that requires that the performance assessment:

“demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose. Any such performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years. Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.”

In development of the required depleted uranium Performance Assessment, EnergySolutions considered guidance NRC has issued to assist applicants and licensees in applying these standards as they reflect years of experience with a variety of waste streams and disposal situations. NUREG-1573 is a key NRC guidance document for conducting performance assessments (NRC, 2000). Additional recent guidance is contained in NUREG-1854 (NRC, 2007).

In particular, there are four areas to consider in applying the performance standards within the context of a performance assessment. First is the compliance period. Second is the dose methodology. Third is the dose standard for the intruder. Fourth is embankment stability.

1.3.1 UAC R313-15-401: Periods of Performance versus Times of Compliance

Prior to implementing UAC R313-25 (e.g., 10 CFR 61), it had been a common practice at waste disposal facilities across the country to randomly dump some waste. This practice jeopardized package integrity and did not permit access to voids between packages so that they could be properly backfilled. Consolidation of wastes into this disposal configuration provided less stable support which could contribute to failure of the disposal embankment cover leading to increased precipitation infiltration and surface water intrusion.

To help achieve stability, NRC noted that, to the extent practicable, waste should maintain gross physical properties and identity over 300 years, under the conditions of disposal. NRC believes that the use of design features to achieve stability is consistent with the concept of ALARA and the use of the best available technology. It is NRC's view that waste forms or containers should be designed to be stable (i.e., maintain gross physical properties and identity, over 300 years). NRC also notes that an

embankment should be evaluated for at least a 500-year time frame to address the potential impacts of natural events and phenomena.

About the same time as Part 61 was promulgated, NRC also put in place requirements for design of uranium mill tailings piles such as the Vitro site which is located immediately east of the Class A West Embankment. In addressing stability requirements for mill tailings, NRC recognizes the need to set practicable standards. NRC specifies that the design for mill tailings waste disposal shall provide reasonable assurance of control of radiological hazards to be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.

In both cases (low-level radioactive waste and mill tailings disposal) NRC recognizes the need to set practical standards that can be implemented, (ranging from 200 up to 1,000 years). NRC also recognizes the design limitations and notes that reasonably achievable designs should be employed to the extent practicable. As such, it is generally not practical to set design standards beyond 1,000 years.

Consequently, an approach consistent with past standard setting practice is employed in this depleted uranium Performance Assessment for purposes of applying the performance standard for stability of the disposal site after closure (UAC R313-25-22). Analysis of the appropriate Periods of Performance and Times of Compliance applicable to this depleted uranium Performance Assessment includes the following promulgated requirements for disposal of depleted uranium waste in the Federal Cell.

1. **500 YEARS:** EnergySolutions' Federal Cell is subject to performance limits on the release of groundwater contamination, as required by UAC R317-6-2 (delineated in EnergySolutions' Ground Water Quality Discharge Permit). However, UAC R317-6-3 classifies groundwater beneath the Federal Cell as Class IV, "*non-potable, saline ground water.*" UAC R317-6-4.7 states: "*Protection levels for Class IV ground water will be established to protect human health and the environment.*" Specific Ground Water Protection Levels and periods of performance for Class IV groundwater are not set by rule. For disposal cells at Clive, this is accomplished by setting Best Available Technology performance standards for non-radiological and radiological contaminants in groundwater at Part I.D.1 as being 200 and 500 years, respectively. Because of this, the Period of Performance for protection of groundwater resources from further degradation is 500 years, following Federal Cell closure.
2. **1,000 YEARS:** In addition to preservation of the current condition of its groundwater resource, EnergySolutions is also required "*When calculating the total effective dose equivalent to the average member of the critical group, the licensee shall determine the peak annual total effective dose equivalent dose expected within the first 1,000 years after decommissioning.*" [UAC R313-15-401(4)]. While specifically referencing a time duration following decommissioning, these requirements specifically, "*apply only to ancillary surface facilities that support radioactive waste disposal activities,*"[UAC R313-15-401(1)] and not the Federal Cell, itself. As such, the 1,000 year Total Effective Dose Equivalent (TEDE) limit is a Time of Compliance and not applicable to the specific Period of Performance following closure of the Federal Cell.

Furthermore, no specific Period of Performance for the closed Federal Cell has been promulgated in UAC R313-25-20, as related to the protection of a hypothetical inadvertent intruder. However, NRC guidance has historically assessed intruder scenarios for a time period equivalent to that indicated in UAC R313-15-401(4), (e.g., 1,000 years after Federal Cell closure), (NRC, 1986). The Federal Cell performance for 1,000 years for the protection of an inadvertent intruder is also supported by the precedent time periods required by 10 CFR 20, Subpart E (for decommissioned sites), 10 CFR 40, Appendix A (for uranium mill tailings), and DOE Order 435.1.

The 500-year Period of Performance for engineered barriers used to limit inadvertent intrusion is not the same as the promulgated Period of Performance for protection of the general population from releases of radioactivity. As such, NRC deemed the engineered barriers and concentration limits inherent with the Class A classification are sufficient to demonstrate protection of an inadvertent intruder.

3. 10,000 YEARS: UAC R313-25-8(5)(a) includes reference to a 10,000-year Period of Performance for “*any facility that proposes to land dispose of significant quantities of concentrated depleted uranium,*” [UAC R313-25-8(5)(a)]. Similarly, NRC’s environmental impact statement for 10 CFR 61 recognizes the need for a Period of Performance, “*commensurate with the persistence of the hazard of the source,*” (NRC 1981; NRC 1982; NRC 2000).

EnergySolutions recognizes that a Period of Performance of 10,000 years was similarly evaluated as part of the NEPA analysis in the Draft Environmental Impact Statement (DEIS) for 10 CFR 61 (NRC, 1981). NRC’s Performance Assessment Working Group (formed to provide information and recommendations on performance assessment methodology required by 10 CFR 61.41) also recommends a 10,000-year Period of Performance, considering it “*sufficient to capture the risk from the short-lived radionuclides (the bulk of the activity disposed) and the peaks from the more mobile long-lived radionuclides, which tend to bound the potential doses at longer timeframes,*” (NRC, 2000).

Given the nature of depleted uranium, a qualitative analysis beyond 10,000 years (e.g., out to peak concentrations) is also warranted to inform the Performance Assessment. Use of the 10,000 year Period of Compliance is also consistent with federal regulations (e.g., 40 CFR 191) and NRC guidance. Extending the analysis qualitatively until a peak is also consistent with NUREG-1573 recommendations.

The NRC has taken a similar approach with the NRC Decommissioning Criteria for the West Valley Demonstration Project at the West Valley Site (NRC, 2002). It is noteworthy that the only Federal standard that goes beyond 10,000 years for compliance is the standard for Yucca Mountain (NRC, 2002). That provision provides a two-level dose standard with a higher dose limit of 100 mrem after 10,000 years.

Separate from requirements to preserve the groundwater resource for a 500-year Time of Compliance, the Utah Division of Drinking Water and U.S. EPA have promulgated radionuclide concentration limits (e.g., maximum contaminant levels of MCLs) in drinking water, based on the associated health effects from ingestion. EPA has developed MCLs for four groupings of radionuclides: (A) Ra-226 and Ra-228; (B) man-made beta and photon emitters; (C) gross alpha, excluding uranium isotopes and radon; and (D) U-234, U-235 and U-238, based on a maximum committed effective dose equivalent (CEDE) of 4 mrem/year. This dose standard is reflected in Division's requirement UAC R313-25-20, which states "*No greater than 0.04 mSv (0.004 rem) committed effective dose equivalent or total effective dose equivalent to any member of the public shall come from groundwater.*"

In compliance with these regulatory requirements, EnergySolutions has addressed applicable requirements and guidance in revision of the Periods of Performance and Times of Compliance assessed in this depleted uranium Performance Assessment, as follows:

1. **500 YEARS:** In compliance with groundwater resource protection standards of UAC R317-6, as embodied in Part I.D.1 of Ground Water Quality Discharge Permit No. UGW450005, the depleted uranium Performance Assessment projects expected groundwater well concentrations for a Period of Performance of 500 years, following Federal Cell closure.
2. **10,000 YEARS:** EnergySolutions has maintained the original 10,000-year Period of Performance for demonstration of protection of the general public and the hypothetical inadvertent intruder. While beyond the regulatory requirements of UAC R317-6, the depleted uranium Performance Assessment projects peak isotopic groundwater well concentrations and doses for a Period of Performance of 10,000 years, following Federal Cell closure.

As part of an unrelated investigation, NRC staff specifically asked the Division to "*provide further information on its position that the onsite residential and agricultural intruder pathways for the [EnergySolutions] site are unrealistic.*" In response, Division staff

"stated that onsite residential and/or farming scenarios at the [EnergySolutions] facility are unrealistic for several reasons. First, the site conditions of low precipitation (i.e., approximately 5-6 inches/year) and high evapotranspiration rates (i.e., approximately 40 - 50 inches/year). Also, there is a lack of suitable irrigation water . . . and the soil is extremely saline. Secondly, Tooele County has designated this part of the county as Heavy Industry and Hazardous Waste Zones which bars any such residential and/or farming uses" (NRC, 2005).

The Division's judgment of the unrealistic nature of farming, discover, drilling, or residential intruder scenarios is consistent with the requirements of UAC R313-25-8(8).

While the Division is on record agreeing that the groundwater classification, level of its totally dissolved solids, and other naturally-occurring constituents create completely unpotable groundwater, (thereby eliminating all reasonable possibility of any member of the public from receiving such a groundwater dose), EnergySolutions has revised the depleted uranium Performance Assessment to demonstrate that no members of the general public who could hypothetically survive consumption of the natural groundwater beneath the Federal Cell will receive a CEDE in excess of 4 mrem/year within a 10,000-year Period of Performance.

3. DEEP TIME: UAC R313-25-9(5(a) requires that, “*additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.*” Consequently, for purposes of informing the Performance Assessment, a qualitative assessment of the Embankment longevity and depleted uranium fate and transport out to geologic time frames is considered. Because of the magnitudes of uncertainties associated therein, NUREG-1573 “*recommends that assessments beyond 10,000 years not be used for determining regulatory compliance with the performance objectives.*” (pg 3-16 of NRC, 2000).

1.3.2 UAC R313-25: Performance Objectives

This depleted uranium Performance Assessment demonstrates compliance with the four primary UAC R313-25 performance objectives described below.

1.3.2.1 UAC R313-25-20: Protection of the General Public

The key endpoints of this depleted uranium Performance Assessment are estimated future, post-closure potential doses to members of the public. The performance objectives required in UAC R313-25-20 are the following:

“Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants or animals shall not result in an annual dose exceeding an equivalent of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of any member of the public. No greater than 4 mrem committed effective dose equivalent or total effective dose equivalent to any member of the public shall come from groundwater. Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable, (ALARA).”

However, NRC based these performance objectives on the dated International Commission on Radiological Protection (ICRP) 2 dose methodology (ICRP, 1959). By comparison, current health physics practices follow the dose methodology used in UAC R313-15, which are based on ICRP 30 methodology (ICRP, 1979). For consistency, NRC recommends, “*that the performance assessment be consistent with the methodology approved by the NRC in Part 20 for comparison with the performance objective [of 10 CFR 61.41]”* (NRC, 2000). Since UAC R313-15 establishes a TEDE limit, rather than the whole body dose, NRC notes in NUREG-1573,

“As a matter of policy, the Commission considers 0.25 mSv/year (25 mrem/year) TEDE as the appropriate dose limit to compare with the range of potential doses represented by the older limits that had whole-body dose limits of 0.25 mSv/year (25 mrem/year) (NRC, 1999, 64 FR 8644; see Footnote 1). Applicants do not need to consider organ doses individually because the low value of the TEDE should ensure that no organ dose will exceed 0.50 mSv/year (50 mrem/year).” (NRC, 1999, 64 FR 8644; see Footnote 1).

This approach was also taken for Yucca Mountain in 10 CFR Part 63, NUREG-1854 and NUREG-1573, and in the NRC Decommissioning Criteria for West Valley. Therefore, while this depleted uranium Performance Assessment does not specifically consider organ doses individually, comparison to a more conservative value of the TEDE ensures that no organ doses exceed the promulgated limitations of UAC R313-25-20.

In this depleted uranium Performance Assessment, EnergySolutions also demonstrates compliance with the performance objective requiring that no members of the living general public (following consumption of the natural groundwater beneath the Federal Cell) receive a CEDE in excess of 4 mrem/year from any potential depleted uranium contamination (including daughters and other contaminants associated with depleted uranium) leached from the Federal Cell, within a 10,000-year Period of Performance.

1.3.2.2 UAC R313-25-21: Protection of the Inadvertent Intruder

UAC R313-25-21 requires assurance of protecting individuals from the consequences of inadvertent intrusion into depleted uranium waste disposed in the Federal Cell. An inadvertent intruder is someone who is exposed to waste unintentionally and without realizing it is there (after loss of institutional control). This is distinct from an intentional intruder, who might be interested in deliberately disturbing the site, or extracting materials from it, or who might be driven by curiosity or scientific interest.

“Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.” [UAC R313-25-21]

Another important term to define in evaluation of this Performance Objective is an intruder barrier:

“A sufficient depth of cover over the waste that inhibits contact with waste and helps to ensure that radiation exposure to an inadvertent intruder will meet the performance objectives set forth in this part, or engineered structures that provide equivalent protection to the inadvertent intruder.” [UAC R313-25-2]

This Federal Cell disposal methodology (with either cover design under consideration) already exceeds the intruder barrier requirements of UAC R313-25 in the following ways.

- An engineered embankment is an important component in intruder protection. Reliance on engineered features is based on the assumption that an intruder encountering the barrier would recognize it as something out of the ordinary and cease attempts at construction or agriculture (thereby reducing their exposure to radiation). The combination of the cover system and depth of disposal protects an intruder from penetrating the Federal Cell and contacting the depleted uranium waste.
- As was demonstrated with the Division’s approval of the Class A West design, the design and operation of the Federal Cell provides a more stable disposal than is required by UAC R313-25. The placement of depleted uranium waste below grade within the Federal Cell, the compacted sand, the placement and compaction of waste above the layers of depleted uranium waste, and either the cover currently-approved rock armor or alternate evapotranspirative covers combine to form a stable disposal configuration. The Division-approved Class A West Embankment design has already been shown to provide stability to ensure the long-term compaction combine to resist slumping and differential settlement, which limits infiltration and reduces the potential for dispersion of the waste over time. In addition to improving the performance of the disposal site, this provides inherent protection for the inadvertent intruder, since it provides a “*recognizable and nondispersible waste*” as contemplated in UAC R313-15-1009.
- EnergySolutions has modeled placement of depleted uranium below grade within the Federal Cell. The result is that even the top layer of depleted uranium waste is far more than 5 meters below the cover, which is sufficient to satisfy disposal requirements for waste classified at Class C limits. The 5-meter thick barrier also inhibits access by an inadvertent intruder. This barrier is composed of earth, other Class A LLRW, and other similar materials.

Although UAC R313-25-21 requires that an inadvertent intruder be protected, NRC staff acknowledged that applicants and licensees are not expected to perform specific intruder dose analyses, because the waste classification itself and segregation requirements were developed to inherently provide inadvertent intruder protection, (NRC, 2000). Even so, this depleted uranium Performance Assessment demonstrates protection of inadvertent intruders.

While an unlimited number of inadvertent intruder scenarios can be developed, Division requirements limit such development to include, “*Identification of the known natural resources at the disposal site whose exploitation could result in inadvertent intrusion into the wastes after removal of active institutional control.*” UAC R313-25-8(8). Of similarly sentiment, NRC’s Performance Assessment Working notes that,

“the overall intent [of exposure scenario development guidance] is to discourage excessive speculation about future events and the PAWG does not intend for analysts to model long-term transient or dynamic site conditions, or to assign probabilities to natural occurrences. . . The parameter ranges and model assumptions selected for the LLW performance assessment should be sufficient to capture the variability in natural conditions, processes, and events. . . Therefore,

PAWG recommends that new site conditions that may arise directly from significant changes to existing natural conditions, processes, and events do not need to be quantified in LLW performance assessment modeling . . . With respect to human behavior, it may be assumed that current local land-use practices and other human behaviors continue unchanged throughout the duration of the analysis. For instance, it is reasonable to assume that current local well-drilling techniques and/or water use practices will be followed at all times in the future.” (NRC, 2000).

NRC further supports the importance of selecting appropriate inadvertent intruder scenarios that reflect current practices and site environments in its guidance to Regulators reviewing performance assessments to,

“[1] verify that conceptual models for the biosphere include consistent and defensible assumptions based on regional practices and characteristics (i.e., conditions known to exist or expected to exist at the site or surrounding region); [2] verify that intermediate results (e.g., fluxes, travel times) are physically reasonable;. . . [3] evaluate the types of scenarios . . . considered in the intruder analysis and confirm that the scenarios considered are appropriate for the site; [4] verify that assumptions and parameters used in defining the exposed intruder, including location and behavior of the intruder, timing of the intrusion, and exposure pathways, are consistent with the current regional practices; and [5] if a garden is assumed in the scenario [implying it is not always required], verify that the garden size is appropriate and consistent with regional practices” NRC (2007).

Examples of traditional exposure scenarios typically used to evaluate potential inadvertent intruder doses (in compliance with UAC R313-25-21) are described in NRC’s draft Environmental Impact Statement supporting 10 CFR 61 (NRC 1981a) and the Update of Part 61 Impacts Analysis Methodology (NRC 1986). The methodology described therein includes evaluation of exposure pathways within a group of four inadvertent intruder scenarios including intruder discovery, intruder drilling, intruder construction, and intruder agriculture. These inadvertent intrusion scenarios represent a potential series of events that are initiated by the successful completion of a water supply well. However, NRC further notes that,

“it would be unreasonable to expect the inadvertent intruder to initiate housing construction at a comparatively isolated location before assuring that water for home and garden use will be available. Thus, this scenario (intruder-driller) is assumed to precede the following three scenarios” (NRC, 1986).

The intruder-drilling scenario is assumed to be an initiating event for the intruder-construction and intruder-agriculture scenarios (NRC 1986, Section 4.1.1.1). This scenario assumes that, in an effort of mining subsurface resources, waste is brought to the ground surface in a mixture with cover material, unsaturated zone material, and drilling mud and is then contained in a mud pit used by the driller. The driller (a separate individual from that in any subsequent exposure scenario) is assumed to be exposed by direct gamma radiation from the waste mixture in the mud pit (NRC, 1986). However, lacking the precursory subsurface mineral resources (NRC 1986, Section 4.2.1), the intruder-driller scenario is inapplicable to the Federal Cell.

The intruder-discovery scenario described in Section 4.2.3 of NRC (1981) involves external exposure to discoverable wastes that are clearly distinguishable from natural materials. The dose assessment methodology described in NRC (1981) was updated in NUREG/CR-4370 (NRC, 1986). Exposure to the intruder-discoverer is assumed to be limited to the topmost waste layer, since the intruder “*would likely stop excavating before digging too deep into the rest of the waste*” (NRC 1986, Section 4.2.3). The intruder-discovery scenario for stable waste streams in the first 500 years after closure is assumed to preempt the intruder-agriculture scenario (and, presumably, the intruder-construction scenario) because construction and inhabitation of a home will not occur once the waste has been discovered and recognized (NRC 1986, Section 4.2.3).

The intruder-construction scenario involves direct intrusion into disposed wastes for activities associated with the construction of a house {(e.g., installing utilities, excavating basements, and similar activities [as described in Section 4.2.2 of NRC (1986)]}. However, because there is no historic evidence of prior residential construction at the Federal Cell, the extreme salinity of Federal Cell’s native soils, the unpotable groundwater, the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the inadvertent intruder-construction scenario is not considered reasonable for the Federal Cell nor included in this depleted uranium Performance Assessment.

The intruder-agriculture scenario assumes an individual is living in the home built under the intruder-construction scenario, and is also exposed from gardening activities involving the waste/soil mixture excavated during construction (NRC 1986, Section 4.2.4). As with the inadvertent intruder-construction scenario, the lack of historic evidence of prior residential agriculture at the Federal Cell, the extreme salinity of Federal Cell’s native soils, the unpotable groundwater, the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the inadvertent intruder-agriculture scenario is not considered “*reasonable*” for the Federal Cell nor included in this depleted uranium Performance Assessment.

As is presented above in Section 1.3.1, the Division is on record agreeing that the groundwater classification, level of its totally dissolved solids, and other naturally-occurring contaminants create completely unpotable groundwater, (thereby eliminating all reasonable possibility of any member of the public from receiving such a groundwater dose). The Division’s judgment of the unrealistic nature of farming, discover, drilling, or residential intruder scenarios is consistent with the requirements of UAC R313-25-8(8).

An archeological survey of the area surrounding the Federal Cell was performed in 1981, as part of the siting criteria used for the Vitro disposal cell (AERC, 1981). This survey found no evidence of long-term residential or agricultural resource sites. A similar cultural and archaeological resource survey was conducted in 2001 (Sagebrush, 2001). In addition to the new survey, Sagebrush’s (2001) report also summarized five additional cultural resource inventories performed within a mile of the subject area, between the original 1981 and 2001 studies. In all surveys, Sagebrush reported no paleontological, prehistoric, or historic resources were discovered in the survey area. In fact, no evidence has been discovered that suggests the Federal Cell has ever been inhabited or developed for agriculture by permanent residents in the past (probably due to unfavorable conditions for human habitation).

EnergySolutions acknowledges that the nearest human resident is located approximately 7.5 miles from the Federal Cell. This single residence supports a caretaker for the Utah Department of Transportation rest stop on Interstate-80. Impacts to this residence are considered in this depleted uranium Performance Assessment. However, it is not reasonable to assume additional residential development in the region due to the natural characteristics of the disposal site, as well as Tooele County zoning restrictions.

In compliance with UAC R313-25-21 and Division directive, EnergySolutions has included credible inadvertent industrial intrusion scenarios in its depleted uranium Performance Assessment. However, since (1) the Federal Cell's groundwater is unpotable and will not support a residence or agriculture, (2) the expense of treating Federal Cell's groundwater with conventional technologies is preventing current industrial occupants from using treatment; (3) Federal Cell's geology holds no mineral resources of value, and (4) Federal Cell's current practices and county-zoning limit use of the area to only industrial purposes, this depleted uranium Performance Assessment only includes scenarios of inadvertent intrusion that may result from recreational and industrial pursuits (e.g., similar to those apparent with EnergySolutions' current developed neighbors).

The performance standard for protection of individuals from inadvertent intrusion (UACR313-25-21) further requires "...protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste." However, these regulations are silent on the specific dose standard to apply. Since UAC R313-25 has been issued, the standard used by NRC (and included in the pending revisions to 10 CFR 61 and associated Branch Technical Position analysis) and others for low-level radioactive waste disposal licensing has been an intruder standard of 500 mrem/yr. The 500 mrem/yr standard is also used in DOE's waste determinations implementing the 10 CFR 61 performance objectives (NUREG-1854). It is noted that 500 mrem/yr was also the standard proposed in 10 CFR 61 in 1981 (46 FR 38081, July 24, 1981). The Statement of Considerations for the final rule did not object to the number. It was removed apparently at the request of EPA, because of its concern of how one would monitor it or demonstrate compliance with it, but not because EPA disagreed with it (47 FR57446, 57449, December 27, 1982). A dose standard of 500 mrem/yr is also used as part of the license termination rule dose standard for intruders (10 CFR 20.1403). Consequently, this depleted uranium Performance Assessment applies a 500 mrem/yr threshold for the intruder dose for purposes of applying the performance standard for protection of individuals from inadvertent industrial intrusion.

1.3.2.3 UAC R313-25-22: Protection of Individuals During Operations

UAC R313-25-22 states that "*Operations at the land disposal facility shall be conducted in compliance with the standards for radiation protection set out in R313-15 of these rules, except for release of radioactivity in effluents from the land disposal facility, which shall be governed by R313-25-20.*"

Historical records submitted annually to the Division demonstrate that impacts from EnergySolutions' existing Class A West Embankment operations are minimized by administrative controls within the applicable regulatory limits. Furthermore, personnel and environmental monitoring data (submitted quarterly to the Division) confirm that the applicable limits for the Class A West Embankment are met on a continuing basis. Since there is no change being proposed for construction of the Federal Cell for ultimate disposal of depleted uranium in the types of waste or necessary administrative controls that will

be managed, protection of individuals during operations will continue as already demonstrated (DRC, 2012).

UAC R313-25-22 also states that “*every reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable, ALARA.*” EnergySolutions’ Radiation Protection Program ensures that all reasonable actions are taken to reduce radiation exposures and effluent concentrations from operations associated with the Class A West Embankment to levels that are considered, “*As Low As Reasonably Achievable*” (ALARA). A report of EnergySolutions’ independent ALARA Program audit is provided annually to the Division in conjunction with conditions of its Radioactive Material License UT 2300478. Since there are no changes being proposed in the waste types and classifications that are proposed to be disposed of in the Federal Cell, the current ALARA Program will not require revision as part of this depleted uranium Performance Assessment.

1.3.2.4 UAC R313-25-23: Stability of the Disposal Site After Closure

To help achieve stability, NRC notes that to the extent practicable disposed waste should maintain gross physical properties and identity over 300 years, under the conditions of disposal (NRC, 1986). NRC believes that the use of design features to achieve stability is consistent with the concept of ALARA and the use of the best available technology. It is NRC’s view that to the extent practicable, waste forms or containers should be designed to be stable (i.e., maintain gross physical properties and identity, over 300 years). NRC also notes that a site should be evaluated for at least a 500-year time frame to address the potential impacts of natural events or phenomena.

Consequently, through approval of its Class A West Amendment Application, EnergySolutions has demonstrated that its Class A West Embankment and cover design will provide long-term stability and that the use of the best available technology in setting design standards in the range from 200 up to 1,000 years is appropriate to provide site stability to the extent practicable (Sections 3.1.3, 3.2.3, 5.1, and 6.3 of McCandless, 2012). As such, this depleted uranium Performance Assessment model of a Federal Cell using an equivalent design does not trigger the need to conduct additional stability analysis.

1.3.2.5 Groundwater Protection Limits

In addition to these radiological criteria, the State of Utah imposes limits on groundwater contamination, as stated in the Ground Water Quality Discharge Permit UGW450005 (Permit) (EnergySolutions, 2010). Part I.C.1 of the Permit specifies that GWPLs shall be used for the Embankment. The Permit specifies general mass and radioactivity concentrations for several constituents of interest to depleted uranium waste disposal. These GWPLs are derived from Ground Water Quality Standards listed in UAC R317-6-2 Ground Water Quality Standards. Exceptions to values in that table are provided for specific constituents in specific wells, tabulated in Table 1B of the Permit.

It is important to note groundwater beneath the Federal Cell is classified as Class IV, saline ground water, according to UAC R317-6-3 Ground Water Classes, and is highly unlikely to serve as a future water source. The underlying groundwater in the vicinity of the Federal Cell is of naturally poor quality because of its high salinity and, as a consequence, is not suitable for most human uses, and is not potable

for humans. Analysis conducted by the World Health Organization in 2003 suggested associations between TDS concentrations in drinking water and the incidence of cancer, coronary heart disease, arteriosclerotic heart disease, cardiovascular disease, and total mortality rates in studies conducted in Australia and the former Soviet Union (WHO, 2003). In the study in Australia, it was determined that mortality from all categories of ischaemic heart disease and acute myocardial infarction was increased in a community with high levels of soluble solids, calcium, magnesium, sulfate, sodium, chloride, fluoride, alkalinity, total hardness, and pH when compared with one in which levels were lower. Similarly, the results of an epidemiological study in the former Soviet Union indicated that the average number of cases of inflammation of the gallbladder and gallstones over a 5-year period increased with the mean level of dry residue (a measure of TDS) in the groundwater.

Since the background water quality of the groundwater renders it unsafe and unusable for consumption, groundwater protection standards are applied at the Federal Cell as a non-degradation or Best Available Technology (BAT) standard. No dose is possible through the groundwater pathway, since its consumption is impossible without extensive treatment. However, the BAT standards for groundwater do not provide any additional protection in terms of human health.

1.4 Historical Management of Depleted Uranium

Large-scale uranium enrichment in the United States began as part of atomic bomb development by the Manhattan Project during World War II. Uranium enrichment activities were subsequently continued under the U.S. Atomic Energy Commission and its successor agencies, including DOE. The K-25 plant in Oak Ridge, Tennessee¹ was the first of three gaseous diffusion plants constructed to produce enriched uranium. The K-25 plant ceased operations in 1985, but uranium enrichment continues at facilities located in Paducah, Kentucky and Portsmouth, Ohio. These two plants are now operated by the United States Enrichment Corporation, created by law in 1993 to privatize uranium enrichment.

In the gaseous diffusion process, a stream of heated uranium hexafluoride (UF_6) gas is separated into a stream of UF_6 gas containing enriched U_{235} (EUF_6) and a stream of UF_6 gas depleted in U_{235} (DUF_6). The enriched uranium materials are used for manufacturing commercial reactor fuel, (typically contains 2 to 5% U_{235}), and military applications (requiring up to 95% U_{235}). The DUF_6 waste materials of interest to this Compliance Report typically contain U_{235} concentrations as low as 0.2 to 0.4%. Since the 1950s, DUF_6 waste materials have been stored at all three storage sites in large steel cylinders, similar to that illustrated in Figure 1-3.

¹ The site of the K-25 plant is now called the East Tennessee Technology Park (ETTP), but is referred to by its original name, the K-25 site, in this Compliance Report.

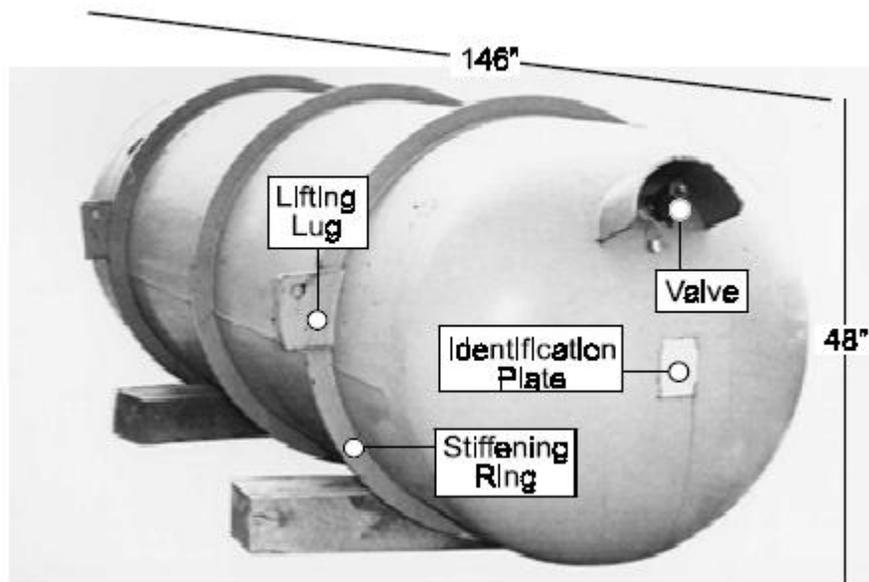


Figure 1-3, Typical Depleted Uranium Storage Cylinder (DOE, 1999)

Depleted uranium was also produced at DOE's Savannah River Site. The Savannah River Site produced depleted uranium as a byproduct of the nuclear material production programs, where irradiated nuclear fuels were reprocessed to separate out the fissionable Pu_{239} . Uranium billets were produced at the DOE Fernald, Ohio site, fabricated into targets at Savannah River Site, and then irradiated in the Savannah River Site production reactors to produce Pu_{239} . The irradiated targets were processed and fission products separated from the plutonium and uranium, which were then separated from each other. After additional purification, the depleted uranium-bearing waste stream was then processed into uranium trioxide (DUO_3). While still classified as depleted uranium, this DUO_3 also contains small quantities of waste fission products and transuranic elements. The Savannah River Site produced approximately 36,000 (55-gal) steel drums of DUO_3 during the production campaigns. This DUO_3 , a solid powder at room temperature and pressure, is considered to be relatively homogeneous, based on known process controls and operations. The 5,408 drums of DUO_3 proposed for disposal in the Federal Cell are from this process; the remaining drums have been disposed elsewhere by DOE.

Because storage began in the early 1950s, many of the drums and cylinders now show evidence of external corrosion and increased breach risk. When a DUF_6 container is breached, the contents react with moisture in air to form caustic hydrofluoric acid (HF) and solid uranyl fluoride (UO_2F_2). By 1998, breaches were identified in eight cylinders (two at Paducah, two at Portsmouth, and four at K-25), generally around spots previously damaged by handling activities. Similarly, a significant number of drums at the Savannah River Site have been placed into overpacks as a mitigating action for corrosion control and to prevent spills.

In an effort to reduce risks associated with container breach, Public Law 107-206, the 2002 Supplemental Appropriations Act for Further Recovery from and Response to Terrorist Attacks on the United States (commonly referred to as the "*Terrorist Attack Response Act*") requires DOE to design, construct, and operate facilities at Paducah and Portsmouth, for conversion of DUF_6 to the safer form, depleted triuranium octaoxide (U_3O_8). As part of this revised management strategy, all K-25 DUF_6 cylinders were shipped in 2004 to Portsmouth to be eventually converted to U_3O_8 . The Terrorist Attack Response Act further required that the U_3O_8 be stored at Paducah and Portsmouth until there is a determination that all or a portion of the depleted uranium is no longer needed. At that point, the U_3O_8 is to be disposed of as low-level radioactive waste. DOE estimates the inventory of U_3O_8 that will eventually require disposal to be approximately 700,000 metric tons over a 20 to 25 year period (DOE, 2007).

Conversion to U_3O_8 is a preferential management strategy, because DUF_6 is a volatile, white, crystalline solid. Conversely, U_3O_8 is kinetically and thermodynamically stable and is the most common form of uranium found in nature. U_3O_8 can be produced in rotary kiln or fluidized-bed reactors by application of superheated steam and hydrogen (from dissociated ammonia) to DUF_6 (producing solid UO_2F_2 powder and gaseous HF). The powder UO_2F_2 is then defluorinated through heat and steam addition to create U_3O_8 .

1.5 Report Scope

UAC R313-25-9(5)(a) requires *EnergySolutions* to demonstrate to the Division that proposed methods for disposal of depleted uranium will not compromise the Federal Cell's demonstrated ability to meet the performance objectives of UAC R313-25. Toward that end, *EnergySolutions* has conducted this depleted uranium probabilistic Performance Assessment using version 10.5 (SP4) of the GoldSim modeling software (GoldSim, 2011).

The GoldSim model, developed and managed by the GoldSim Technology Group, is a Monte Carlo simulation software solution for dynamically modeling complex systems in business, engineering and science. GoldSim supports decision and risk analysis by simulating future performance while quantitatively representing the uncertainty and risks inherent in all complex systems. GoldSim is a general purpose simulator that utilizes a hybrid of several simulation approaches, combining an extension of system dynamics with some aspects of discrete event simulation, and embedding the dynamic simulation engine within a Monte Carlo simulation framework. As part of a joint effort by NRC and DOE, the GoldSim model and the supporting sub-models have undergone extensive reviews concerning its use to demonstrate compliance with the individual protection standards (Pensado, et. al, 2002).

This Report documents the depleted uranium Performance Assessment, conducted in compliance with UAC R313-25-9(5)(a). Analysis of Appendix A includes evaluation of potential groundwater migration of contaminants to a Point of Compliance well for a period of 500 years following embankment closure, projected peak groundwater well concentrations and general public doses for a period up to 10,000 years following Federal Cell closure, doses to hypothetical individuals who have inadvertently intruded into the waste within 10,000 years following Federal Cell closure, and additional simulations out to deep geologic time frames to qualitatively inform the Performance Assessment. Responses to the Division's Preliminary Completeness Review are included in Appendix B. Appendix C lists responses to the Division's Round 1 Interrogatories. Appendix D included responses to the Division's Round 2 Interrogatories. Responses to Round 3's Interrogatories are included in Appendix E.

2. DEPLETED URANIUM PERFORMANCE ASSESSMENT COMPONENTS

Version 1.2 of the Neptune Modeling Report is included as Appendix A to this Report. Components of this depleted uranium Performance Assessment include a current long-term climate record representative of the Federal Cell; improved representation of near-surface processes that affect net infiltration, such as evaporation and runoff; representation of movement of water through the cover; and evaluation of radiation dose for hypothetical inadvertent intruder scenarios following the closure of the Federal Cell.

2.1 Site Characteristics

The proposed location for EnergySolutions' Federal Cell is west of the Cedar Mountains in Clive, Utah. Clive is located along Interstate-80, approximately 3 miles south of the highway, in Tooele County. The Federal Cell will be approximately 50 air-miles east of Wendover, Utah and approximately 75 highway miles west of Salt Lake City, Utah. The Federal Cell will sit at an elevation of approximately 4,275 feet above mean sea level (amsl) and be accessed by both highway and rail transportation. The Federal Cell will be southwest of DOE's above-ground disposal embankment used for disposal of uranium mill tailings that were removed from the former Vitro Chemical company site in South Salt Lake City between 1984 and 1988.

Currently, EnergySolutions receives waste shipped via truck and rail. Depleted uranium waste will be disposed below native grade in the permanent near surface engineered disposal Federal Cell, which is clay-lined with an engineered cover consisting of either multiple layers of natural soil and rock (already approved by the Division) or an alternate evapotranspirative cover (currently under review by the Division). The Federal Cell design (i.e., the Class A West Embankment design) has been shown to perform for a minimum of 500 years based on requirements of UAC R313-25-9, which provides long-term disposal with minimal need for active maintenance after site closure (DRC, 2012).

2.1.1 Climate

EnergySolutions has operated a weather station at Clive since July 1992. The station monitors wind speed and direction, 2-m and 10-m temperatures, precipitation, pan evaporation and solar radiation. A 20-year Summary Report from January 1, 1993 through December 31, 2012, provided to the Division on February 19, 2013, has been incorporated into this depleted uranium Performance Assessment (MSI, 2013). Since the Federal Cell will be located entirely within Section 32, this information adequately characterizes the site. Furthermore, the Federal Cell will have no significant effects upon the meteorological conditions or air quality of the region.

2.1.2 Weather Patterns

The Federal Cell region is in the Intermountain Plateau climatic zone that extends between the Cascade-Sierra Nevada Ranges and the Rocky Mountains and is classified as a middle-latitude dry climate or steppe. Hot dry summers, cool springs and falls, moderately cold winters, and a general year-round lack of precipitation characterize the climate. Mountain ranges tend to restrict the movement of weather systems into the area, but the area is occasionally affected by well-developed storms in the prevailing

regional westerlies. The mountains act as a barrier to frequent invasions of cold continental air. Precipitation is generally light during the summer and early fall and reaches a maximum in spring when storms from the Pacific Ocean are strong enough to move over the mountains. During the late fall and winter months, high pressure systems tend to settle in the area for as long as several weeks at a time.

2.1.3 Temperature

Regional climate is regulated by the surrounding mountain ranges, which restrict movement of weather systems in the vicinity. The most influential feature affecting regional climate is the presence of the Great Salt Lake, which can moderate downwind temperatures since it never freezes (NRC, 1993). Frequent invasions of cold air are restricted by the mountain ranges in the area. Data from 1992 through 2012 indicate that monthly temperatures range from about -2°C (29°F) in December to 26°C (78°F) in July (MSI, 2013).

2.1.4 Winds

In the 20-year period of time (July 1993 through December 2012) the most frequent (and predominant) winds were from the south-southwest direction, with the second most frequent direction being the east-northeast, followed by the south. Wind Rose data incorporated into this depleted uranium Performance Assessment has been obtained from the on-site weather station (MSI, 2013).

2.1.5 Precipitation

The Federal Cell will receive an average of 8.62 inches of precipitation per year. Measurements taken at the Clive weather station show that the lowest monthly precipitation recorded was 0 inches in May 2001. The highest recorded monthly precipitation was 4.28 inches, in May 2011 (MSI, 2013).

2.1.6 Evaporation

Pan evaporation measurements are taken from April through October when ambient temperatures remain above freezing. Maximum hourly evaporation values usually occur in July. The 18-year average annual evaporation at the Clive weather station is 52.73 inches (excluding 2 years of reported instrument malfunction) (MSI, 2013).

2.1.7 Geology

The EnergySolutions Federal Cell will be located on the eastern fringe of the Great Salt Lake Desert. The Clive site is located in, and is bounded by, the Great Salt Lake Desert to the west at approximate elevations of 4,250 to 4,300 feet amsl. Also to the west, low-lying hills rise 50 to 100 feet from the desert floor. To the east and southeast, the site is bounded by the north-south trending Lone Mountains, which rise to a height of 5,362 feet amsl. At the base of the Lone Mountains alluvial fans slope gently toward the west at a gradient of approximately 40 feet per mile. The site has topographic relief of approximately 11 feet, sloping in a southwest direction at a gradient of approximately 0.0019. The most recent characterization of the site geology and hydrogeology is reported in the Revised Hydrogeologic Report (EnergySolutions, 2012a).

The Federal Cell will rest on Quaternary lakebed deposits of Lake Bonneville. Site subsurface logs indicate that lacustrine deposits extend to at least 250 feet underneath the site. The underlying Tertiary and Quaternary age valley fill is composed of semi-consolidated clays, sands, and gravel where it comes in contact with bedrock. Although the exact depth to and relationships of various bedrock units are unknown, the presence of nearby outcrops and the regional block-faulted basins suggest that the valley-fill deposits are several hundred feet thick within the area of the site. Estimated down-dip projections from bedrock outcrop on the southwest corner of Section 31 and bedrock found at depth in Clean Harbors wells suggest that the contact may dip to the east about three degrees.

To the north of the site are the Grayback Hills, composed of Permian-Triassic carbonates. Igneous extrusives form a resistant cover on the Grayback Hills, and are mapped as late-Eocene trachyandesite lava flows and andesite/dacite volcanoclastics.

Geomorphic processes at the site are limited to micro processes that occur in the soil. For example the Great Salt Lake Desert is located in a semiarid to arid region where precipitation is less than evaporation. When the soil water evaporates, dissolved mineral matter is precipitated and forms calcium carbonate, gypsum and alkali (sodium and potassium carbonates) in the soil. Macro geomorphic processes are almost nonexistent where the general rate of weathering is very slow. This is due to the low amounts of precipitation, the lack of fluvial activities and the lack of relief at the site.

2.1.8 Hydrogeology

Alluvial and lacustrine sediments that fill the valley floor are estimated to extend to depths ranging from 300 to over 500 feet. North-south trending mountains and outcrops define the hydrogeologic boundaries for the aquifer system. Lone Mountain located two miles east of the site, rises approximately 950 feet above the valley floor. The Grayback Hills located to the north and outcropping features to the west rise 500 feet and 230 feet respectively above the valley floor (EnergySolutions, 2012a).

Four hydrostratigraphic units have been delineated in the unsaturated zone and shallow aquifer system at the Federal Cell, consisting of upper silty clay/clayey silt (Unit 4), upper silty sand (Unit 3), middle silty clay (Unit 2), and lower sand/silty sand (Unit 1). The site aquifer system consists of a shallow unconfined aquifer that extends through the upper 40 feet of lacustrine deposits. A confined aquifer begins around 40 to 45 feet below the ground surface and continues through the valley fill. Due to the low precipitation and relatively high evapotranspiration, little or no precipitation reaches the upper unconfined aquifer as direct vertical infiltration. Groundwater recharge is primarily due to infiltration at bedrock and alluvial fan deposits which then travels laterally and vertically through the unconfined and confined aquifers. Groundwater flow in this area is generally directed north to northeasterly. Although the term “aquifer” is used to describe water-bearing zones at the Clive facility, hydraulic conductivities and transmissivities are relatively low.

Fresh water from the recharge zones along the mountain slopes develops progressively poorer chemical quality in response to dissolution of evaporate-minerals during its travel through the regional-scale flow systems. The groundwater quality in the unconfined aquifer at the Federal Cell is saline with concentrations of several chemical species (sulfate, chloride, total dissolved solids, iron, and manganese) significantly exceeding the EPA secondary drinking water standards.

2.1.9 Surface Water

The area to contain the Federal Cell lies within the Great Basin drainage, a closed basin having no outlet. The site drains generally toward the west-southwest toward the eastern fringe of the Great Salt Lake Desert.

The nearest usable body of water to the Federal Cell is to the east, 28.1 miles away. At this location, a perennial stream flows from Big Spring (1,000 feet south of I-80) to the Timpie Springs Waterfowl Management Area, about 2,000 feet north of I-80. Activities at the EnergySolutions' Federal Cell will have no effect on surface-water quantities or quality at the Federal Cell. There are no perennial surface-water systems associated with the Federal Cell. Water necessary for construction is provided by existing wells in the vicinity requiring transport to the site, or impounded water.

No surface water bodies are present on the Federal Cell. The nearest stream channel ends about two miles east of the site and is typical of all drainages along the transportation corridors within 20 miles of the site. Stream flows from higher elevations evaporate and infiltrate into the ground before reaching lower, flatter land. The stream channel reduces until there is no evidence of a stream. The watershed up-gradient of the site covers approximately 46 square miles.

2.1.10 Groundwater

Local groundwater recharge from meteoric sources is generally limited, since pan-evaporation greatly exceeds precipitation (NRC, 1993). Recharge is more likely to occur in areas adjoining the surrounding mountain ranges, moving as subsurface flow to the center of the basin. Given the strong evaporation potential at the site, it is expected that some water in the unsaturated zone (vadose zone) move upward. An upward gradient is not only due to evaporation of water at the ground surface, it is also driven by the transpiration of plants, which pulls water from the ground and releases it to the dry atmosphere. The coupled effect of these two processes, known as evapotranspiration, serves to keep near-surface soils dry enough that precipitation often does not penetrate to lower soils.

Groundwater at the Federal Cell is found within a low-permeability saline aquifer starting near the bottom of the Unit 3 stratigraphic unit, and saturating the Unit 2 stratigraphic unit. The depth to groundwater is between approximately 20 and 30 feet bgs at an approximate elevation of 4,250 ft amsl (Brodeur, 2006). The regional (saturated) groundwater system flows primarily to the east-northeast toward the Great Salt Lake (EnergySolutions, 2013) and the local shallow groundwater follows a slight horizontal gradient to the north-northeast. Occasional transient shallow aquifer mounding occurs due to infiltration of surface water.

The underlying groundwater in the vicinity of the Federal Cell is of naturally poor quality because of its high salinity and, as a consequence, is not suitable for most human uses (NRC, 1993). Groundwater beneath the Federal Cell ranges in total dissolved solids (TDS) from 30,000 mg/L to 100,000 mg/L, with a site-wide average TDS content of 40,500 mg/L. The predominant cations and anions are sodium and chloride, respectively. For comparison purposes, sea water typically has a TDS content of 35,000 mg/L, thus the salinity content at the site is higher than average sea water.

2.1.11 Ecology

Ecological exploratory field studies were recently conducted in 2012 to quantify biogeography, bioturbation, and biological communities near the Federal Cell to assess local ecological analogs (SWCA, 2012). These studies observed that average plant species cover consists of 14.3% black greasewood, 5.9% Sandberg bluegrass, and approximately 3% cover each of shadscale saltbrush and gray molly occurring in low densities with 1.6% and 1.3% cover, respectively. Ground cover is dominated by 79.2% biological soil crust cover.

Field studies also included small mammal trappings, with 83 deer mice and one kangaroo rat trapped. Small mammals were observed in the north portion of Section 29 (i.e., immediately north of the licensed-Section 32 on which will be located the Federal Cell). Burrows of deer mice, kangaroo rats, ground squirrels, and badgers were also observed during the field studies.

Nineteen ant mounds were recorded and measured, with an average of 24 ant mounds observed per hectare. The average individual ant mound area and volume were estimated to be approximately 2,683 cm² and 28,348 cm³, respectively. The belowground area of the excavated ant mounds was found to be relatively shallow, with most of the ant nests within 0.6 meters of the surface.

Analyses of plant species cover, small mammal densities, animal burrow volumes, ant mound volumes, and soil chemistry and nutrition parameters identified several relationships between the variables under consideration. Positive correlations were witnessed between total vegetation cover, mammal densities, and burrow volumes. In contrast, no correlation was observed between total vegetation cover and ant mound area or volume. There were strong positive correlations between ant mound area, mound volume, and cover of weedy species. There was also a strong, negative correlation between ant mounds and soil silt, and somewhat strong negative correlations between animal densities, burrow volumes, and soil clay content. Field studies concluded that the high soil pH did not appear to be limiting for any of the native or weedy plant species observed. However, plant cover, particularly of shadscale saltbrush, showed strong, negative correlations with high soil salinity.

SWCA also examined the root density and maximum rooting depth of dominant plant species near the Federal Cell. Observed root densities were higher near the surface of the soil, where roots were mostly fibrous with few woody structures. A few large, woody roots were encountered in deeper soils. Rooting depths were shallower than expected, with the maximum rooting depth of dominant woody plant species ranging from 16 to 28 inches. Woody plant species maximum rooting depths were proportional to aboveground plant mass with an above-ground height root depth ratio of 1:1 and an above-ground width root depth ratio of approximately 1.4:1. The halogeton-disturbed plot had higher ratios of plant height

and width to maximum rooting depth (1.4:1 and 1.7:1, respectively). The low proportion of roots to above-ground biomass is expected for annual plants, which invest the bulk of their energy in reproduction and little energy in root systems.

2.2 Federal Cell Design

The new Federal Cell is proposed to be directly connected to the west side of the existing 11e.(2) Embankment, but separated south of the Class A West Embankment. Such a location provides a relative disposal footprint of 1,786,050 ft². The embankment design provides a total airspace volume of 13,216,770 ft³ for placement of depleted uranium below grade within the same CLSM disposal configuration requirements currently in use at the Class A West Embankment. As such, when accounting for the added fill volume provided by the CLSM, a total Federal Cell depleted uranium disposal capacity is estimated as 6,100,000 ft³ (which is sufficient capacity for disposal of the targeted depleted uranium from SRS, Portsmouth plant and Paducah facility).

Note that the former Class A South design included an isolation barrier and groundwater monitoring system beneath this barrier, intended to provide separation between Class A LLRW and 11e.(2) waste materials. This separation was considered necessary due to the differing long term stewardship regimes applicable to each waste type (Class A waste staying with the state of Utah and 11e.(2) going to the Department of Energy). It is anticipated that these distinctions will not be required for a Federal Cell, and accordingly the isolation barrier and groundwater monitoring system will not be necessary.

Analyses in support of the Class A West Embankment cover design are applicable to the Federal Cell on the following bases:

1. The Class A West Embankment has a larger surface area and thicker overall waste column than the Federal Cell. This indicates that bounding conditions have been evaluated for infiltration, runoff, and static and seismic stability.
2. Waste characteristics and placement procedures will be identical, as captured in the LLRW and 11e.(2) Construction Quality Assurance/Quality Control (CQA/QC) Manual.
3. Embankment liner and construction procedures will be identical, as captured in the LLRW and 11e.(2) Construction Quality Assurance/Quality Control (CQA/QC) Manual.

2.3 Federal Cell Cover Designs

As is supported by the analysis documented in Appendix A, principle design features of the licensed Class A West Embankment have been demonstrated to provide long-term isolation of waste, minimize the need for continued active maintenance after site closure, and improve the site's natural characteristics in order to protect public health and safety (Sections 3.1 – 3.3 of McCandless, 2012). The environment, site personnel, and the public are protected from unsafe levels of radiation both during and after active disposal operations (Sections 4.2 and 4.4 of McCandless, 2012). Long-term stabilization of the Class A West Embankment is accomplished through erosion control and flood protection (Sections 3.1.5, 3.2.5, 3.4.4, and 5.1.1 of McCandless, 2012).

Additionally, the Class A West Embankment custodial maintenance and surveillance are performed to assure continued long-term compliance with applicable regulatory standards (Section 6.3 of McCandless, 2012). As such, the Class A West Embankment cover design will perform equivalently on the Federal Cell. As with the Class A West Embankment, the controlled areas of the Federal Cell will be fenced both during construction and after operation to prevent public access (Sections 3.1.11, 4.3.6, 7.0, 7.1.3, 7.3, and 8.7 of McCandless, 2012).

The current Class A West Embankment cover design to be used on the Federal Cell is a critical component in the isolation of waste from the leaching potential of infiltration. DOE's Vitro Embankment and EnergySolutions' LARW Embankment use a traditional rock armor cover design similar to that currently approved for construction on the Class A West Embankment. In the rock armor cover design, the top slope (with a modeled infiltration rate of 0.09 cm/yr) consists of the following, from top to bottom:

- **Rip Rap cobbles.** Approximately 24 inches of Type-B rip rap will be placed on the top slopes, above the upper (Type-A) filter zone. The Type-B rip rap used on the top slopes ranges in size from 0.75 to 4.5 inches with a nominal diameter of approximately 1.25 to 2 inches. Engineering specifications indicate that not more than 50% of the Type B rip rap would pass a 1 1/4-inch sieve.
- **Filter Zone (Upper).** Six inches of Type-A filter material will be placed above the sacrificial soil in the top slope cover. The Type-A filter material ranges in size from 0.08 to 6.0 inches, with 100% passing a 6-inch sieve, 70% passing a 3-inch sieve, and not more than 10% passing a no. 10 sieve (0.079 inch). The Type-A size gradation corresponds to a poorly sorted mixture of coarse sand to coarse gravel and cobble, according to the Universal Soil Classification System.
- **Sacrificial Soil (Frost Protection Layer).** A 12-inch layer consisting of a mixture of silty sand and gravel will be placed above the lower filter zone to protect the lower layers of the cover from freeze/thaw effects. The sacrificial soil material ranges in size from <0.003 to 0.75 inches, with 100% passing a 3/4-inch sieve, 50.2% passing a no. 8 sieve (0.093 inch), and 7.6% passing a no. 200 sieve (0.003 inch).

- **Filter Zone (Lower).** Six inches of Type-B filter material will be placed above the radon barrier in the top slope cover. This filter material ranges in size from 0.2 to 1.5 inches, with 100% passing a 1 1/2- inch sieve, 24.5% passing a 3/4-inch sieve, and 0.4% passing a no. 4 sieve (0.187 inch). The Type-B size gradation corresponds to a coarse sand and fine gravel mix, according to the Universal Soil Classification System.
- **Radon Barrier.** The top slope cover design contains an upper radon barrier consisting of 12 inches of compacted clay with a maximum hydraulic conductivity of 5×10^{-8} cm/sec and a lower radon barrier consisting of 12 inches of compacted clay with a hydraulic conductivity of 1×10^{-6} cm/sec or less.

The design for the Class A West Embankment's traditional rock armored side slope cover is different, but similar to the top slope, (except for the thickness of the waste layer and the material used in the rip rap layer). The layers used in the Class A West Embankment side slope cover (with a modeled infiltration rate of 0.168 cm/yr) consist of the following, from bottom to top:

- **Rip Rap cobbles.** Approximately 24-inches of Type-A rip rap will be placed on the side slopes above the Type-A filter zone. The Type-A rip rap ranges in size from 2 to 16 inches (equivalent to coarse gravel to boulders) with a nominal diameter of 12 inches. Engineering specifications indicate that 100% of the Type-A rip rap would pass a 16-inch screen and not more than 50% would pass a 4 1/2- inch screen.
- **Filter Zone (Upper).** (Same design as top slope.)
- **Frost Protection Layer (Sacrificial Soil).** (Same design as top slope.)
- **Filter Zone (Lower).** The thickness of the Type B filter in the side slope will be 18 inches. The Type B filter material in the side slope will have the same size specifications as the top slope.
- **Radon Barrier.** (Same design as top slope.)

Evapotranspirative covers are increasingly being employed as alternative cover designs for municipal solid waste and hazardous waste sites in arid and semiarid climates. Unlike conventional rock armor cover systems, which use materials with low permeability to limit movement of water into waste, evapotranspirative cover systems minimize water percolation by storing and releasing water through evaporation from the soil surface and through transpiration from vegetation. The primary objective of evapotranspirative cover systems is to use the water balance components of soil and vegetation to hold precipitation and release it through soil surface evaporation or transpiration without allowing water percolation into waste layers.

Since the amendment of the Resource Conservation and Recovery Act Subtitle D (40 CFR 258.60) in March 2004, evapotranspirative cover systems and demonstration sites have been installed at hazardous and radioactive waste disposal facilities in the arid west, including Hill Air Force Base (Utah), Monticello Mill Tailings (Utah), Los Alamos National Laboratory (New Mexico), Sandia National Laboratories (New Mexico), Sierra Blanca (Texas), Rocky Mountain Arsenal (Colorado), and the Hanford Site (Washington) (Rock et.al, 2012). In addition to these facilities, evapotranspirative cover systems have been proposed for the U.S. Ecology Nevada Site (Nevada), the Molycorp Tailings Facility (New Mexico), and Clean Harbors (Utah).

While not yet formally approved, EnergySolutions has petitioned the Division for approval to construct an alternative evapotranspirative cover design on their Class A West Embankment (Shrum, 2012). To support that petition, EnergySolutions conducted an updated, site-specific Performance Assessment that demonstrates the alternate evapotranspirative cover design's ability to protect the general public during operations, protect the general public after closure, protect the inadvertent intruder, and to be stable over time. The model shows that the alternative evapotranspirative cover design significantly reduces infiltration into waste. This reduced infiltration further demonstrated that “. . . *that no radionuclides have the potential to reach the groundwater point of compliance within 10,000 years.*” (page 60 of Appendix A of Shrum, 2012).

The arrangement of evapotranspirative cover design for use as an alternate cover on the Federal Cell (once approved by the Division for construction on the Class A West Embankment) is (beginning at the top of the cover):

- **Surface layer.** This layer is composed of native vegetated Unit 4 material with 15% gravel mixture. This layer is 6 inches thick. The functions of this layer are to control runoff, minimize erosion, and maximize water loss from evapotranspiration. This layer of silty clay used in both evapotranspirative designs provides storage for water accumulating from precipitation events, enhances losses due to evaporation, and provides a rooting zone for plants that will further decrease the water available for downward movement.
- **Evaporative Zone layer.** This layer is composed of Unit 4 material. The thickness of this layer is varied in the Performance Assessment from 6 inches to 18 inches, to evaluate the influence of additional thickness on the water flow into the waste layer. The purpose of this layer to provide additional storage for precipitation and additional depth for plant rooting zone to maximize evapotranspiration.
- **Frost Protection Layer.** This material ranges in size from 16 inches to clay size particles. This layer is 18 inches thick. The purpose of this layer is to protect layers below from freeze/thaw cycles, wetting/drying cycles, and inhibit plant, animal, or human intrusion.

- **Upper Radon Barrier.** This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This layer has the lowest conductivity of any layer in the cover system. This is a barrier layer that reduces the downward movement of water to the waste and the upward movement of gas out of the disposal cell.
- **Lower Radon Barrier.** This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This is a barrier layer placed directly above the waste that reduces the downward movement of water.

A second alternate evapotranspirative cover design under consideration by the Division includes the addition of a filter zone between the frost protection layer and the upper radon barrier. This addition consists of six inches of Type-B filter material, placed below the frost protection material layer in evapotranspirative cover design. The filter material ranges in size from 0.2 to 1.5 inches. The Type-B size gradation corresponds to a coarse sand and fine gravel mix. This high conductivity layer is placed on the upper radon barrier which has the lowest conductivity of any layer in the cover system. The function of this coarse-to-fine interface is to collect water that has drained vertically from the layers above and direct it laterally to a surface drainage system. As such, if approved for construction on the Class A West Embankment, the alternate evapotranspirative cover design will perform equivalently on the Federal Cell.

2.4 Source Term

Because the Class A West Amendment Application already successfully demonstrated the Class A West Embankment design's ability to safely contain disposed waste inventories up to the Class A limits of UAC R313-15-1009 (which also applies to any Class A waste used as fill in the Federal Cell), the waste inventory considered in this depleted uranium Performance Assessment has been limited to the disposal of depleted uranium wastes in the Federal Cell of two general waste types: 1) depleted uranium trioxide (DUO_3) waste from the Savannah River Site (SRS) and 2) anticipated depleted uranium waste as U_3O_8 from gaseous diffusion plants (GDPs) at Portsmouth, Ohio and Paducah, Kentucky. The species list consists of the following radionuclides:

- Depleted Uranium
 - **uranium isotopes:** U-232, -233, -234, -235, -236, -238
 - **progeny of uranium:** Pb-210, Rn-222, Ra-226, -228, Ac-227, Th-228, -229, -230, -232, Pa-231
- Other Wastes Associated with the Depleted Uranium Canisters:
 - **Miscellaneous fission product:** Sr-90, Tc-99, I-129, Cs-137
 - **transuranic radionuclides:** Np-237, Pu-239, -239, -240, -241, -242, Am-241

Additionally, the quantity and characteristics of depleted uranium waste from other sources that has already been disposed of at Clive has previously been modeled and is therefore not included (in support of condition 6 of License UT2300249, issued 3 December 1990 at a limit of 110,000 pCi/g; and increased to 370,000 pCi/g, the specific activity of depleted uranium, on 22 October 1998).

The list of radionuclides associated with the depleted uranium wastes are classified by R313-15-1009 as no more than Class A. Those nuclides classified as Class A according to Tables I or II of UAC R313-15-1009 [or classified according to UAC R313-15-1009(2)(f)] are listed in Section 4.1.2.2 and Appendix 4 of Appendix A. Concentration limits for radionuclides not listed on Table I or Table II of R313-15-1009 are set at their respective specific activities.

2.4.1 Partitioning Coefficients (K_d)

The partitioning coefficient is the equilibrium ratio of the adsorbed contaminant concentration in soil or waste (mg/kg) to the concentration in the pore water or leachate (mg/L). Higher K_d values indicate that the specific radionuclide is more likely to partition to the soil and less likely to be released into groundwater. The K_d values used in the depleted uranium Performance Assessment have evolved over time, as radionuclide inventories changed and more information was obtained from the literature and from site-specific K_d testing. The modeling performed in this depleted uranium Performance Assessment incorporates the current approved K_d values for the site. The modeling preferentially uses

- Approved site-specific K_d values;
- The lowest measured soil K_d values published in the literature; and
- Published K_d values calculated from the soil:plant ratio.

Approved site-specific K_d values were available for Cs, Np-237, Tc-99, and U. The most conservative (lowest) K_d values found in the literature were used for nuclides that did not have site-specific K_d values. The soil:plant ratio was only used where actual measured soil K_d values are not available, and the published K_d value from the soil:plant ratio was decreased by two orders of magnitude to be conservative.

2.4.2 Fractional Release Rate

The depleted uranium Performance Assessment treats the Federal Cell contaminated zone as a single homogeneous source of changing thickness and radionuclide concentrations as the result of leaching, erosion, and in-growth and decay. Erosion or human activities result in redistribution of the contaminated soil that, in turn, creates new contaminated zones.

As natural precipitation infiltrates through either the Division-approved rock armor or under-review alternate evapotranspirative cover and into the depleted uranium zone, radionuclides are leached from the waste and transported through the unsaturated (vadose) zone and saturated zone (aquifer) to a down-gradient Point of Compliance. Fractional releases of contamination from the Federal Cell into the groundwater pathway are characterized by a water/soil concentration ratio for each radionuclide, which is defined as the ratio of the radionuclide concentration in the water to the radionuclide concentration in the contaminated zone.

2.4.3 Waste Containers

While they provide enhanced intruder barriers, no other waste isolation due to containerization is considered in the depleted uranium Performance Assessment. The depleted uranium Performance Assessment model considers the time required for the water to percolate through the Federal Cell cover. Although the initial waste moisture contents cannot be known with certainty, due to the inherent variability in the waste and in climatic conditions while the embankment is open, previous open-cell modeling suggests that drying of the waste occurs. Therefore, the moisture content in the waste at the time of cell closure will be below the levels reached at eventual pseudo-steady-state.

2.5 **Disposal In-Depth Scenario**

EnergySolutions commits to only dispose of depleted uranium below grade in a licensed Federal Cell. The general design aspect of the Federal Cell mirrors the Class A West Embankment and is that of a hipped cover, with relatively steep sloping sides nearer the edges. The upper part of the Federal Cell has a more moderate slope than the sides. Only the top slope region is modeled in Section 4.1.2.1 and Appendix 3 of Appendix A, since no depleted uranium will be placed beneath the Federal Cell's side slopes.

The Class A West Amendment Application addresses the pertinent characteristics of the principal design features for waste placement and backfill in the Federal Cell. Depleted uranium waste included in this analysis may take a variety of physical forms, including soil or soil-like material, compressible debris, incompressible debris, oversized debris, and containerized Class A LLRW. Liquid waste may not be disposed in the Federal Cell. Waste placement activities will be conducted in accordance with the CQA/QC Manual.

With downward contaminant transport pathways influencing groundwater concentrations, and upward contaminant transport pathways influencing dose and uranium hazard, a balance is achieved in the placement of different kinds of waste. The depleted uranium Performance Assessment examines three disposal in-depth scenarios (with one being the below-ground option being considered for configuration of the depleted uranium waste within the Federal Cell). As with the Class A West Embankment design, the peak height within the Federal Cell that is available for waste disposal is 75.3 ft from the engineered cover to the Federal Cell's liner. Revision 0 of this Compliance Report assumed disposal in a Class A South embankment. The supporting GoldSim model has been reconstructed to reflect a Federal Cell (version 1.2).

No depleted uranium waste is modeled beneath the Federal Cell's side slopes in the depleted uranium Performance Assessment. While EnergySolutions has committed to only dispose depleted uranium below-grade, several depth options are examined to inform the performance of the Federal Cell. The configuration options examined are (depths are downward from the base of the top slope engineered cover).

1. **3m Model**
Clean Fill from cover to 9.9 ft
GDP contaminated waste from 9.9 ft to 11.6 ft
SRS waste from 11.6 ft to 13.23 ft
GDP uncontaminated waste from 13.23 ft to 44.65 ft

2. **5m Model**
Clean Fill from cover to 16.54 ft
GDP contaminated waste from 16.54 ft to 18.19 ft
SRS waste from 18.19 ft to 19.84 ft
GDP uncontaminated waste from 19.84 ft to 44.65 ft

3. **10m Model (completely below grade)**
Clean Fill from cover to 33.07 ft
GDP contaminated waste from 33.07 ft to 34.72 ft
SRS waste from 34.72 ft to 36.38 ft
GDP uncontaminated waste from 36.38 ft to 44.65 ft

As with the Class A West Embankment, the design of the Federal Cell enables isolation from EnergySolutions' other embankments after it has been filled and covered. Thus, once the Federal Cell is closed, it will not be disturbed by continuing operations at the site. As with the Class A West Embankment, the final Federal Cell cover integrates long-term water and erosion control methods into the overall design, thus eliminating the need for active maintenance of a closed Federal Cell. Additionally, the sensitivity of the projected results to variations in Federal Cell characteristics and disposal scenarios is addressed in Appendix 15 of Appendix A.

2.6 Receptors and Exposure Scenarios

Receptors in the depleted uranium Performance Assessment are categorized in UAC R313-25-9 according to the labels "*members of the public*" and "*inadvertent intruders*." A member of the public is essentially a receptor who is exposed outside the boundaries of the Federal Cell, where the inadvertent intruder is someone who intrudes onto the Federal Cell and may directly contact the waste. The "*critical group*" receptors evaluated are modeled to receive exposure both upon the Federal Cell and in adjacent areas according to the activities foreseen (ranching, recreational, and industrial uses). These scenarios are evaluated under post- institutional control conditions.

The GoldSim Model has been run with and without consideration for the formation of gullies. Scenarios run without gullies are reported as exposure scenarios to members of the general public. Conversely, exposure scenarios wherein it is assumed that gullies are formed (i.e., signifying potential intrusion into the Federal Cell) are reported as exposure scenarios to inadvertent intruders.

2.6.1 Ranching Scenario

The land surrounding the Federal Cell is currently utilized for cattle and sheep grazing. Ranchers typically use off-highway vehicles (OHVs), including four-wheel drive trucks) for transport. Activities are expected to include herding, maintenance of fencing and other infrastructure, and assistance in calving and weaning. Ranchers may be exposed to contamination via the pathways outlined in Table 1 and Appendix 11 of Appendix A.

2.6.2 Recreation Scenario

Recreational uses on the land surrounding the Federal Cell may involve OHV use, hunting, target shooting of inanimate objects, rock-hounding, wild-horse viewing, and limited camping. It is assumed in the depleted uranium Performance Assessment that recreational OHV riders (“*Sport*” OHVs; i.e. , OHV users who use their vehicles for recreation alone) and hunters using OHVs (“*Hunters*”), both of whom may also camp at the site, represent the most highly-exposed recreational receptors. Recreationalists may be exposed to contamination via the pathways outlined in Table 1 and Appendix 11 of Appendix A.

2.6.3 Industrial Scenario

Most of the land within a 10-mile radius of the Federal Cell is public domain administered by BLM. This dry and arid desert area limits other viable uses of the land. Three hazardous waste facilities are located near the Federal Cell:

- Clean Harbors’ Grassy Mountain facility, a commercial, hazardous waste, treatment, storage and disposal facility located greater than ten miles north-northwest of EnergySolutions’ proposed Federal Cell. This facility was issued its original permit to operate on June 30, 1988;
- Clean Harbors’ Aragonite facility a 140 million Btu slagging rotary kiln with a vertical afterburner chamber located approximately 8 miles east-northeast of EnergySolutions’ proposed Federal Cell. This facility applied for its original permit to operate on July 22, 1987; and,
- Clean Harbors Clive facility, a defunct incinerator site currently permitted for transfer and storage of hazardous waste located approximately 1.25 miles west of EnergySolutions’ proposed Federal Cell. This facility applied for its original permit to operate on February 14, 1988.

No new industrial facilities have been established in this area of Tooele County’s West Desert since June 30, 1988. Individuals who work at these facilities do not live on site, nor do they represent permanent residential population centers.

Tooele County currently has 28 zoning districts including MG-H for Hazardous Industries and MG-EX for mining, sand and gravel excavation. In 1987, the West Desert Hazardous Industry Area or Corridor (WDHIA), with a MG-H zoning designation, was created to prohibit the construction of private dwellings and to provide an area in a remote locations where hazardous and low-level radioactive waste could be stored, treated and disposed in a safe manner (referred to as hazardous industries). The corridor consisted of 78,720 acres at a time when there was a boom in the hazardous and radioactive waste industry. Residential construction was prohibited within a ten mile radius of a hazardous industry (Tooele County, 2012). On November 22, 2005, the Tooele County Planning Commission decreased the size of the WDHIA to 9,440 acres and changed the corridor to four non-contiguous areas, surrounded by State Trust, MG-EX zoned and BLM lands. The prohibited distance to residential development was decreased from ten to five miles to accommodate a request by UDOT to have a resident live at the rest stop on I-80 (Tooele County, 2012).

Both the upper unconfined and lower confined aquifers have been classified as Class IV, “*non-potable, saline ground water*” due to total dissolved solids and other naturally-present constituents. As such, consideration of a groundwater ingestion scenario as an exposure or dose pathway is not representative of “*current local well-drilling techniques and/or water use practices*,” (NRC, 2000). Even so, EnergySolutions recognizes current local groundwater practices involve pumping of water as a limited source of non-ingestible industrial water (such as for dust suppression). While of comparably poor water quality, similar local wells installed for the production of industrial water have been screened into the deeper confined aquifer as production sources for industrial water (due to the relatively low yield of the upper, unconfined aquifer).

In fact, EnergySolutions requested permission from the Division to install such a well in Section 29 (immediately north of the area licensed for radioactive waste management), (Envirocare, 2005; included as Section 6 to Appendix D). Analyses and representative well characteristics from Envirocare (2005) have been used to model potential doses for an inadvertent industrial intruder well scenario in support of the response to this Interrogatory. Since a cost-benefit/business analysis is implied in Envirocare’s 2005 decision to seek approval to install a well in the northwest corner of Section 29 (as opposed to continuing to truck water), repeating such an activity as part of this response is unnecessary. Envirocare deemed pumping water from a local well financially feasible and commissioned the study (attached as Section 6 to the Round 2 Response Report). Envirocare abandoned its pursuit of the Section 29 well when it became apparent that burdensome regulatory requirements would make it more expensive than continuing to truck water from another source. It is assumed that these same regulatory hurdles will not be present in the Inadvertent Industrial Well scenario considered below.

However, it is important to note that Envirocare’s 2005 petition to install the well was that of an “*informed*” or “*advertent*” intruder. Envirocare knew what quality of water was being sought and, as such, the limited uses to which it could be applied. Conversely, if someone were to explore for water in the valley in the future, after the loss of institutional control, without knowledge of water quality, they would most likely install a well nearer to the foothills – where water quantity is more abundant and of higher quality. Water quality continues to degrade as it migrates to the center of the valley – this is the conceptual model for the entire Basin and Range Province. It is extremely unlikely that an industrial user

without any knowledge of the valley would select the middle of the valley as their well installation site of primary interest. Additionally, for any industrial use other than dust suppression, the inadvertent intruder will quickly realize the poor quality of the groundwater – when their associated pumps and other industrial equipment become corroded and unusable. This poor quality water naturally contains high concentrations of Uranium and other NORM isotopes. Once an industrial user becomes aware that the water (even in its natural form) must be treated before its possible uses can be expanded – that individual no longer is “*inadvertent*” in its knowledge or intended groundwater uses.

The quality of water from the deeper aquifer is of similar classification to that from the shallow aquifer (very high TDS, brackish, and of extremely poor taste and smell). An assumption that there is any possible or reasonable chance to drink it is as unlikely as an assumption that the shallow aquifer is ingested. Therefore, no ingestion was considered credible or representative of current practice.

While highly improbable, it is assumed that an inadvertent industrial intruder driller uses a mud rotary system (which is common in the Clive area) to drill a well (similar in physical characteristics to that proposed in 2005) 90 feet from the design toe of the DU waste within the Federal Cell. For the purposes of this analysis, it is assumed that this occurs sometime after site closure/ institutional control. As is justified in the response to Interrogatory CR R313-25-20-92/2: Inadvertent Intruder Dose Standard and Scenarios, all exposure scenarios (whether acute or chronic) are subject to a dose limit of 500 mrem/year.

These are the known uses of groundwater in the valley. Since this scenario considers direct application of contaminated water onto a broad industrial land surface as dust suppression, any resulting external exposure pathway bounds that of a volumetrically-limited imaginary reverse osmosis brine impoundment. In fact, the current users use reverse osmosis to treat groundwater pulled from the mountain front, which has much lower TDS (yet, still requires reverse osmosis treatment) and a higher yield. These current users are also several miles upgradient of EnergySolutions’ proposed Federal Cell and will not be impacted by its construction and operation. Envirocare’s 2005 analysis modeled what Envirocare intended to do, which was to install a deep well near the licensed area (also upgradient) for direct use in dust control.

Finally, it is important to note that EnergySolutions (even in support of its 2005 analysis) has never considered the use of an reverse osmosis system down-gradient of its licensed areas. This is because the poor native groundwater condition (i.e., extremely high TDS) downgradient of EnergySolutions’ licensed areas prevents effective use of reverse osmosis systems. In fact, the reason the only reverse osmosis system currently in use in that valley is located at the foothills – is that the TDS for the groundwater from that foothill location is approximately half that naturally beneath EnergySolutions’ embankments. Reverse osmosis systems will not work effectively on groundwater with TDS levels significantly higher than those at Aragonite.

2.6.3.1 Acute Inadvertent Well Driller Intruder Scenario

A distinct acute exposure scenario to an inadvertent intruder considered in this analysis is referred to as the “acute well drilling scenario”. The acute well drilling scenario is based on the assumption that after active institutional control ceases, an intruder drills a well within the licensed buffer zone (90 feet from the toe of the disposed depleted uranium). The acute well drilling scenario considers exposures during the short period of time required for drilling and construction of the well. During well drilling, the following relevant exposure pathways are assumed:

- External exposure photon-emitting radionuclides in the unshielded cuttings pile containing waste, and
- Inhalation of radionuclides suspended in air from the uncovered cuttings pile containing waste.

The importance of the acute well drilling scenario arises primarily from the assumption that an inadvertent intruder could be located near an unshielded cutting pile for a substantial period of time.

2.6.3.2 Chronic Inadvertent Industrial Intruder Scenario

A distinct chronic exposure scenario to an inadvertent intruder considered in this analysis is referred to as the chronic post- drilling scenario. The chronic post- drilling scenario is based on the assumption that after active institutional control ceases, an inadvertent intruder who works near the Federal Cell, uses water produced from the intruder well for industrial purposes (such as dust suppression). While it is recognized that this industrial individual did not conduct activities that actually intruded into the waste, it is assumed that any associated industrial activities are conducted within the buffer area. Additionally, it is assumed that the industrial intruder is unaware of any possible depleted uranium-related contaminants that may have leached into the unconfined aquifer. Under this condition, NRC still characterizes the inadvertent industrial user as an inadvertent intruder, since:

“Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite [that may result in subsequent exposure to members of the general public].” (NUREG-1573, pg. 3-11).

The following relevant exposure pathways involving the contaminated material sprayed onto the surface are then assumed to occur:

- External exposure photon-emitting radionuclides in the unshielded surface-sprayed wastewater, and
- Inhalation of radionuclides suspended in air from the unshielded surface-sprayed wastewater.

The importance of the chronic post-drilling scenario arises primarily from the assumption that an intruder could inadvertently use contaminated water for dust suppression for a substantial period of time. It is assumed that water extracted from the production well consists of contaminated wastewater from the unconfined aquifer (not within the well screen depth) that has leaked down into the uncontaminated deep aquifer (where the well casing is screened).

2.6.4 Other General Public Exposure Scenarios

The ranching, recreation, and industrial scenarios are characterized by potential exposure related to activities both on the Federal Cell and in the adjoining area. Specific off-site points of potential exposure also exist for other receptors based upon present-day conditions and infrastructure. Unlike ranching, recreational, and industrial receptors who might be exposed by a variety of pathways on or adjacent to the site, these off-site receptors would likely only be exposed to wind-dispersed contamination, for which inhalation exposures are likely to predominate. Five specific off-site locations and receptors are evaluated in the depleted uranium Performance Assessment, including:

- Travelers on Interstate-80, which passes 4 km to the north of the site;
- Travelers on the main east-west rail line, which passes 2 km to the north of the site;
- Workers at the Utah Test and Training Range (UTTR, a military facility) to the south of the Federal Cell, who may occasionally drive on an access road immediately to the west of the Federal Cell fence line;
- The resident caretaker at the east-bound Interstate-80 rest facility (the Grassy Mountain Rest Area at Aragonite) approximately 12 km to the northeast of the site, and,
- OHV riders at the Knolls OHV area (BLM land that is specifically managed for OHV recreation) 12 km to the west of the site.

3. ANALYSIS OF FEDERAL CELL PERFORMANCE

As documented in the modeling report included in Section 5 and Appendix 16 of Appendix A, the GoldSim platform was selected for this depleted uranium Performance Assessment, because of its ability to probabilistically simulate complex processes known to have a significant role in water flow in landfill covers in arid regions, including water flow in variably-saturated porous media, material hydraulic property functions, atmospheric surface boundary conditions including precipitation and evapotranspiration, root water uptake, and free-drainage boundary conditions.

3.1 Protection of the Post-Closure General Public

By rule, the depleted uranium Performance Assessment's specific technical information, "*shall include the following analyses needed to demonstrate that the performance objectives of UAC R313-25 will be met: Analyses demonstrating that the general population will be protected from releases of radioactivity shall consider the pathways of air, soil, ground water, surface water, plant uptake, and exhumation by burrowing animals. The analyses shall clearly identify and differentiate between the roles performed by the natural disposal site characteristics and design features in isolating and segregating the wastes. The analyses shall clearly demonstrate a reasonable assurance that the exposures to humans from the release of radioactivity will not exceed the limits set forth in UAC R313-25-20*" [UAC R313-25-9(1)].

The information contained in Section 6.2 and 6.3 of Appendix A and other relevant documents EnergySolutions has submitted indicate that the requirements of R313-25-9(1) have been met. Each of the major media pathways of this requirement is addressed in the following paragraphs.

3.1.1 Air Pathway

Due to the extreme depth of disposal, analysis modeled in Appendices 8 and 18 of Appendix A demonstrates that the transport of dust to the site boundary following closure (affected mainly by the natural site characteristics, including wind speed, wind direction, and atmospheric stability conditions) is well below regulatory limits. After final placement of the depleted uranium waste and closure of the Federal Cell, the design prevents any further migration of radioactivity through the air pathway because all waste will be beneath a thick earthen cover. Analysis presented in Section 6.2 of Appendix A demonstrates that the maximum dose to a member of the public following Federal Cell closure and institutional control is far below applicable regulatory limits.

The Federal Cell's design is based on the disposal of uranium mill tailings, which are initially higher in Ra₂₂₆ than the depleted uranium (which require time periods exceeding the 10,000-year regulatory limit to in-grow due to uranium chain decay). Therefore, as is reported in Appendix 18 of Appendix A, radon releases are negligible within the Compliance Period, because of the comparatively low Ra₂₂₆ parent waste concentrations and the clay radon barriers of the cover designs (that limit the surface radon flux to less than 20 pCi/m²-s).

3.1.2 Soil Pathway

The Federal Cell's design minimizes exposures to contaminated soil by members of the public. After closure of the Federal Cell, all depleted uranium and other waste will be covered. One of the proposed cover systems contains a surface layer of riprap to protect against erosion and human intrusion. Beneath the riprap, the cover system contains a drainage layer and a clay radon barrier. The alternate evapotranspirative cover design under review consists of layers of soil and mulch similar to native area conditions.

As summarized in Section 6.2.1 of Appendix A, the soil pathway involves the exposure of the public to contaminated depleted uranium from the Federal Cell. If an exposure occurred, doses could result from external radiation or ingestion of soil on dirty hands. The primary site characteristic that prevents the likelihood of such exposures following closure are the site's remote location (the low population density in the site vicinity), the lack of natural resources to provide for population expansion, and the extreme depth of depleted uranium disposal.

3.1.3 Groundwater Pathway

As is described in Section 6.1.1 of Appendix A, radionuclide transport was modeled with the GoldSim model assuming the 4 mrem/year groundwater protection level currently required of EnergySolutions in their Ground Water Quality Discharge Permit. The model calculated the release and transport of depleted uranium radionuclides from the Federal Cell, through the unsaturated zone, and horizontally through the shallow unconfined aquifer to a compliance-monitoring well located 90 feet from the edge of the Federal Cell. The groundwater modeling included many conservative assumptions that helped to ensure that the radionuclide concentrations at the compliance monitoring well were not underestimated. For example, the distance from the bottom of the waste to the aquifer was decreased from its actual value by 1.3 feet to conservatively account for the effects of the capillary fringe at the water table and to account for variations in the water table level. No delay factors for waste container life were used to delay the onset of radionuclide releases from depleted uranium waste. The transport modeling shows that, for most depleted uranium radionuclides at the Class A limits, groundwater protection levels are met for 500 years after disposal of the waste.

The primary site characteristics that prevent public exposures via the groundwater pathway are the very poor groundwater quality at the site, the low population density, and the relatively slow groundwater flow velocities. The groundwater is not potable because of its very high concentration of dissolved salts. This characteristic alone prevents any appreciable consumption of the water by humans or livestock. The horizontal groundwater flow velocity is approximately 0.5 meters per year, resulting in groundwater travel times of approximately 60 years from the toe of the side slope region of the Federal Cell to the compliance well.

Several of the Federal Cell's design features provide protection of the public from exposure to waste via the groundwater pathway. Both cover systems allow very little water to flow into the disposed waste. This limits the contamination of the groundwater by minimizing the contact of water with the depleted uranium waste. Another important design feature of the Federal Cell is the bottom clay liner below the disposed depleted uranium waste. The clay absorbs many of the radionuclides and slows their potential release from the cell and subsequent transport to the water table aquifer.

The infiltration model for the Federal Cell covers use GoldSim to demonstrate that the infiltration and radionuclide transport models show that any depleted uranium waste disposed satisfies all of the groundwater protection criteria, provided that the concentrations of Tc₉₉ are limited to the concentrations used in the transport modeling. By comparison, the Tc₉₉ disposal concentrations are limited to 1,720 pCi/g under the Class A West side slope. As such, EnergySolutions proposes the same Federal Cell disposal limitations of 23,800 pCi/g under the top slope (since no depleted uranium will be disposed beneath the Federal Cell's side slope). All other radionuclide concentrations in the Federal Cell will be limited only by what is necessary for the waste to qualify as Class A. This groundwater modeling provides a conservative estimate for the groundwater exposure scenario.

3.1.4 Surface Water Pathway

Due mainly to the natural site characteristics, there are no radioactive releases expected through the surface water pathway from non-intruder scenarios. The annual precipitation is low and the evaporation is high. No permanent surface water bodies exist in the site vicinity. In addition, the site is far from populated areas. The Federal Cell design features minimize the potential for releases by the surface water pathway. Federal Cell design includes drainage ditches around the waste disposal areas. After precipitation events, these ditches divert runoff from the closed disposal cell cover to areas away from the disposal cells.

3.1.5 Vegetation Pathway

As is documented in Appendix 9 of Appendix A, vegetation models developed for the depleted uranium disposal evaluate the redistribution of soils, and contaminants within the soil, by native flora and fauna. The biotic models are consistent with observed flora and fauna on and near the Federal Cell, with flora and fauna characteristic of Great Basin alkali flat and Great Basin desert shrub communities.

The Appendix A Model also evaluates the effects of vegetation on the cover system. Vegetation had two primary effects on the cover system: increasing the hydraulic conductivity of the cover material and root clogging of the lateral drainage layers. After final placement of the cover, releases and doses from the plant pathway are limited by the site's natural characteristics, which include low rainfall, thin plant cover, and the presence of plants that are highly efficient at removing water from the soil and transpiring the moisture back to the atmosphere.

Exposure by the plant uptake pathway could occur by (1) the production of food crops in contaminated soil at the site, and (2) root intrusion into the waste by native plants that are subsequently consumed by humans or animals. However, there is insufficient water at the site for the production of food crops. In addition, saline soils present at the site limit the number and type of plant species that can tolerate such conditions. Additionally, there are few deep-rooted native plants in the site vicinity. Examination of deep-rooted native plants present in the site vicinity reveal root depths insufficient to penetrate the cover system, overlying wastes, and into the depth at which depleted uranium is modeled for disposal (i.e., greater than 5 meters below the base of the cover).

3.1.6 Burrowing Animals Pathway

Burrowing animals at the site include jackrabbits, mice, foxes, and ants. After final placement of the cover, the thick cover and other embankment materials isolate the depleted uranium waste from burrowing animals (controlling releases and doses). Because of this, the likelihood of any animals burrowing through the entire cover, overlying waste, and exhuming depleted uranium materials is sufficiently low that it was not included in the safety assessment calculations.

In the arid environment of the Federal Cell, ants fill a broad ecological niche as predators, scavengers, trophobionts and granivores. However, it is their role as burrowers that is modeled (see Appendix 9 of Appendix A). Ants burrow for a variety of reasons but mostly for the procurement of shelter, the rearing of young, and the storage of foodstuffs. How and where ant nests are constructed plays a role in quantifying the amount and rate of subsurface soil transport to the ground surface near the Federal Cell. Factors relating to the physical construction of the nests, including the size, shape, and depth of the nest, are key to quantifying excavation volumes. Factors limiting the abundance and distribution of ant nests such as the abundance and distribution of plant species, and intra-species or inter-species competitors, also can affect excavated soil volumes. Parameters related to ant burrowing activities include nest area, nest depth, rate of new nest additions, excavation volume, excavation rates, colony density, and colony lifespan. The GoldSim model evaluates the impact of ant burrowing on the transport of contaminants using the following three steps:

1. Identification of which ant species overwhelmingly contribute to the rearrangement of soils near the surface of the Federal Cell.
2. Calculation of soil and contaminant excavated volume using maximum depth, nest area, nest volume, colony density, colony life span, and turnover rate for predominant ant species.
3. Calculation of burrow density as a function of depth to determine the distribution of contaminants within the vertical soil profile for each predominant ant species.

3.1.7 Post Closure Doses to Members of the General Public

This depleted uranium Performance Assessment includes projections of radionuclide transport in groundwater, consistent with the required groundwater protection limits of EnergySolutions' Ground Water Quality Discharge Permit. The GoldSim platform calculated the release and transport of depleted uranium radionuclides from the Federal Cell, through the unsaturated zone, and horizontally through the shallow unconfined aquifer to a compliance-monitoring well located 90 feet from the edge of the Federal Cell.

Table 3-1 presents the maximum dose to members of the general public due to the disposal of depleted uranium in the Federal Cell. The reported 95% upper confidence interval of the mean peak doses is commonly used to represent reasonable maximum exposure in CERLCA risk assessments. While the highest doses are projected for the Rancher, compliance with the 25 mrem/year performance objective for protection of the member of the general public is clearly established. Additionally, Table 3-1 reveals that the rock armor cover provides better protection for the Rancher, OHV, and Hunter. Conversely, the evapotranspirative cover (which better restricts infiltration into the depleted uranium wastes), provides enhanced protection of the general public to the I-80, Knolls, rail road, rest area, and UTTR access road receptors.

Table 3-2 estimates 100-percent mortality of all members of the general public that consume native groundwater from beneath the Federal Cell. The major contributions to total mortality are the extremely high TDS, sulfate, and chloride concentrations naturally present in this Class IV aquifer. As such, any increase in the already-high native radiologic groundwater concentrations will have insignificant impacts to the overall non-radiologically-dominated mortality due to ingestion of the native groundwater. Therefore, even when considering the relatively higher infiltration rates of the rock armor cover design, doses to the general public (where no members of the public remain living following consumption of native groundwater) will still be below 4 mrem/year. Therefore, inclusion of depleted uranium with either the rock armor cover or the evapotranspirative cover, do not compromise the Federal Cell's performance and protection of the general public from radiological dose resulting from ingestion of groundwater.

3.2 Protection of the Post-Closure Inadvertent Intruder

Exposures to inadvertent intruders are also assessed by EnergySolutions' GoldSim model. Based upon current and reasonably anticipated future land uses, three future use inadvertent intruder exposure scenarios were identified in which gullies are assumed to be formed: ranching, recreation, and industrial. After institutional controls are no longer maintained, it is expected that exposures to contamination in the ranching, recreation, and industrial scenarios (wherein inadvertent intrusion activities result in gullies formed in the closed cover) could occur from the Federal Cell. The primary exposure routes for the ranching, recreation, and industrial scenarios include ingestion, inhalation, and external irradiation.

Table 3-1

**Peak Total Effective Dose Equivalent to the General Public
(mrem/yr)**

Receptor	Mean	Median	95% Percentile
<u>Rock Armor Cover:</u>			
Rancher	0.0060	0.0047	0.015
Hunter	0.00025	0.00021	0.00062
OHV enthusiast	0.00039	0.00031	0.00094
I-80 receptor	1.5E-07	1.2E-07	3.9E-07
Knolls receptor	1.6E-06	1.2E-06	4.3E-06
Rail road receptor	2.4E-07	1.9E-07	6.1E-07
Rest area receptor	3.1E-05	2.5E-06	7.8E-06
UTTR access road	7.8E-05	6.2E-05	0.0002
<u>Evapotranspirative Cover:</u>			
Rancher	0.016	0.014	0.037
Hunter	0.0008	0.00071	0.0017
OHV enthusiast	0.0013	0.0011	0.0027
I-80 receptor	4.9E-07	4.3E-07	1.0E-06
Knolls receptor	4.4E-06	3.5E-06	1.1E-05
Rail road receptor	7.7E-07	6.7E-07	1.7E-06
Rest area receptor	1.0E-05	9.0E-06	2.2E-05
UTTR access road	0.00025	0.00022	0.00055

Table 3-2

Mortality Rates From The Consumption Of Native Groundwater

	Average Native Groundwater Concentration^a	Radiological Mortality Slope Factor (per μCi)^b	Risk^d
Radiologics (pCi/L)			
H-3	2.89E+02	3.49E-08	3.08E-07
C-14	8.46E+00	1.07E-06	2.76E-07
K-40	4.18E+02	1.59E-05	2.03E-04
I-129	1.94E+00	1.51E-05	8.90E-07
Np-237	4.02E-01	4.07E-05	4.99E-07
Ra226	5.05E-01	2.65E-04	4.09E-06
Ra-228	9.75E-01	7.40E-04	2.20E-05
Sr-90	1.09E+00	4.96E-05	1.65E-06
Tc-99	5.52E+00	1.58E-06	2.67E-07
Th-230	2.15E-01	6.18E-05	4.06E-07
Th-232	1.14E-01	6.92E-05	2.41E-07
U-234	2.10E+00	4.59E-05	2.94E-06
U-235	1.75E-01	4.48E-05	2.39E-07
U-238	1.11E+00	4.18E-05	1.42E-06
		Drinking Water Unit Risk (per $\mu\text{g/L}$)^c	
Anions (mg/L)			
Bromide	1.56E+01	2.00E-05	3.12E-01
Chloride	3.14E+04	5.00E-04	1.57E+04
Nitrate	1.63E+00	8.00E-03	1.31E+01
Nitrite	1.38E+00	5.00E-04	6.91E-01
Sulfate	6.52E+03	1.44E-01 ^e	9.39E+05
Metals (mg/L)			
Antimony	5.00E-03	2.00E-06	1.00E-05
Arsenic (ICP)	8.80E-02	2.50E-07	2.20E-05
Arsenic (GFAA)	4.30E-02	2.50E-07	1.08E-05
Barium	1.90E-02	1.00E-03	1.90E-02
Beryllium	3.00E-03	1.00E-05	3.00E-05
Cadmium	4.40E-03	2.50E-06	1.10E-05
Chromium	1.80E-02	1.50E-05	2.70E-04
Cyanide	6.00E-03	3.00E-06	1.80E-05
Mercury	3.00E-04	1.50E-06	4.50E-07
Molybdenum	6.64E-01	2.50E-05	1.66E-02
Selenium (GFAA)	3.80E-02	2.50E-05	9.50E-04
Silver	8.00E-03	2.50E-05	2.00E-04
TDS	6.08E+04	1.64E-02 ^e	1.00E+06

	Clive's Average Natural Groundwater Concentration ^a	Drinking Water Unit Risk (per µg/L) ^c	Risk ^d
Zinc	6.60E-02	1.50E-03	9.90E-02
Volatiles (mg/L)			
Acetone	1.51E+01	4.50E-03	6.81E+01
2-Butanone (MEK)	1.43E+01	2.10E-05	3.01E-01
Carbon disulfide	3.74E+00	5.00E-04	1.87E+00
Chloroform	2.44E+00	5.00E-05	1.22E-01
1,2-Dichloroethane	2.44E+00	2.60E-06	6.33E-03
Methylene chloride	2.39E+00	2.10E-05	5.02E-02
1,1,2-Trichloroethane	1.36E+01	1.60E-06	2.18E-02
Vinyl Chloride	1.28E+01	2.10E-05	2.70E-01
Semi-Volatiles (mg/L)			
Benz(a)anthracene	3.94E+01	2.10E-04	8.27E+00
Benzo(a)pyrene	3.94E+01	2.10E-04	8.27E+00
Benzo(b)fluoranthene	4.11E+01	2.10E-04	8.64E+00
Benzo(k)fluoranthene	3.94E+01	2.10E-04	8.28E+00
Chrysene	3.94E+01	2.10E-04	8.27E+00
Dibenz(a,h)anthracene	3.94E+01	2.10E-04	8.27E+00
Diethyl phthalate	6.61E+00	4.00E-01	2.64E+03
2-Methylnaphthalene	5.46E+00	1.00E-04	5.46E-01
Naphthalene	4.79E+00	1.00E-04	4.79E-01
Pesticides (mg/L)			
Chlordane	5.47E+00	1.00E-05	5.47E-02
TOTAL CARCINOGENIC MORTALITY RISK			1.96E+06

^a Long-term average concentrations from up-gradient well GW-19A, (EnergySolutions, 2012c). Reported concentration for non-naturals is an average of the detection limit.

^b (Eckerman,1999).

^c (EPA, 2013).

^d Deaths per 1,000,000 individuals.

^e (Patterson, 2005)

Chapter 6.2.1 of Appendix A discusses the Federal Cell's design objectives that protect inadvertent intruders from exposure. As is demonstrated, the radiation dose to an inadvertent intruder is not expected to exceed radiation limits. Several design features provide the required protection. Overall features include:

- Lack of nearby residential population
- Federal Cell cover system
- Waste Form
- Limitation of depleted uranium waste under Federal Cell top slope
- Limitation of depleted uranium waste to below grade

While onsite residential occupation is extremely unlikely, the impact on Federal Cell performance by inadvertent intruders is modeled in the depleted uranium Performance Assessment via the possible formation of gullies that are caused by inadvertent human intervention (e.g., OHV activity, cattle trails, industrial well construction and use), which may result in direct human contact with the waste for future receptors. For those cases when gullies are formed as a result of hunting, ranching and OHV, comparison of doses is made to Inadvertent Intruder performance objectives.

Table 3-3 summarizes the doses to potential inadvertent intruders at the Federal Cell due to the disposal of depleted uranium. The reported 95% upper confidence interval of the mean peak doses is commonly used to represent reasonable maximum exposure in CERLCA risk assessments. As with exposure of the general public, the inadvertent rancher intruder is projected to receive the highest dose. However, conversely with the trend observed for protection of the general public, the evapotranspirative cover better protects the inadvertent intruder than does the rock armor cover. Even so, compliance with the performance objectives for the inadvertent intruder of 500 mrem/year is very clearly established.

3.3 Protection of Individuals During Operations

EnergySolutions' extensive operating record demonstrates compliance of their administrative controls, engineering controls, and operations designs to the protection of the General Public during operations (for exposures from normal operating conditions and accident scenarios). As such, construction of a Federal Cell does not create any further unanalyzed conditions for exposures from normal operation conditions and accident scenarios.

Table 3-3

**Peak Total Effective Dose Equivalents to the Inadvertent Intruder
(mrem/yr)**

<u>Receptor</u>	<u>Mean</u>	<u>Median</u>	<u>95% Percentile</u>
<u>Rock Armor Cover:</u>			
Acute Well Driller	1.6E-07	1.3E-09	9.4E-07
Chronic Well User	7.9E-06	6.1E-08	4.6E-05
Rancher	0.0059	0.0046	0.015
Hunter	0.00026	0.00020	0.00062
OHV enthusiast	0.00039	0.00031	0.00096
<u>Evapotranspirative Cover:</u>			
Acute Well Driller	8.6E-09	2.2E-10	5.2E-08
Chronic Well User	4.1E-07	1.1E-08	2.5E-06
Rancher	0.016	0.014	0.037
Hunter	0.0008	0.00071	0.0017
OHV enthusiast	0.0013	0.0011	0.0027

EnergySolutions' Division-approved Radiation Protection Program, required by UAC R313-15-101(1), outlines EnergySolutions' radiation protection program (Sections 7.0, 7.1, 7.3, and 7.4 of McCandless, 2012). Additionally, EnergySolutions' Safety and Health Manual describes site safety, incident reporting, emergency response, equipment operation, personal protective equipment, respiratory protection, medical surveillance, exposure monitoring, hazard communication, confined space entry, and other safety related programs (Sections 8.4, 8.6, 8.7 of McCandless, 2012). Included therein are descriptions of EnergySolutions' ALARA program, including dose goals that are significantly below the regulatory dose criteria for workers. Since its creation, EnergySolutions' radiological control program has successfully maintained worker exposures as a fraction of the regulatory limit, as demonstrated by worker dosimetry records and calculation of CEDEs (Sections 4.3, 4.4, 7.0, 7.1, 7.3, and 7.4 of McCandless, 2012). EnergySolutions actively reviews work practices, performs operational radiological surveys and has an active ALARA review committee. The data clearly demonstrates EnergySolutions' proactive approach has resulted in successfully maintaining worker doses ALARA. Given that the Federal Cell's design will mirror that of the Division-approved Class A West Embankment and not require operational or procedural revision, protection of individuals during Federal Cell operations is demonstrated.

3.3.1 Air Pathway

As in use for wastes managed at the Class A West Amendment Application, EnergySolutions' engineering and operational controls prevent the resuspension and dispersion of waste particulates during operations. DOE is required to ship their depleted uranium in containers. Depleted uranium will not be dumped in bulk, but rather disposed in its shipping container, in CLSM. Water spray is used in the cells as need to prevent resuspension of radioactivity. As such, depleted uranium management for the Federal Cell will also be compliant.

Haul roads are also wetted and maintained to prevent the resuspension and dispersion of particulate depleted uranium. Polymers are spread on inactive, open areas to bind the surface and prevent resuspension. EnergySolutions also performs routine air monitoring to identify if an airborne situation is developing that may require corrective actions. Similarly, radon releases during operations are projected to be negligible because of low Ra₂₂₆ parent waste concentrations.

For accident conditions, depleted uranium dust or particulate matter could be released to the atmosphere and inhaled by individuals. The Class A West Amendment Application and the Federal Cell analysis documented in Section 6.2 of Appendix A evaluate tornado and severe winds, train derailment, truck turnover or collision, and truck fire. All analyses show that the maximum dose to a member of the public are far less than 25 mrem/yr, even if the individual is continually present at the Federal Cell boundary.

3.3.2 Soil Pathway

As summarized in Section 6.2.1 of Appendix A, operation-related exposures from the soil pathway involve the exposure of the public to contaminated material from the Federal Cell. If an exposure occurs, doses for this pathway result from external radiation or ingestion of soil on dirty hands. The primary site characteristic that prevents the likelihood of such exposures during operations and institutional control is the site's remote location (the low population density in the site vicinity, and the lack of natural resources to provide for population expansion). During operation, the Federal Cell will be monitored in the same

manner as the Division-approved Class A West Embankment (as described in *EnergySolutions*' Environmental Monitoring Program), to ensure that no releases or doses have occurred via the soil pathway (Section 4.4 of McCandless, 2012). Because of these administrative controls, inclusion of additional volumes of depleted uranium does not compromise the Federal Cell's performance and protection of the general public from exposure via the soil pathway during operations. Additionally, the primary site characteristic that prevents the likelihood of such exposures during operations is the site's remote location (the low population density in the site vicinity, and the lack of natural resources to provide for population expansion).

EnergySolutions' engineering and operational controls also prevent the resuspension and dispersion of dust particulates during operations. Depleted uranium will be shipped and disposed in containers, then surrounded by CLSM. Water spray is used in the cells as needed to prevent resuspension of radioactivity. Haul roads are also wetted and maintained to prevent the resuspension and dispersion of particulate waste. Polymers are spread on inactive, open areas to bind the surface and prevent resuspension. In support of its Class A West Embankment operations, *EnergySolutions* also performs continuous air monitoring to identify excessive airborne releases that require corrective actions, suspending all waste handling operations when winds exceed 30 mpg (Section 4.4 of McCandless, 2012). Because of these administrative controls, inclusion of additional volumes of depleted uranium does not compromise the Federal Cell's performance and protection of the general public from atmospheric transport of dust or soil contaminants during operations.

3.3.3 Surface Water Pathway

The nearest stream channel is greater than five miles east of the Federal Cell. During operations, surface water from precipitation is directed away from the waste disposal embankment by drainage ditches and berms. All possibly contaminated contact storm-water is recovered and conveyed to evaporation ponds where it is monitored and controlled. No contact storm-water is released offsite, thereby maintaining releases from surface water ALARA (Section 3.1.5, 3.2.5, 3.4.4, and 4.0 of McCandless, 2012). During operation, the Federal Cell will be monitored as described in *EnergySolutions*' Environmental Monitoring Program, to ensure that no releases or doses have occurred via the surface water pathway (Section 4.4 of McCandless, 2012). Because of these administrative controls, inclusion of additional volumes of depleted uranium does not compromise the Federal Cell's performance and protection of the general public from the surface water pathway during operations. Additionally, the natural site characteristics limit operational radioactive releases through the surface water pathway. The annual precipitation is low and the evaporation is high. No permanent surface water bodies exist in the site vicinity. In addition, the site is far from populated areas.

3.3.4 Vegetation Pathway

During operation of the Federal Cell, releases and doses through the plant pathway are limited by the design, operation, and maintenance of the Federal Cell. Plants on the site are removed and prevented from contacting waste materials. Because of these administrative controls, inclusion of additional volumes of depleted uranium does not compromise the Federal Cell's performance and protection of the general public from plant or animal driven migration of contaminants during operations.

3.3.5 Burrowing Animals Pathway

Factors limiting the abundance and distribution of ant nests such as the abundance and distribution of plant species, and intra-species or inter-species competitors, also can affect excavated soil volumes. Since vegetation is regularly removed during operations, no burrowing animals are projected to enhance radioactivity release. Similarly, other burrowing animals are not considered a viable exposure pathway during operations, given the combination of administrative controls, site characteristics, and design features.

3.3.6 Ground Water Pathway

During operations, precipitation falling onto disposed but uncovered wastes may result in leaching of contaminants through the clay liner and into the groundwater beneath the Federal Cell. The Federal Cell's clay liner is designed to absorb many of the radionuclides and slows their potential release from the cell and subsequent transport to the water table aquifer. Analysis of this pathway in support of LARW and Class A West waste management operations has led to a Division-imposed open cell time limit of 25 years. Once placed, all waste must be below final cover within this time limit (Lundberg, 2014). Since the same clay liner modeled in support of the Class A West open cell time limit is proposed for the Federal Cell (and other applicably equivalent physical characteristics), the same Division-approved model projects that groundwater concentrations will not exceed the limitations promulgated in EnergySolutions' Ground Water Quality Discharge Permit so long as they are not left uncovered longer than 25 years.

3.4 **Post-Closure Stability of the Federal Cell**

Satisfaction of UAC R313-25-22 demonstrates that the performance standard for stability of the Federal Cell must be sited, designed, and closed to achieve long-term stability to eliminate to the extent practicable the need for ongoing active maintenance of the site following closure. The intent of this requirement is to provide reasonable assurance that long-term stability of the disposed waste and the disposal site will be achieved. As such, the Federal Cell (which closely mirrors the Division-approved Class A West Embankment design) also satisfies UAC R313-25-22.

To help achieve stability, NRC suggests that to the extent practicable, waste should maintain gross physical properties and identity over 300 years, under the original conditions of disposal. NRC believes that the use of design features to achieve stability is consistent with the concept of ALARA and the use of the best available technology. It is also NRC's view that, to the extent practicable, waste forms or containers should be designed to be stable (i.e., maintain gross physical properties and identity, over 300 years). NRC also suggests sites be evaluated for at least a 500-year time frame to address the potential impacts of natural events or phenomena.

About the same time as Part 61 was initially promulgated, NRC promulgated requirements for design of uranium mill tailings piles such as the Vitro site (adjacent to the Clive site). In addressing stability requirements for mill tailings, NRC recognizes the need to set practicable standards. In the case of uranium mill tailings piles, NRC specifies that the design provide reasonable assurance of control of radiological hazards to be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.

In both cases (low-level radioactive waste and mill tailings disposal), NRC recognizes the need to set practical standards that can be implemented. The design standards range from 200 up to 1,000 years. NRC further recognizes design limitations and notes that reasonably achievable designs should be employed to the extent practicable. As such, it is not practical to set design standards for stability beyond 1,000 years.

Post-closure stability was evaluated in licensing the Class A West Embankment. In its approval, the Division determined that the Class A West Embankment design meets the regulatory-required performance objective stability criteria,

“The licensee has evaluated the long-term stability of the proposed CAW embankment, including analyses of the effects of natural processes that include erosion, mass wasting, slope failure, foundation settlement and settlement of wastes and backfill, infiltration through the cover and adjacent soils, and surface drainage at the disposal site. The analyses were developed to provide reasonable assurance that there will not be a need for ongoing active maintenance of the CAW Embankment cell and associated drainage features following final closure of the CAW Embankment. Collectively, the analyses completed for the proposed CAW Embankment demonstrate, to the Divisions satisfaction . . . that long-term stability of the CAW Embankment will be achieved with reasonable assurance.” (pg 79 of URA, 2012).

Disposal of containers of depleted uranium in CLSM in the Federal Cell (mirroring the Division-approved Class A West Embankment design) is consistent with the waste disposal methods considered in that licensing action; i.e., a solid waste is disposed in a CLSM matrix that fills voids and prevents subsidence. Therefore, post-closure stability of the embankment is met.

3.5 Stability of the Federal Cell In Geologic Time

“The specific technical information shall also include the following analyses needed to demonstrate that the performance objectives of UAC R313-25 will be met: Analyses of the geologic-time stability of the disposal site shall be based upon qualitative analyses of active natural processes including submersion, erosion, mass wasting, infiltration through covers over disposal areas and adjacent soils, and surface drainage of the disposal site. The analyses shall provide reasonable assurance that there will not be a need for critical design features to address geologic-time depleted uranium waste dispersal.” [UAC R313-25- 9(4)(d) and UAC R313-25-9(5)]

While included in this depleted uranium Performance Assessment as part of improving qualitative understanding of Federal Cell performance (see Appendix 13 of Appendix A), EnergySolutions agrees with NRC cautions and recognizes that regulatory compliance should include limited,

“consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation”(NRC, 2000).

Furthermore,

“[t]hese events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose.” (NRC, 2000).

As such, geologic-time trends are examined in this Compliance Report, by exploring simulations until the time of peak radioactivity. For this Compliance Report, peak radioactivity associated with radon production from depleted uranium, occurs at about 2.1 million years (My). The time frame of this component requires consideration of climatic changes that have occurred historically on approximately 100 thousand years (ky) cycles for more than 1 My. These cycles include periods of extensive glaciation and inter-glacial periods.

The planet is currently in an inter-glacial period. In effect, the 10 ky model is projected under inter-glacial conditions, and the deep time model includes an evaluation of the effect on depleted uranium disposal of future 100-ky glacial cycles for the next 2.1 My. Analysis conducted in support of this Compliance Report qualitatively assesses the potential impact of glacial epoch pluvial lake events on the overall depleted uranium waste embankment from 10 ky through 2.1 My post-closure. A pluvial lake is a consequence of periods of extensive glaciation, and results from low evaporation, increased cloud cover, increased albedo, and increased precipitation in landlocked areas.

The Federal Cell’s principal design features have been developed to perform their required functions over the Compliance Period. Qualitative trends in depleted uranium transport away from the Federal Cell during geologic-time frames have also been evaluated (see Section 6.5 of Appendix A). In conjunction with this design feature, it is important to note that scenarios included in this Compliance Report demonstrate that waste placed below ground surface escape the effects of pluvial lake erosion. As such, it is concluded that the Federal Cell will not require further design changes or ongoing active maintenance following Federal Cell closure, in reaction to geologic events.

3.6 Post-Closure Protection of the Groundwater Resource

The groundwater protection criteria to which EnergySolutions is required to demonstrate compliance in its Ground Water Quality Discharge Permit are based on an annual dose of 4 mrem to an individual drinking groundwater. The projected dose from direct ingestion of the groundwater is zero, because of the poor groundwater quality. The high salinity of the groundwater, without rigorous treatment, prevents its use for drinking, livestock watering, or crop irrigation. Groundwater protection requirements place limits on the individual radionuclide concentrations in the groundwater at the compliance-monitoring well. The radionuclide concentration limits must not be exceeded for at least 500 years following closure of the Federal Cell.

The Class A West Embankment analysis (applicable to the Federal Cell) for the rock armored cover design projects that 0.09 cm/yr and 0.168 cm/yr of water will infiltrate through the traditional rock armored cover’s top and side slope, respectively (Whetstone, 2011), with the differences in infiltration

rates due to the top and side slope design differences. It further demonstrates that at these levels, the Federal Cell's use of the rock armored cover will satisfy all of the groundwater protection criteria for radionuclide concentrations limited by what is necessary for the waste to qualify as Class A (with the exceptions of Bk-247, Ca-41, Cl-36, I-129, Re-187, and Tc-99, as limited in condition 55.A of License UT2300249).

Conversely, the relatively lower infiltration rates associated with the evapotranspirative cover design, it is projected that no water-transported depleted uranium radionuclides will reach the point of compliance within 10,000 years (other than a less than 5% chance of an groundwater protection limit-exceedance in Tc-99). Therefore, no limitations beyond those associated with a Class A classification for depleted uranium radionuclide concentrations are necessary to protect members of the general public from exposure to the groundwater at the Point-of-Compliance well within the 10,000 year assessment period (other than that recommended for Tc-99).

Table 3-4 summarizes the distribution of the peak groundwater concentrations at the compliance point within the 500-year regulatory limit. As is illustrated, the mean (of the peak of the means) and the 95th percentile for Tc₉₉ and I₁₂₉ exceed the GWPL in the 10m Model beneath the Division-approved Class A West rock armor cover. In such a situation, compliance with GWPLs can be maintained by disposal concentration limitations similar to those applied to the Class A West Embankment disposal. Conversely, construction of the alternate evapotranspirative cover under review by the Division may require disposal concentration limits for Tc₉₉.

Table 3-4

**Peak Groundwater Concentrations
(pCi/L)**

Cover Model	GWPL	Mean	Median	95% Percentile
Rock Amor Cover (Division-Approved):				
Sr ₉₀	42	0	0	0
Tc ₉₉	3,790	14,000	110	81,000
I ₁₂₉	21	13	5.8E-07	81
Th ₂₃₀	83	1.5E-21	3.8E-37	1.2E-26
Th ₂₃₂	92	1.3E-27	0	9.3E-33
Np ₂₃₇	7	7.6E-18	0	4.7E-26
U ₂₃₃	26	2.9E-17	2.3E-32	4.7E-22
U ₂₃₄	26	1.6E-16	3.0E-32	2.1E-21
U ₂₃₅	27	1.6E-17	2.6E-33	1.8E-22
U ₂₃₆	27	2.4E-17	4.3E-33	3.2E-22
U ₂₃₈	26	1.4E-15	2.4E-31	1.7E-20
Evapotranspirative Cover (under review):²				
Sr ₉₀	42	0	0	0
Tc ₉₉	3,790	740	20	4,460
I ₁₂₉	21	0.48	6.8e-7	3.4
Th ₂₃₀	83	1.9e-26	0	3.4e-31
Th ₂₃₂	92	1.4e-32	0	2.1e-37
Np ₂₃₇	7	9.8e-18	0	1.3e-24
U ₂₃₃	26	3.9e-22	0	1.0e-25
U ₂₃₄	26	1.5e-21	0	8.1e-26
U ₂₃₅	27	1.1e-22	0	6.8e-27
U ₂₃₆	27	2.2e-22	0	1.1e-26
U ₂₃₈	26	1.1e-20	2.2e-36	6.4e-25

² As projected in McCandless, (2012).

4. CONCLUSIONS

As part of its approval of the Class A West Amendment Application, the Division acknowledged that EnergySolutions' overall cell design, operation, construction, and monitoring program is in compliance with all applicable regulatory requirements, noting

“On November 26, 2012, the Director of the Division of Radiation Control (DRC) approved the proposed amendments to the EnergySolutions (Licensee and Permittee) Low-Level Radioactive Waste Disposal License (RML UT 2300249) and Ground Water Quality Discharge Permit (No. UGW450005). The license amendments and permit modifications were part of a request submitted by EnergySolutions in May 2011 to combine the two existing low-level radioactive waste disposal embankments into a single disposal embankment.” (DRC, 2012).

As such, activities conducted at EnergySolutions' Class A West Embankment are designed to protect the health and safety of workers, the general public, and the environment. EnergySolutions' operations are conducted under the ongoing regulatory scrutiny of the Division, Utah Division of Solid and Hazardous Waste, Utah Division of Air Quality, and Utah Division of Water Quality. These inspectors provide continuing assurance that the interests of radiological and environmental safety are properly addressed.

For the majority of applicable regulatory requirements, disposal of depleted uranium in a Federal Cell mirroring the Division-approved Class A West Embankment does not impact the Division's prior certification of EnergySolutions' compliance. However, as a result of a desire to dispose of depleted uranium and in compliance with UAC Rule 313-25-9(5), EnergySolutions has conducted a detailed, probabilistic performance assessment to demonstrate to the Division that:

- 1) its proposed methods for disposal of depleted uranium in the Federal Cell will ensure that future operations, institutional control, and site closure will continue to be conducted safely,
- 2) the Federal Cell will continue to comply with its performance objectives, and
- 3) the Federal Cell will continue to be in compliance with applicable Division requirements.

This Performance Assessment further reveals that the groundwater resource is better protected by construction of an evapotranspirative cover, as opposed to a rock armor cover. Conversely, inadvertent intruders (e.g., rancher, hunter, OHV) are better protected by the rock armor cover than the evapotranspirative cover. However, the performance objectives requiring protection of the post-closure public and inadvertent intruder are well-satisfied by either cover design.

This depleted uranium Performance Assessment demonstrates EnergySolutions' continued regulatory compliance resulting from its proposed disposal of depleted uranium. As such, it is concluded that acceptance and disposal of depleted uranium produced at DOE's Savannah River Site can be completed compliant with regulatory requirements. Furthermore, this report also demonstrates that EnergySolutions



may accept and dispose of similar depleted uranium waste from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky, and depleted uranium waste from the National Enrichment Facility currently under construction in New Mexico (up to the limits and configurations modeled in the Performance Assessment).

EnergySolutions further supports its claims of compliance with Division Rules through the development and execution of a detailed, probabilistic performance assessment using the GoldSim model. This model and the resulting findings demonstrate to the Division that EnergySolutions' proposed methods for disposal of depleted uranium will ensure that future operations, institutional control, and site closure can be conducted safely, and that the site will comply with the Division's radiological criteria contained in the UAC.

While included in this Compliance Report as part of improving qualitative understanding of the Federal Cell's performance, EnergySolutions agrees with NRC cautions and recognizes that regulatory compliance should include limited,

“consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation”(NRC, 2000).

Furthermore,

“[t]hese events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose.” (NRC, 2000).

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APPENDIX A

Final Report for the Clive DU PA Model

(Clive DU PA Model v1.2)

APPENDIX B

Responses to October 25, 2013 Preliminary Completeness Review

Responses to the Division’s individual completeness findings (listed in italics) are provided herein. A full list of references cited below can be found in the Division’s Preliminary Completeness Review (October 25, 2013). It is recognized that the stated purpose of the Preliminary Completeness Review (PCR) of EnergySolutions’ depleted uranium Performance Assessment is to ascertain whether or not all necessary components have been included and addressed. It is not the stated purpose, however, to make judgment on the technical and regulatory adequacy of the submittal components, “*It should be emphasized that this [PCR] does not address the technical merits of the EnergySolutions documents, but only whether the submission is complete when tested against the cited Utah regulations and guidance documents. . . [However,] in some instances, the distinction between completeness and technical comments is not distinct. [As such,] it is possible that some of the comments included here may be judged to be technical comments . . .*” (PCR, pg. 2).

The Division has indicated that technical Interrogatories are being prepared that will likely lead to a revision of the depleted uranium Performance Assessment GoldSim model. In order to more efficiently target subsequent revisions to the depleted uranium Performance Assessment GoldSim model, EnergySolutions is deferring response to those findings of the Preliminary Completeness Review that focus on the regulatory adequacy, technical accuracy, and content justification instead of incompleteness (as summarized in Table A-1). It is hoped by doing so that the review process is expedited; as a revised model at this stage might require re-starting some aspects of the review. Therefore, this response does not include re-submittal of Appendix A to the Compliance Report nor any of its attachments; since those have not been revised at this time.

NUREG-1573 defines a Performance Assessment as “*a quantitative analysis used in connection with demonstrating compliance with the . . . post-closure performance objective(s) governing radiological protection of the general public.*” EnergySolutions submitted its depleted uranium Performance Assessment in compliance with Utah Administrative Code (UAC) R313-25-9(5)(a), in demonstration that it will be able to maintain radiological protection of the general public, as a result of the disposal of depleted uranium. However, the Preliminary Completeness Review cites the absence of regulatory components in the depleted uranium Performance Assessment that have already demonstrated to the Division’s satisfaction as part of the Class A West Embankment design (McCandless, 2012).

Table B-1

Summary of Preliminary Completeness Review Findings of Technical Merit

<u>PCR Section</u>	<u>Comment Identifier</u>
2.1	<p>Comment 1, Inadequate References</p> <p>Comment 5. Assumption that CAS Cell Design was Acceptable</p>
2.2	<p>Section 1.4, Basis for Performance Assessment.</p> <p>Sections 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, and 2.11.</p> <p>R313-25-2 defines “inadvertent intruder” with regard to activities that might occur after site closure.</p> <p>Section 2.18, R313-25-19, Protection of the General Population from Releases of Radioactivity (starting on p. 2-27) – Concerns 3, 4, 5, and 6.</p>
3.1	<p>Comment 1</p> <p>Comment 4. Deep Time – Time:</p> <p>Comment 5. Deep Time – Sediment Concentration</p> <p>Comment 8. PA Intent:</p> <p>Comment 11. Inconsistent Definitions:</p> <p>Comment 12. Incomplete Figures:</p> <p>Comment 13. Incomplete Discussion of Sensitivity Plots:</p> <p>Comment 15. Federal vs. Agreement-State Regulations:</p>
3.2	<p>ES, page 2.</p> <p>ES, page 6.</p> <p>Section 1.3, page 16, paragraph 1; Section 4.1.2.11, page 39; Section 6.4, page 77, paragraph 1.</p> <p>Section 1.3, page 16.</p> <p>Section 4.1.2.7, page 32.</p> <p>Section 4.1.2.8, page 32.</p> <p>Section 4.1.2.8.2, page 34.</p> <p>Section 4.1.2.10.1, page 37.</p> <p>Section 4.1.2.10.1, page 27</p> <p>Section 4.1.2.12, page 39.</p> <p>Section 4.1.2.12, page 40.</p> <p>Section 5.1.7, page 45.</p> <p>Section 5.2, page 45.</p> <p>Section 6.1.1, page 55.</p> <p>Section 6.1.1, page 57.</p> <p>Section 6.1.2, page 58.</p> <p>Section 6.2.2, page 63.</p> <p>Section 6.2.2, page 64.</p> <p>Section 6.2.2, page 65.</p> <p>Section 6.2.2, page 67.</p> <p>Section 6.3.1, page 68.</p> <p>Section 6.3.1, page 68-69.</p>

**Table B-1
(continued)**

<u>PCR Section</u>	<u>Comment Identifier</u>
	Section 6.3.2, page 70.
	Section 6.3.2, page 71.
	Section 6.3.2, page 72.
	Section 6.4, Table 11, page 76.
	Section 6.5, page 78.
	Section 6.5, page 78.
	Section 6.5.1, page 79.
	Section 6.5.1, page 80.
	Section 7.1, page 83.
	Section 7.2, page 85.
4.1	Comment 1.
4.2	Section 4.1.1, page 5. Section 6.0, page 9.
5.2	Pages vi and vii. Section 1, page 1. Section 1, page 1. Section 3, page 5. Section 3.4.2.2, page 11. Section 4.2.2, page 18. Section 5, page 20, first paragraph. Section 5, page 20, last paragraph. Section 5, page 21, Containerization. Section 6, page 22. Section 6, page 22. Section 7.1.1.1, page 27. Figure 7.2.1.5, page 40. Section 7.2.2, page 42. Section 8.3, page 45. Section 8.2, page 45. Section 9.1.1, page 47. Section 9.2, page 51. Section 10.3.1, page 57.
6.1	Comment 1. Comment 2.
6.2	Section 2.2.2, page 6. Section 2.3.2, page 7. Section 3.1.2, page 10. Section 3.2.1, page 12. Section 3.2.2, page 14.

**Table B-1
(continued)**

<u>PCR Section</u>	<u>Comment Identifier</u>
	Section 3.2.3, page 16. Section 3.3, page 17. Section 3.3, page 18. Section 3.3, page 19. Section 3.3, page 20. Section 3.5.2.3, page 23.
7.2	Section 2, page 7. Section 3.1, page 11. Section 3.2, page 15. Section 5.1.5 and 5.1.6, page 27. Section 8.0, page 30. Section 8.3, page 37. Section 9.2.1, page 49.
8.1	Comment 1.
8.2	Section 1.0, Table 3, page 2. Section 5.0, page 17. Section 5.0, page 18. Section 5.0, page 18.
9.2	Section 3.3, page 4. Section 4.2, page 11.
10.1	Comment 1. Comment 2.
10.2	Section 4, page 5.
11.2	Section 3.1, page 11. Section 3.3.1, page 16; Section 3.3.3, page 18. Section 3.4.3, page 22. Section 3.4.5, page 25. Section 3.4.5, page 25. Section 4.5, page 30.
12.2	Section 1, page 1. Section 1, page 1; Section 2, page 2. Section 2, page 3.
13.1	Comment 1.

**Table B-1
(continued)**

<u>PCR Section</u>	<u>Comment Identifier</u>
15.1	Comment 1. Missing Approvals Comment 2. Lack of Page Numbers: Comment 3. GoldSim Model Calibration:
15.2	Section 5.0, Table 2. Appendix B. Section 2.6.

2.0 REVIEW OF ENERGYSOLUTIONS “UTAH LOW-LEVEL RADIOACTIVE WASTE DISPOSAL LICENSE – CONDITION 35 (RML UT2300249) COMPLIANCE REPORT,” JUNE 1, 2011

2.1 GENERAL COMMENTS

Comment 1. Inadequate References: In general, the Compliance Report³ refers to the 2008 EnergySolutions license renewal application as justification for limiting further consideration of numerous issues addressed in the plans and manuals provided as part of the license renewal application. When addressing a specific issue, without review of the relevant plan or manual in the Compliance Report, sufficient reasons have not been provided by EnergySolutions to conclude that revisions are not necessary. Individual review of each technical issue should be documented and provided as necessary. At a minimum, specific citations (chapter, section, page, etc) to past license renewal applications with descriptions and justification need to be added. Examples of this problem include, but are not limited to: Section 2-2, page 2-4, refers “Occupation Dose Limits for Adults,” where the licensee states there is a plan or manual that addresses exposures but does not provide a name, chapter or page number or Section 2-7, page 2-6, “Posting Requirements” where the licensee refers to the Radiation Safety Manual but does not provide chapter or page number.

EnergySolutions’ Response: Since its initial submittal, the Division has approved the design associated with EnergySolutions’ Class A West Amendment Application to Radioactive Material License UT2300249. More specific references to and added justification from the approved Class A West Amendment Application have been provided in response to the Comment 1 Interrogatory.

Comment 2. Over-reliance on Past Licensing Activities: In addition to the primary function as the site-specific PA, the Compliance Report and its Appendix A also serve as a license amendment application request. As such, the Compliance Report is expected to have sufficient detail to provide a complete picture of the large-quantity DU disposal proposal. However, sufficient detail is lacking. Too much reliance is placed on past licensing activities without showing how past work embraces DU disposal. See comment for Paragraph 4 of page 4 for examples of the deficiencies.

EnergySolutions’ Response: The revised Compliance Report includes additional detail supporting statements that rely on prior licensing actions.

Comment 3. Erroneous Rule References: Multiple errors have been made in citations to the Utah Radiation Control Regulations. Please re-examine all references and correct them as needed.

EnergySolutions’ Response: Citations to the Utah Radiation Control Regulations have been reviewed for accuracy in the main report.

³ EnergySolutions, “Utah Low-Level Radioactive Waste Disposal License – Condition 35 (RML UT2300249) Compliance Report,” June 1, 2011

Comment 4. Failure to Consider Multiple Rules in R313-15 and R313-25: On multiple locations in the Compliance Report, EnergySolutions fails to identify key rule requirements applicable to a major license amendment such as the DU waste proposal. In other locations, key phrases from existing rules have been omitted without explanation or justification. These are identified in the discussion below, and must be corrected.

EnergySolutions' Response: Since the depleted uranium Performance Assessment has been submitted in compliance with UAC R313-25-8(5)(a) and not in and of itself as an actual application for License issuance or renewal, the request to address the rules cited in the Division's Interrogatory are inapplicable. This is particularly the case since the Division is actively reviewing the 2012 License Renewal Application. The report has been re-written to focus only on R313-25-8(5)(a).

Comment 5. Assumption that CAS Cell Design was Acceptable: At multiple locations in the June 1, 2011 DU submittal, the licensee assumes that the CAS Cell design was acceptable to DEQ. This assumption is unwarranted because DRC review of this proposal was never completed. The DEQ acknowledges two EnergySolutions submittals that included engineering design information, dated January 4, 2008 and June 9, 2009. Between these submissions, DRC provided EnergySolutions a November 26, 2008, Completeness Review. Based on our records, no other interrogatory was prepared by DRC or delivered to EnergySolutions. In fact, on May 2, 2011, EnergySolutions submitted a request to retract its January 4, 2008, CAS Cell license amendment request. As a result, after the EnergySolutions response to this Completeness Review, DEQ will re-open the project and begin a detailed review of both the January 4, 2008, and June 9, 2009, EnergySolutions submittals. In the event that EnergySolutions decides to alter or modify these design submittals, and to expedite review of the DU proposal, any design changes made by EnergySolutions will need to be provided upon submittal of your response to this DEQ Completeness Review.

EnergySolutions' Response: Since its initial submittal, the Division has approved the design associated with EnergySolutions' Class A West Amendment Application to Radioactive Material License UT2300249. More specific references to and added justification from the approved design and analysis of Class A West Amendment Application (as applicable to the Federal Cell) have been provided.

Comment 6. Clive Facility Definition: The PA uses the term "Clive facility" or sometimes just the term "the facility" throughout. Please define the term "Clive Facility" and describe what that entails, in particular, distinguishing it from its component parts.

EnergySolutions' Response: The term has been removed from the main report.

2.2 SPECIFIC COMMENTS

Section 1.3. This section lists the expected mass of DU waste, in the form of U₃O₈, from the DOE de-conversion facilities at Paducah, Kentucky, and Portsmouth, Ohio (projected for a 20–25-year operating period). Please provide an estimate of the total mass of DU waste that has been and will be received from the Savannah River Site (SRS), and identify its chemical and physical form. If any other source or generator of DU waste is considered for Clive disposal, please indicate its specific source (by generator), chemical/physical form(s), estimates of total mass, and volume.

EnergySolutions’ Response: Sections 1, 1.4, and 2.3 of the report identifies the mass of depleted uranium received from SRS as “3,577 metric tons.” Furthermore, Section 1.4 notes, “DOE estimates the inventory of U₃O₈ that will eventually require disposal to be approximately 700,000 metric tons over a 20 to 25 year period.” Other radiological characteristics are summarized in Report section 2.3. A more detailed description has already been provided in Appendix 4 of Appendix A.

Section 1.4, Basis for Performance Assessment. This section makes reference to parts of R313-25-8(5). On page 1-8, the applicant proposes to use an intruder dose of 500 millirem per year (mrem/year). However, Utah Radiation Control Rule R313-15-401 states, in part, that the License Termination Rule applies only to ancillary surface facilities that support radioactive waste disposal activities. Therefore, it appears the 500 mrem/yr dose standard does not apply to the disposal embankment; and instead the 25/75/25 mrem/yr dose requirements of UAC R313-25-19 should apply instead. Additional detail on DEQ findings in this matter are found below. In addition, the NRC had not considered large quantities of DU as radioactive waste when it promulgated 10 CFR Part 61 in 1982.

DRC staff acknowledge that NRC staff have proposed to the Commission consideration of a 500 mrem/yr dose standard for the inadvertent intruder. However, this federal rulemaking effort will not be complete for a year or more. In the meantime, the DEQ licensing action is based on current DRC rule requirements. Therefore, if EnergySolutions is intent on using a 500 mrem/year for the intruder dose, please explain and justify why this would protect human health and the environment. Also, be advised that EnergySolutions will need to request a variance from the Utah Radiation Control Board.

EnergySolutions’ Response: Additional justification for the use of a 500 mrem/yr inadvertent intruder dose has been provided in Section 1.3 in response to the Division’s Interrogatory.

Table 2-1, Applicable Requirements Potentially Impacted by the Disposal of Depleted Uranium (pp. 2-2 and 3). Please make the following modifications to the table:

1. R313-15-402 – please delete this reference, it is not applicable to the CAS Cell. For more information, see discussion below.
2. R317-6 – description on how this rule applies has been omitted. Please revise the table.

EnergySolutions' Response: Since the Compliance Report has been re-written to focus on UAC R313-25-8(5)(a), this table has been deleted.

Sections 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, and 2.11. These sections each broadly mention various plans or manuals submitted to the Division of Radiation Control as part of previous licensing activities. However, they should make more specific reference to the relevant discussion in the appropriate plan or manual; e.g., by chapter and page. For example, Section 2.2 states that the 2008 license renewal application includes models demonstrating that atmospheric pathway doses to the general public during operations will remain below required regulatory levels. The text should cite the specific place(s) in the documents that discusses the models to confirm that they included the handling of large quantities of DU.

EnergySolutions' Response: Since its initial submittal, the Division has approved the design of EnergySolutions' Class A West Amendment Application to Radioactive Material License UT2300249. More specific references to and added justification from the approved design of Class A West Amendment Application have been provided in support of the Federal Cell in the main report.

Section 2.8, R313-15-906; Procedures for Receiving and Opening Packages. This section discusses receipt and opening of waste packages at Clive. In Section 1.3, EnergySolutions also describes how DOE has identified corroded 55-gallon drums of DU waste at the SRS that have been overpacked (p. 1-6); and discovery of corroded DUF6 Storage Cylinders (DUF6 Cylinders) at their Paducah, Kentucky, and Portsmouth, Ohio, facilities (p. 1-6). Please disclose: (1) the range of weight (tare, net, and gross) expected for each type of DU waste package, for each physical/ chemical form of DU waste, be it UO₃ or U₃O₈; and (2) if the Paducah and Portsmouth DU waste will be shipped to Clive in existing DUF6 Cylinders. Please explain how currently approved EnergySolutions waste handling procedures (in various plans), designed for management of solid LLRW materials, will apply to DUF6 Cylinders, designed by DOE for storage of gaseous DUF6.

EnergySolutions' Response: Sections 1, 1.4, and 2.3 of the report identifies the mass of depleted uranium received from SRS as "3,577 metric tons." Furthermore, Section 1.4 notes, "DOE estimates the inventory of U₃O₈ that will eventually require disposal to be approximately 700,000 metric tons over a 20 to 25 year period." Other radiological characteristics are summarized in Report section 2.3. Additionally, a more detailed description has already been provided in Appendix 4 of Appendix A. EnergySolutions does not proposed to make changes to the current waste handling and disposal procedures already approved by the Division as part of the Class A West Amendment Application. Specifically, depleted uranium will be disposed in the Federal Cell in CLSM in accordance with existing CQA/QC Manual requirements for CLSM mix design, placement controls, and void filling.

Section 2.9, R313-15-1002; Method for Obtaining Approval of Proposed Disposal Procedures (p. 2-7). Regarding the 55-gallon (~7.35 ft³) drums from SRS (in UO₃ form) and DUF6 Cylinders mentioned in Section 1.3, it appears the latter will be significantly larger (~151 ft³). Please verify whether or not the same DUF6 cylinders will be re-used for DU waste transport to Clive,

and if they will be directly disposed in the embankment. If any other types of DU waste containers are to be used for transport and disposal, please indicate their size, volume, type, and weight, etc. Please justify how existing waste disposal procedures at Clive, designed for disposal of containers of LLRW solid materials, will apply to disposal of the recycled DUF₆ Cylinders filled with DU oxides.

EnergySolutions' Response: The size and type of container used for depleted uranium disposal is irrelevant based on the way the conceptual model is constructed. No credit is taken for the container or placement methodology beyond the assumption of a stable embankment at closure. This means that current broad controls over waste placement apply without revision – if disposed in containers, voids within and surrounding the container must be filled with CLSM (a low-strength flowable concrete grout). In other words, physical behavior of the recycled DUF₆ cylinders filled with depleted uranium oxides will be consistent with that of other LLRW solid materials. Figure 2-1 of the Compliance Report demonstrates that the Federal Cell's disposal capacity is sufficient for the targeted depleted uranium disposal.

Section 2.10, R313-15-1009; Waste Classification (p. 2-7). Table 2-2 provides concentrations of radioactive elements, including U-235, found in some of the DU waste streams. However, the Compliance Report has not addressed the applicability of License Condition 13 to the disposal of large quantities of DU containing U-235. Further review of License Condition 13 should be documented and submitted.

Additionally, Utah Radiation Control Rule R313-15-1009 provides a concentration limit for Ra-226 as a Class A waste. Because of the very long half-life of DU (principally U-238), the concentration of Ra-226 in the waste will continue to increase for thousands of years beyond the 10,000-year period assessed in the PA and will eventually exceed the Class A concentration limit. A discussion of the matter should be provided.

EnergySolutions' Response: License Condition 13 applies to Special Nuclear Material (SNM). The Nuclear Regulatory Commission defines SNM as:

“Special nuclear material’ (SNM) is defined by Title I of the Atomic Energy Act of 1954 as plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235. The definition includes any other material that the Commission determines to be special nuclear material, but does not include source material. The NRC has not declared any other material as SNM.”

There is no data to indicate that there is anything more than trace amounts of U-235 that would not exceed that allowed by the SNM exemption.

The concentration limits in R313-15-1009 apply to classification at the time of disposal. The stated purpose of the depleted uranium Performance Assessment is to evaluate the long-term implications of increasing concentration of U-238 daughter products. Therefore, the method for determining classification is not applicable at some arbitrary future time.

R313-25-6; General Information Omitted. Review of the CR shows this section of the rule has been omitted. Please modify it to ensure, at a minimum, the requirements of R313-25-6(3) and (4) are included and adequately addressed.

EnergySolutions' Response: Since the Compliance Report has been re-written to focus on UAC R313-25-8(5)(a), this table has been deleted.

R313-25-2 defines "inadvertent intruder" with regard to activities that might occur after site closure. However, the first paragraph on page 2-15 refers to the "protection of inadvertent intruders from radiation exposures during facility operations," which is inconsistent with this definition. The paragraph should be revised to address this apparent inconsistency.

EnergySolutions' Response: The inadvertent intruder discussion in Section 1.3 has been clarified.

R313-25-9(1) and (2), Institutional Information - Omission. No discussion is provided in the EnergySolutions CR about how and when EnergySolutions will comply with the requirements of this rule. In that the Clive facility is not located "... on land not owned by the federal or state government ...", please demonstrate that binding legal provisions are in place "... for assumption of ownership in fee by the federal or a state agency." Alternatively, explain how EnergySolutions will provide other institutional controls to enable long-term site control and maintenance for a minimum period of 10,000 years or more after site closure.

EnergySolutions' Response: In accordance with License Condition 12, the Clive facility was granted an exemption to the land ownership requirements.

In accordance with R313-25-28(2), "The period of institutional controls will be determined by the Director, but institutional controls may not be relied upon for more than 100 years". Therefore, EnergySolutions is prohibited from providing "...other institutional controls to enable long-term site control and maintenance for a minimum period of 10,000 years or more after site closure." Accordingly, the Performance Assessment evaluates environmental fate and transport of contaminants of concern correctly assuming no active maintenance or control measures.

It is noted that Utah Code Annotated 19-3-106.2 provides for a perpetual care fund to address the care and maintenance of a commercial radioactive waste disposal facility beginning 100 years after the date of final closure of the facility. This fund has a minimum target initial balance of \$100 million, met through a combination of annual cash payments, earnings on the fund balance, and surety funding. Furthermore, EnergySolutions recognizes that agreement to secure stewardship over the Federal Cell must be obtained from DOE prior to DU disposal (as is outlined in Section 1 of the Compliance Report).

Section 2.15, R313-25-10; Financial Qualifications to Carry Out Activities (p. 2-23). It appears this section addresses the requirements of R313-25-10. In light of the fact that 2.5 of the 3 different DU waste depths considered in the CR are above native ground elevation, please

explain and justify why the Director should not revise the surety to address the need for long-term disposal site maintenance should future pluvial lakes cause wave-cut erosion.

EnergySolutions' Response: In accordance with R313-25-28(2), “*The period of institutional controls will be determined by the Director, but institutional controls may not be relied upon for more than 100 years*”. Therefore, EnergySolutions is prohibited from providing “...*other institutional controls to enable long-term site control and maintenance for a minimum period of 10,000 years or more after site closure.*” Accordingly, the Performance Assessment evaluates environmental fate and transport of contaminants of concern correctly assuming no active maintenance or control measures. Furthermore, EnergySolutions recognizes that agreement to secure stewardship over the Federal Cell must be obtained from DOE prior to depleted uranium disposal (as is outlined in Section 1 of the Compliance Report). Finally, although the Performance Assessment evaluates disposal both above- and below-grade, depleted uranium will be disposed below grade to enhance assurance of continued isolation under geologic-time events such as the return of a large lake inundating Clive. Figure 1-2 of the Compliance Report demonstrates that the entire depleted uranium inventory evaluated can be disposed in such a manner.

R313-25-16; Transfer of License – Omission. No description is found in the CR to explain and justify how the DU waste proposal will comply with this requirement. Specific attention must be given to R313-25-16(5).

EnergySolutions' Response: In accordance with License Condition 12, the Clive facility was granted an exemption to the land ownership requirements. Under the land ownership exemption, EnergySolutions is not required to transfer the license as contemplated in R313-25-16. “*Following closure and the period of post-closure observation and maintenance, the licensee may apply for an amendment to transfer the license to the disposal site owner [emphasis added].*” Accordingly, evaluation of compliance with R313-25-16 is not needed until such time as an application to transfer is proposed. Furthermore, EnergySolutions recognizes that agreement to secure stewardship over the Federal Cell must be obtained from DOE prior to DU disposal (as is outlined in Section 1 of the Compliance Report).

Section 2.17; R313-25-18, Individual Exposure Assurance (p. 2-27) – In the last paragraph of this section, please disclose where the Requirements 2508-1 through 4 can be found, or alternatively, provide those references as an attachment to the revised CR. Also, because the DU waste and progeny in-growth will pose higher risks to human health and the environment with time, please describe and justify how future adverse exposures to individuals can be controlled and prevented in light of the fact that there are no provisions currently in place for the Clive disposal site “... for assumption of ownership in fee by the federal or state agency” [see R313-25-9(2)]. Please describe in detail how the DU waste proposal will allow EnergySolutions to comply with the requirements of R313-25-19 (protection of general public) and R313-25-22 (inadvertent intruder protection). Alternatively, EnergySolutions may cross-reference those sections of the CR that resolve these requirements.

EnergySolutions' Response: Protection of the general public and the inadvertent intruder are discussed in sections 3.1 and 3.2, respectively, of the Compliance Report.

Section 2.18, R313-25-19, Protection of the General Population from Releases of Radioactivity (starting on p. 2-27) – Several concerns were found in this section during our review, as follows:

1. *EnergySolutions Requirements Section (pp. 2-27 and 28) – This section omits the 4 mrem/yr dose limit for the groundwater pathway mandated by R313-25-19. Please correct this omission and revise the section accordingly. In order to comply with the provisions of R313-25-8(5)(a), please demonstrate how dose to an individual via the groundwater pathway will remain below this limit for 10,000 years or more after site closure.*

EnergySolutions' Response: Demonstration of compliance with a 4 mrem/yr groundwater standard has been added in Section 3.1.

2. *Basis for Dose Conversion – We appreciate the argument that dose limits in R313-25-19 are based on whole body dose, and that more modern means are available to determine dose to an individual, namely a total effective dose equivalent (TEDE) methodology. Please disclose what internationally recognized publication (and dose conversion factors) was used by Neptune to calculate the TEDE doses quoted in Table 2-3 and the Ground Water Protection Levels found in Table 2-4. We recognize that this information is in the DU PA but should be included here as well or appropriately cross-referenced.*

EnergySolutions' Response: As noted in the Division's Interrogatory, the information requested has been included in Appendices 4, 11, and 12 of Appendix A. EnergySolutions finds no performance objective in R313-25-8(5)(a) requiring an additional summary of this information in the main report.

3. *Unidentified Exposure Scenarios – Neither the EnergySolutions CR text nor the tables themselves identify the exposure scenario(s) represented by the predictions listed in Tables 2-3 and Table 2-4. Please identify all exposure scenarios used in these tables. Please confirm how much of the DU waste was exposed at the surface for each of the waste depths listed in these tables. Please identify the percentage of the embankment area where DU waste was exposed by erosion in each exposure scenario.*

EnergySolutions' Response: While already included in Appendix 11 of Appendix A, a summary of the exposure scenarios has been added in report Section 2.4 and 2.5.

4. *Peak Doses in Table 2-3 – Please identify the DU waste isotopes and exposure pathways behind each receptor scenario listed in this table. Please also explain how the doses may vary, should certain fundamental assumptions change in the Neptune predictions, including, but not limited to, DU waste nuclides, source term activity, cover system erosion rates, relative area of cover system eroded (or area of DU waste exposed) in the model, etc.*

EnergySolutions’ Response: While already included in Appendices 11 and 15 of Appendix A (thereby signifying a complete component), a summary of the exposure scenarios and associated sensitivity analysis have been added in report Section 2.4 and 2.5.

5. *Groundwater Pathway, 500-Year Groundwater Prediction Timeframe, Table 2-4 – Please explain and justify how a 500-year simulation of concentrations in the groundwater pathway can demonstrate EnergySolutions compliance with the minimum 10,000 year quantitative predictions required by R313-25-8(5)(a) for each exposure pathway. Alternatively, provide results of groundwater fate and transport modeling for a minimum 10,000-year period after site closure.*

EnergySolutions’ Response: The stated purpose of the table (now labeled as Table 3-4) is to demonstrate the Federal Cell’s ability to comply with requirements of EnergySolutions’ Ground Water Quality Discharge Permit (as per UAC R317-6). Refer to the discussion in Section 3.1 and Table 3-2 for the depleted uranium Performance Assessment’s demonstration of compliance with the 10,000 year groundwater standard.

6. *Groundwater Protection Levels, Table 2-4 – Please disclose if any differences exist in the dosimetry and/or dose conversion methods used to derive the Ground Water Protection Levels listed, versus those doses methods used for Table 2-3. If there are differences, please explain and justify why they should be acceptable, i.e., why they represent the most modern dosimetry methodology.*

EnergySolutions’ Response: The groundwater transport methodology employed in the depleted uranium Performance Assessment is described in Appendices 5, 6, 7, and 11 of Appendix A (thereby being a complete component of the required submittal). Ground Water Protection Levels were taken from the Ground Water Quality Discharge Permit, Table 1A; Table 1A includes notes as to the derivation of each standard listed.

7. *Groundwater Point of Compliance, Table 2-4 – Please identify the relative horizontal location and distance of the compliance monitoring well from the CAS Cell, as used in the groundwater transport model.*

EnergySolutions’ Response: Since its initial submittal, the Division has approved the design associated with EnergySolutions’ Class A West Amendment Application to Radioactive Material License UT2300249. The same methodology of Sections 4.4, 5.4, 6.1, and Attachment 3 of that Amendment Application that detail the location and distances also applies to the Federal Cell and the Point of Compliance well.

R313-25-23; Disposal Site Suitability Requirements for Land Disposal – Near-Surface Disposal - Omission. *No text is provided in the EnergySolutions CR to address how the DU proposal will meet the requirements of this section of state rule. Please amend the CR to address and resolve each of the 11 requirements found in this rule. In all cases, site suitability must be considered in light of the “deep time” aspects for DU disposal and progeny in-growth. Where engineered features are not sufficient to control and contain the proposed DU waste, please explain and*

justify how site characteristics will come to bear to sequester and control DU contaminants, and protect public health and the environment.

One key omission that must be carefully addressed is driven by the above-grade disposal planned for the DU waste. Any demonstration of compliance with R313-25-23 must include pluvial lake formation and wave-cut erosion. In your resolution of this requirement, EnergySolutions may be able to draw on discussions submitted to demonstrate compliance with R313-25-7 (see Division comments above).

EnergySolutions' Response: Suitability of the Class A West Embankment design was approved by the Division in their acceptance of the Class A West Amendment Application. Suitability of this same design also applies to the Federal Cell. See also sections 2.4 and 2.5 of the Compliance Report. Although the Performance Assessment evaluates disposal both above- and below-grade, depleted uranium will be disposed below grade to enhance assurance of continued isolation under geologic-time events such as the return of a large lake inundating Clive. Figure 1-2 of the Compliance Report demonstrates that the entire depleted uranium inventory evaluated can be disposed in such a manner.

Section 2.22, R313-25-24: Disposal Site Design for Near-Surface Land Disposal (p. 2-38). The state rule lists 6 requirements that must be met. Unfortunately, EnergySolutions has only addressed the first one (site design features). Please revise the CR to address facility compliance with the missing five requirements; i.e., R313-25-24(2) thru (6). In this process, please ensure that both the engineered disposal embankment and site characteristics together can provide protection of public health and the environment, pursuant to R313-25, for at least 10,000 years post-closure.

EnergySolutions' Response: Suitability of the Class A West Embankment was approved by the Division in their acceptance of the design from the Class A West Amendment Application. See also sections 3.4 and 3.5 of the Compliance Report for its applicability to the Federal Cell.

R313-25-25 thru 30: Multiple Rule Omissions. These requirements in the DRC rule have been omitted from the CR, and must be included with justification for how the DU proposal will comply with the respective rules. In total, there are 20 regulatory items needing consideration and resolution, as follows:

<u>Rule</u>	<u>Title</u>
R313-25-25	Near Surface Land Disposal Facility Operation and Disposal Site Closure
R313-25-26	Environmental Monitoring
R313-25-27	Alternative Requirements for Design and Operations
R313-25-28	Institutional Requirements
R313-25-30	Applicant Qualifications and Assurances

Please revise the CR to resolve this omission, so that the DEQ review can move forward.

EnergySolutions' Response: Demonstration of the Class A West Embankment's compliance with these requirements has already been approved by the Division in their acceptance of the Class A West Amendment Application. This demonstration is therefore directly applicable to the proposed Federal Cell.

Section 2.25, R313-25-32; Financial Assurance for Institutional Control (pp. 2-38 and 2-39). The requirements text in the first two paragraphs of this section is from R313-25-31(1)(a) and (b), and not from R313-25-32. Please remove. Because significant quantities of DU disposal were not considered by the NRC in its original 10 CFR 61 rulemaking (circa early 1980s), please explain and justify why a 100-year Institutional Control period, as required by R313-25-28(2), is adequate for shallow land disposal of DU waste where progeny in-growth creates a greater future risk to human health and the environment.

EnergySolutions' Response: In accordance with R313-25-28(2), "The period of institutional controls will be determined by the Director, but institutional controls may not be relied upon for more than 100 years". Therefore, EnergySolutions is prohibited from relying upon institutional controls beyond 100 years after closure. Accordingly, the Performance Assessment evaluates environmental fate and transport of contaminants of concern correctly assuming no active maintenance or control measures.

3.0 REVIEW OF NEPTUNE AND COMPANY, INC., APPENDIX A, "FINAL REPORT FOR THE CLIVE DU PA MODEL VERSION 1.0," JUNE 1, 2011

3.1 GENERAL COMMENTS

Comment 1. Intergenerational Consequences: The ALARA analysis presented in Section 6.4 of the Final Report⁴ implies that either an undiscounted value of \$1,000 per person-rem or a discounted value of \$2,000 per person-rem may be used, and it includes discount factors of 3% and 7%. Two issues with these values needs to be considered.

First, as stated in NUREG-1530 and included in revisions of NUREG/BR-0058, it is the policy of the NRC to use a value of \$2,000 per person-rem for ALARA determinations.

Second, as stated in NUREG/BR-0058, Revision 4, when intergenerational consequences are involved, lower discount rates (including potentially no present worth, or 0%) should be used:

For certain regulatory actions, such as those involving decommissioning and waste disposal issues, the regulatory analysis may have to consider consequences that can occur over hundreds, or even thousands, of years. The OMB recognizes that special considerations arise when comparing benefits and costs across generations. Under these circumstances, OMB continues to see value in applying discount rates of 3 and 7 percent. However, ethical and technical

⁴ Neptune and Company, Inc., "Final Report for the Clive DU PA Model version 1.0," June 1, 2011 (including Appendices 1 through 17) (hereafter Appendix A to the Compliance Report; also referred to as "Final Report")

arguments can also support the use of lower discount rates. Thus, if a rule will have important intergenerational consequences, one should consider supplementing the analysis with an explicit discussion of the intergenerational concerns such as how future generations will be affected by the regulatory decision. Additionally, supplemental information could include a presentation of the values and impacts at the time in which they are incurred with no present worth conversion. In this case, no calculation of the resulting net value or value-impact ratio should be made. Also, one should consider a sensitivity analysis using a lower, but positive discount rate.

EnergySolutions' Response: ALARA analysis is presented in Section 6.4 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 2. Inadvertent Intruder: *The definition of "inadvertent intruder" in 10 CFR 61.2 is:*

"...a person who might occupy the disposal site after closure and engage in normal activities, such as agriculture, dwelling construction, or other pursuits in which the person might be unknowingly exposed to radiation from the waste."

Utah Administrative Code (UAC) R313-25-2 defines "inadvertent intruder" as:

"...a person who may enter the disposal site after closure and engage in activities unrelated to post closure management, such as agriculture, dwelling construction, or other pursuits which could, by disturbing the site, expose individuals to radiation."

Both definitions are similar, in that they suggest agriculture and dwelling construction as activities that an inadvertent intruder might take. However, they differ in that the NRC's definition requires the inadvertent intruder to "occupy the disposal site," while the UAC's definition only requires the inadvertent intruder to "enter the disposal site." Synonyms for "occupy" include "live in," "dwell in," "reside in," and "inhabit;" thus, a hunter or off-highway vehicle enthusiast who occasionally "enters" the site would not meet the NRC's definition of inadvertent intruder but would meet the UAC's definition. On the one hand, the UAC's definition means that many more individuals can be classified as inadvertent intruders; on the other hand, it does not require that the inadvertent intruder be someone who inhabits the site and who would likely receive the largest exposure.

UAC R313-25-20 provides a different perspective on inadvertent intruders than does UAC R313-25-2:

"Design, operation, and closure of the land disposal facility shall ensure protection of any individuals inadvertently intruding into the disposal site and occupying the site or contacting the waste after active institutional controls over the disposal site are removed."

UAC R313-25-20 requires protection of individuals occupying the site (or contacting the waste) rather than those who are simply entering the site and, therefore, is more akin to the definition in 10 CFR 61.2.

As documented in NRC 2012, the NRC is proposing to amend 10 CFR 61.13 to specifically require licensees under 10 CFR Part 61 to conduct an inadvertent intruder analysis. The proposed language states, in part:

“An intruder assessment shall: (1) Assume that an inadvertent intruder occupies the disposal site at any time during the compliance period after the period of institutional controls ends, and engages in normal activities including agriculture, dwelling construction, resource exploration or exploitation (e.g., well drilling), or other reasonably foreseeable pursuits that unknowingly expose the intruder to radiation from the waste.”

Note that the proposed language specifies occupancy.

Given the apparently dissimilar definitions, the Final Report should explain why the selected approach, which does not consider site occupancy, was selected.

EnergySolutions’ Response: See responses provided in Preliminary Completeness Review Section 2.2, comments 1.4 and R313-25-2.

Comment 3. Compliance Period: UAC R313-25-8(5)(a) includes the statement:

“For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years.”

The Final Report performs all of its analyses (except the deep time) at 10,000 years, the minimum allowed under UAC R313-25-8(5)(a). Furthermore, the Final Report does not discuss the rationale behind the selection of 10,000 years as the period of performance.

The NRC (2011b) and the Utah Division of Radiation Control (UDRC 2012) have both expressed concerns regarding limiting the compliance period (or period of performance) to 10,000 years. The applicant should provide the basis for using the minimum compliance period and justify why a longer period of analysis should not be required in light of R313-25-8(1)(b).

EnergySolutions’ Response: See EnergySolutions’ responses provided in Section 2.2 to Section 2.18, point 5.

Comment 4. Deep Time – Time: In defining the length of the deep time assessment, the Executive Summary (ES) (page 5) states:

“Peak activity of the waste occurs when the principal parent 238U (with a half-life that is approximately the age of the earth—over 4 billion years), reaches secular equilibrium with its decay products. This occurs at roughly 2.1 My from the time of isotopic separation, ...”

In order to determine whether 2.1 million years (My) is the appropriate time for deep time assessment, the applicant should clarify the above statement. First, decay products usually reach secular equilibrium with their principal parent, rather than the other way around. Second, the

text should discuss how the value of 2.1 My was determined based on a half-life of 4.49×10^9 years for U-238 and the half-lives of its decay products (e.g., 244,500 years for U-234).

EnergySolutions' Response: Deep time is description in the Executive Summary of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 5. Deep Time – Sediment Concentration: Section 6.5.2 of the Final Report provides U-238 lake sediment concentrations derived from successive lake events. Section 7.2 (page 84) then states, “Despite these possible conservatisms in the deep-time model, the lake water and lake sediment concentrations are small.” The report should give the basis for presenting only the U-238 sediment concentrations (rather than the full U-238 decay series), as well as the basis for concluding that these concentrations are “small.”

For example, 40 CFR 192.12(a) states:

“The concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than—

- (1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and*
- (2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.”*

Although 40 CFR 192.12 was developed specifically for the cleanup of uranium mill tailings sites under Title 1 of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), the U.S. Environmental Protection Agency (EPA) has used the criteria in 40 CFR Part 192 when setting remediation goals at Comprehensive Environmental Response, Compensation, and Liability Act sites with radioactive contamination. The applicant should indicate why the 40 CFR Part 192 soil criteria should not apply to the deep time assessment.

EnergySolutions' Response: Sediment concentration methodology for the deep time is described in Section 6.5.2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 6. Ra-226 Class A Concentration Limit: Table 1 of UAC R313-15-1009 includes a 10 nanocuries per gram (nCi/g) limit on the concentration of Ra-226 that can be included as Class A waste. The specific activity of U-238 in DU308 is about 285 nCi/g. As the U-238 decays, the activities of its daughter products build towards the U-238 activity. After 10,000 years, the Ra-226 activity would be about 0.2 nCi/g, but after about 61,000 years, it would exceed the Class A limit in Table 1 of R313-15-1009. After about 266,000 years, it would exceed the Class C limit of 100 nCi/g. The applicant should provide justification for disposing of material that will exceed the regulatory limits. A qualitative analysis of estimated temporal changes in Ra-226 activity concentration should be provided as part of the associated deep-time analysis.

EnergySolutions' Response: The concentration limits in R313-15-1009 apply to classification at the time of disposal. The stated purpose of the depleted uranium performance assessment is to evaluate the long-term implications of increasing concentration of U-238 daughter products. Therefore, the method for determining classification is not applicable at some arbitrary future time. The effects of the deep-time temporal changes in Ra-226 activity have been evaluated in the depleted uranium Performance Assessment,

“Peak activity of the waste occurs when the principal parent ^{238}U (with a half-life that is approximately the age of the earth- over 4 billion years), reaches secular equilibrium with its decay products [, including Ra-226]. This occurs at roughly 2.1 My from the time of isotopic separation, and the model evaluates the potential future of the site in this context.” (page 5 of Appendix A).

Comment 7. Other Wastes: Section 2.2 (page 25) of the Final Report states:

“...this Clive DU PA Model considers only to the long-term performance of DU disposed in this waste cell [the Class A South].”

UAC R313-25-8(5)(a) requires:

“...a performance assessment...for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of....”

The applicant should indicate the basis for not including in the PA “other wastes” and waste already disposed of. This is of particular concern because the applicant has proposed that the 11e.(2) wastes share the same Federal Cell as the DU (Appendix 3, “Embankment Modeling for the Clive DU PA Model,” May 28, 2011, Figure 2). Additionally, during the October 10, 2011, meeting, Neptune (on behalf of EnergySolutions) indicated that low-level radioactive waste (LLW) would be disposed of in the CAS cell along with the DU.

The applicant should indicate the basis and justification for not including in the PA “other wastes”, including 11e.(2) waste disposed of in the Federal Cell, and LLW disposed of within the CAS. Alternatively, the applicant needs to modify the PA to account for all DU, LLW, and 11e.(2) wastes to be disposed of in the Federal Cell. Thirdly, the applicant needs to evaluate the impact of alternative disposal cell designs on the PA results, including 1) two separate disposal cells one for DU and LLW and the other for 11e.(2) waste and 2) three separate disposal cells one for DU, a second for LLW, and a third for 11e.(2) waste.

EnergySolutions' Response: Analysis of the design from the Class A West Embankment's ability to perform, as required, with disposal of Class A wastes has been assessed and approved as part of EnergySolutions' Class A West Amendment Application. “Other wastes” associated with the depleted uranium wastes (as noted in Section 2.3 of the Report) to be placed in the Federal Cell have been included in the depleted uranium Performance Assessment.

Comment 8. PA Intent: Section 2.1, page 21, states:

“...the intent of a PA is not necessarily to estimate actual long-term human health impacts or risks from a closed facility. Rather, the purpose of the Model is to provide a robust analysis that can examine and identify the key elements and components of the site, the engineered system, and the environmental setting that could contribute to potential long-term impacts.”

This statement should be revised to indicate that the intent of the PA is to demonstrate that disposal of DU at the Clive facility would meet the requirements of UAC R313-25-8 and the performance standards of 10 CFR Part 61, Subpart C.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 9. Critical Group: Section 4.1.2.10.1 describes the dose receptors and exposure pathways that are evaluated in the PA. The PA includes ranchers and recreationists (e.g., hunters, off-highway vehicle enthusiasts), but no residents. Resident receptors seem to have been excluded because there are currently no individuals living in close proximity to the site [i.e., the nearest resident is a caretaker at the eastbound Interstate 80 Grassy Mountain Rest Area at Aragonite, approximately 12 kilometers (km) (7.5 miles) northeast of the site]. In NUREG-1573, in response to public comments, the NRC’s Performance Assessment Working Group (PAWG) recommended an approach to defining a critical group when there are currently no residents living nearby the disposal facility. Because there are no justifiable methods or procedures for forecasting human habits or lifestyles in the future (i.e., the very long term), the PAWG recommends that an analogue site, of comparable geology and climate, be identified and that the critical group be defined in terms of the analogue site. For example, for the Clive facility, the caretaker at the Interstate 80 Aragonite rest area [approximately 12 km (7.5 miles) to the northeast] might be used as an analogue site. The Final Report should document why it did not use the approach established by the PAWG.

EnergySolutions’ Response: The discussion of Critical Group in Section 1.3 of the Compliance Report has been expanded.

Comment 10. Analysis of Routine Operations and Likely Accidents: Utah Radiation Control Rule R313-25-8(4)(c) states:

“Analysis of the protection of individuals during operations shall include assessments of expected exposures due to routine operations and likely accidents during handling, storage, and disposal of waste. The analysis shall provide reasonable assurance that exposures will be controlled to meet the requirements of R313-15.”

The Final Report should explain why these analyses were not included in the DU PA.

EnergySolutions’ Response: Since its initial submittal, the Division has approved the design from the EnergySolutions’ Class A West Amendment Application to Radioactive Material License UT2300249, demonstrating protection of individuals during operations. Management of depleted uranium and its disposal in the Federal Cell does not create any further “*unanalyzed conditions*” from those already approved.

Comment 11. Inconsistent Definitions: The Final Report frequently cites “peak mean” values. In some cases, identified in specific examples in Section 3.2, this terminology may not be correct. The document should be carefully reviewed to determine if the terms “peak,” “mean,” “peak of the mean,” and “mean peak” are correctly and consistently used.

EnergySolutions’ Response: Definitions cited are included in Section 3.2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 12. Incomplete Figures: Many of the graphs, including those identified in specific examples in Section 3.2, lack proper notation as to metrics for the x and y axes.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 13. Incomplete Discussion of Sensitivity Plots: As indicated in the specific examples in Section 3.2, the various sensitivity and partial dependence plots are complex and should be discussed in greater detail in the text to ensure that the information they contain is sufficiently transparent.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 14. Links to References: The file Report References AtoZ.zip (available from the Utah Division of Radiation Control’s website: <http://www.radiationcontrol.utah.gov/EnSolutions/performassess/duperfass.htm>) contains the references used in the Final Report. Many of the references are given as Internet shortcuts, especially those that are copyrighted and/or must be purchased. To check the availability of these references, SC&A tested each Internet shortcut. With six exceptions, we successfully accessed the websites from which each reference could be obtained, although we did not actually purchase the references. The six Internet shortcuts that did not function as expected are shown below.

Internet Shortcut

Burnham and Anderson 2002
Efron and Tibshirani 1994
Link et al. 1999
Linsalata and Cohen 1980
MSUE 2011
NCRP 1988

Additionally, website links are embedded within the Final Report document itself. SC&A checked each of those links and found them to be active, except for those on pages 883 and 887 that link to the Neptune, Inc., website (i.e., neptuneinc.org), most of which require a usercode and password.

EnergySolutions' Response: At the time of its initial submittal (1 June 2011), links included in the depleted uranium Performance Assessment report were complete. EnergySolutions recognizes that as time passes from its initial submittal, texts will continue go out of print, authors will age and die, and internet links will continue to be changed. However, at the time of its submittal, the report was complete. As such, EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing. However, the Division should note that the accessibility of any updated references provided will likewise be time sensitive.

Comment 15. Federal vs. Agreement-State Regulations: In various sections of the appendices, e.g., Appendix A, Section 1.3, reference is made to Federal rules as though they have primacy for the Clive Facility. However, Utah is an agreement state under the Atomic Energy Act of 1954, as amended. Section 274 of the Act provides a statutory basis under which NRC has relinquished to Utah portions of its regulatory authority to license and regulate byproduct materials (radioisotopes), source materials (uranium and thorium), and certain quantities of special nuclear materials.

As an agreement state, Utah has developed its own rules, and it has primacy for administering the NRC agreement state regulatory program. It is the Utah rules, not Federal rules, that specifically govern regulated activities related to radioactive materials at the Clive Facility. Accordingly, all relevant appendices in the PA should be revised to discuss regulation primarily relative to Utah rule, rather than primarily Federal rule. Where Federal rules are referred to, the corresponding Utah rule should also be cited, and any differences in wording between the two should be described.

EnergySolutions' Response: EnergySolutions has revised the references in the main report, with preference given to Utah requirement (where available).

3.2 SPECIFIC COMMENTS

ES, page 2. The third paragraph states, "The model does not consider the effects of enhanced infiltration or radon diffusion from a compromised radon barrier." The Final Report should explain why the effects of a compromised radon barrier are not considered, since the durability of the radon barrier over time is problematic and as described in the Final Report, plant roots and burrowing animals are active at the Clive site and could compromise the radon barrier by creating "short-circuit" pathways.

EnergySolutions' Response: Infiltration and radon diffusion are discussed in the Executive Summary of Appendix A. See also sections 3.4 and 3.5 of the Compliance Report for discussion

of stability in near time and geologic time. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

ES, page 2. The last paragraph states, “The potentially significant cover degradation process of gully formation is evaluated using a simple modeling construct, in order to determine whether it warrants more sophisticated modeling approaches.” The text should reference the section within the Final Report that contains the determination as to whether a more sophisticated modeling approach is warranted.

EnergySolutions’ Response: Appendices 10 of Appendix A discusses the selection of gully methodology. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

ES, page 3. The last two sentences of the first paragraph state:

“No associated effects, such as biotic processes, effects on radon dispersion, or local changes in infiltration are considered. When gullies encounter DU waste, doses and uranium hazards are increased, but when wastes are buried sufficiently deep the gullies have essentially no effect on human exposures.”

The Final Report should provide the justification for not assuming that gully erosion will lead to increased infiltration.

EnergySolutions’ Response: Appendices 10 of Appendix A discusses the selection of gully methodology. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

ES, page 3. The second paragraph states that typical NRC intrusion scenarios do not adequately describe likely human activities in the arid west and will usually underestimate the performance of the disposal system. The Final Report should explain why an underestimation is usual and under what unusual circumstances the performance will not be underestimated.

EnergySolutions’ Response: Section 1.3 of the Compliance Report and Appendices 11 of Appendix A discuss NRC’s intrusion scenarios. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

ES, page 4. The second-to-last paragraph states:

“In accordance with UAC Rule R313-25-8, doses are calculated within a 10,000 year compliance period and may be compared to a performance criterion of 25 mrem in a year for a MOP, and 500 mrem in a year for an inadvertent intruder.”

The Final Report should confirm that concentrations of radionuclides in the groundwater are only compared to the groundwater protection limits (GWPLs) and are not factored into the dose assessment. It should also provide the rationale for assuming that the groundwater will never

have beneficial uses and that potential exposure routes and receptors will not exist over the minimum 10,000-year compliance period.

EnergySolutions' Response: Sections 3.1 and 3.6 of the Compliance Report describe compliance with the Ground Water Quality Discharge Permit and the 4 mrem/yr drinking water standard for the protection of the general public.

ES, page 5. *The first sentence on the page states:*

“These doses and the supporting contaminant transport modeling that provides the dose model with radionuclide concentrations in exposure media, are evaluated for 10,000 yr, in accordance with UAC R313-25-8(2).”

This statement might at first appear to be inconsistent with the discussion in Section 6.1, where the groundwater concentrations are only evaluated for 500 years. Please discuss the basis for these apparently conflicting assumptions.

EnergySolutions' Response: Sections 3.1 and 3.6 of the Compliance Report describe compliance with the Ground Water Quality Discharge Permit and the 4 mrem/yr drinking water standard for the protection of the general public.

ES, page 6. *The first paragraph states, “Consequently, six different models are considered for the dose and groundwater concentration endpoints.” Since the erosion scenarios are claimed to not affect the groundwater modeling results, it seems that there would be only three groundwater concentration endpoints representing the three emplacement depths.*

EnergySolutions' Response: The classifications of different models for dose and groundwater concentration endpoints are discussed in the Executive Summary of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Table ES-7. *Footnotes 1, 2, and 3 are missing.*

EnergySolutions' Response: Table ES-7 is a reproduction of Table 18 (page 87 of Appendix A). The Division is pointed to the corresponding footnotes thereon.

Section 1.3, page 15. *The last paragraph states that 10 CFR 61.42 defines ALARA; rather, the definition is given in 10 CFR 61.41.*

EnergySolutions' Response: The definition of ALARA is provided in Section 1.3 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 1.3, page 16, paragraph 1; Section 4.1.2.11, page 39; Section 6.4, page 77, paragraph 1. *When discussing the NRC's “options for discounting costs of human exposures over time,” the Final Report should describe the NRC's position on intergenerational impacts, as defined in NUREG/BR-0058, Section 4.3.5.*

EnergySolutions' Response: Details from NUREG/BR-0058 are summarized in Section 1.3 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 1.3, page 16. *The text should include a reference (NUREG-1530) for the NRC cost of \$2,000 per person-rem.*

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 2.1, page 23. *The second sentence on the page states:*

“Note that there are 5,000 estimates of the peak of the mean for each receptor from the 5,000 simulations that are run. This is usually enough simulations to stabilize an estimate of the mean.”

The Final Report should reference the work that was performed to demonstrate that additional simulations will not significantly change the statistics.

EnergySolutions' Response: Appendices 15, 16, and 17 of Appendix A discuss the basis for the number of simulations chosen in the depleted uranium Performance Assessment.

Section 4.1.2.5, page 30. *This section provides a number of assumptions regarding total dissolved solids, pH, solubilities, and other parameters. These assumptions should be supported with appropriate references.*

EnergySolutions' Response: Detail and additional citations for geochemistry are provided in Appendix 6 of Appendix A.

Section 4.1.2.6, page 31. *The Final Report should provide the basis for establishing a point of compliance for groundwater at 27 meters (90 feet) from the edge of the embankment interior.*

EnergySolutions' Response: Since its initial submittal, the Division has approved design from the EnergySolutions' Class A West Amendment Application to Radioactive Material License UT2300249. Justification and methodology of Sections 4.4, 5.4, 6.1, and Attachment 3 of this Amendment Application also apply to the location and distance between the Federal Cell and the Point of Compliance well.

Section 4.1.2.7, page 32. *The Final Report should provide support for the statement in the third paragraph that “Accumulation on-site seems more likely.”*

EnergySolutions' Response: On-site accumulation is discussed in Section 4.1.2.7 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2.8, page 32. *The Final Report should provide support for the statement that the “...effect on radionuclide transport might be small”.*

EnergySolutions’ Response: Radionuclide transport is discussed in Section 4.1.2.8 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2.8.2, page 34. The specific literature meant in the statement “Correlations reported in the literature” should be referenced.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2.8.3, pages 34 and 35. This section discusses burrowing mammals and generally concludes that “...the burrows are sufficiently shallow that it is unlikely that they will have a significant impact on radionuclide transport.” The Final Report should provide literature- and/or field-based support or justification for this statement and clarify whether this conclusion includes the “short-circuiting” effect that burrows would have for radon transport.

EnergySolutions’ Response: The Division approved EnergySolutions’ Class A West Amendment Application to Radioactive Material License UT2300249, in which the Division accepted the analysis demonstrating that the approved cover design is capable of satisfying its performance objectives, including consideration of burrowing animals. The disposal of large volumes of depleted uranium in a Federal Cell with this same cover design (as contemplated in this depleted uranium Performance Assessment) has no impact on this Division-accepted cover design demonstration.

Section 4.1.2.10.1, page 37. In the first paragraph of the section, the text states “...the IHI [inadvertent human intruder] is someone who intrudes onto the facility and may directly contact the waste (e.g., by well drilling, or basement construction).” This statement requires revision or additional justification. Contrary to what is expressed here, UAC R313-25-20 does not restrict inadvertent intrusion scenarios to someone who directly contacts the waste. The rule speaks rather of “any individuals inadvertently intruding into the disposal site and occupying the site or contacting the waste after active institutional controls over the disposal site are removed”. It is noted that an inadvertent intruder (1) inadvertently intrudes into the site, and EITHER (2a) occupies the site, OR (2b) contacts the waste, or both, after active institutional controls over the disposal site are removed. The Final Report should clarify whether there is ever any exposure assumed for obtaining water from a well (e.g., for dust suppression, cleaning, etc.).

EnergySolutions’ Response: The inadvertent intruder is discussed in Section 1.3 of the main report has been clarified. Even so, EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2.10.1, page 27, addresses only a ranching scenario and a recreational scenario. While each of these scenarios is likely, neither one is a scenario in which the greatest radioactive doses would likely occur, should the scenario come to pass. The PA should consider other likely scenarios in which the doses would likely be far greater. This will be more protective of inadvertent intruders and members of the public. These scenarios include an industrial scenario,

in which industrial activities, such as industrial waste disposal, are conducted on site. This may involve construction and use of buildings with basements, as well as use of groundwater from onsite wells for dust suppression, etc. The scenario may also involve digging of materials for onsite cover use. Another scenario that should be considered is mining for sand and clay onsite, e.g., for road construction. Both types of activities have historically taken place on and/or near the site.

EnergySolutions' Response: The inadvertent intruder discussion in Section 1.3 of the main report has been clarified. Even so, EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2.12, page 39. *The correct, updated reference for the groundwater discharge permit is missing. It should be Ground Water Quality Discharge Permit No. UGW450005 (UWQB 2012), not (UWQB 2010) as given in the body of the text on page 39, and not UWQB (State of Utah, Division of Water Quality, Utah Water Quality Board), 2009. Ground Water Quality Discharge Permit No. 450005, 23 Dec 2009, as listed in the PA References, and found on page 90.*

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2.12, page 40. *The text says, "The main concern for the PA model is the potential for transport of ⁹⁹Tc, a contaminant in the DU waste, to the point of compliance." The text should provide a reference to a section in the PA that fully discusses transport of technetium in groundwater at the site and tells what steps will be taken to mitigate its presence in groundwater at concentrations in excess of Utah limits.*

EnergySolutions' Response: Appendices 4, 5, and 7 of Appendix A discuss technetium-99 transport in the groundwater. Additional analysis can also be found in Attachment 3 of the Class A West Amendment Application (McCandless, 2012) and is directly applicable to the Federal Cell.

Section 4.1.2.12, page 40. *The text says, "Note that according to the Permit, groundwater at Clive is classified as Class IV, saline ground water, according to UAC R317-6-3 Ground Water Classes, and is highly unlikely to serve as a future water source. The underlying groundwater in the vicinity of the Clive site is of naturally poor quality because of its high salinity and, as a consequence, is not suitable for most human uses, and is not potable for humans."*

The text claims that "groundwater in the vicinity of the Clive site is of naturally poor quality because of its high salinity and, as a consequence, is not suitable for most human uses, and is not potable for humans." This statement is missing important context relative to use of the groundwater following suitable treatment. That context should be provided in the text and accommodated in the model. A number of countries throughout the world regularly treat saline water of approximately the same or even greater average TDS content than at Clive (i.e., about 40,500 mg/L) to make the water potable for their citizens to drink or employ for other "human

uses.” Desalination of Mediterranean sea water (e.g., with TDS at about 37,000–39,000 mg/L) is currently expected to provide up to 80% of the needs of Israel as of next year (Sales 2013). Desalination along the Persian Gulf (with TDS content commonly ranging between 41,000 and 48,000 mg/L) provides potable water for citizens of a number of countries. Kennecott Utah currently desalinates saline groundwater in nearby Jordan Valley and provides the treated, potable water via a distributor to about 14,000 people each year. Regionally, Arizona and California either use or plan to use reverse osmosis to provide potable water from saline or brackish water sources. As population soars over hundreds, thousands, tens of thousands, hundreds of thousands, or millions of years, as the need for drinkable water rises, and as water treatment technology continues to advance, treatment of saline water via desalination is expected to increase over time. Groundwater at Clive is found at depth as well as in the shallow aquifer, and such groundwater can potentially be produced at rates sufficient to provide, after desalination, potable water for a small community. Whether that is done depends on whether there is sufficient economic incentive to do so. The water, from a technology standpoint, can be made potable. The PA should discuss the potential to treat uncontaminated groundwater and mention the logistical, economic and regulatory difficulties of attempting to treat groundwater contaminated by radionuclides.

EnergySolutions’ Response: The discussion of the groundwater beneath the Federal Cell in Sections 1.3, 3.1, and 3.6 of the Compliance Report has been expanded to address the Division’s Interrogatory.

A 4-inch diameter extraction well, completed in the shallow water-bearing unit at the Clive Facility, produces less than 40 gallons per hour, with the pump running less than half-time to prevent cavitation. By comparison:

- Israel Desalination Enterprises’ Sorek Desalination Plant will provide 7 million gallons of water per hour when completed. The source of water is the Mediterranean Sea.
- The Carlsbad Desalination Project in San Diego will produce 2.1 million gallons of water per hour. The source of water is the Pacific Ocean.

Kennecott Utah Copper Company (KUCC) is remediating contaminated groundwater in the Salt Lake Valley. The project is part of a Natural Resource Damage Claim filed by the State of Utah under CERCLA against KUCC for damages to deep groundwater in the Southwest Salt Lake Valley due to historic mining practices. There are concerns about the levels of selenium and mercury in the discharge from the treatment facility.

It is inappropriate to use city-scale desalination of ocean water and state-mandated remediation systems as practical examples of desalination of Clive facility groundwater. The shallow water-bearing zone is not capable of yielding sufficient quantities of water to a treatment system. Also, naturally occurring levels of radium, uranium, selenium, arsenic, and thallium in shallow groundwater at Clive can exceed UAC R317-6-2 Groundwater Quality Standards.

Perhaps most significantly, the postulated scenario is not reasonable when one considers that it attempts to “force” groundwater extraction and desalination onto a site with poorer background quality and considerably lower yield than the surface water of the Great Salt Lake, not far distant. Clearly, if desalination was desired to supplement water resources in Utah, this large surface water body would be the resource utilized first.

Section 4.1.2.13, page 40. The Final Report should provide a reference for the statement, “Given that long-term climatic cycles of 100 ky are considered very likely....”

EnergySolutions’ Response: Long-term climatic cycles are discussed in Section 4.1.2.13. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2.13, page 42. The text indicates that “...an assumption that the sediments completely mix is expedient, and probably leads to conservative results”. The Final Report should indicate under what conditions mixing of the sediments does not lead to conservative results.

EnergySolutions’ Response: The stochastic analysis includes simulations of a shallow lake reworking disposed depleted uranium material (thereby including a full range of mixing scenarios and distributions). Additional detail regarding sedimentation mixing is present in Appendix 13 of Appendix A. However, EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5.1.1, page 43. The text says, “For the deep-time model, there are no receptors that are considered, and doses are not calculated. Instead, concentrations of radionuclides are estimated in lake water and in lake sediment in the general vicinity of the CAS embankment.”

Please provide additional discussion of how the PA accounts for radionuclide concentrations in lake water and lake sediment as a function of time. Also please provide further explanation as to why the PA does not perform a quantitative analysis of doses to persons exposed to radioactivity from the wastes in the embankment as a function of time as the embankment erodes.

In addition, please provide the rationale for not performing a qualitative assessment of the time to peak dose, since this determination is required by UAC R313-25-8(5)(a).

EnergySolutions’ Response: Qualitative assessment detail of varied radionuclide concentrations within deep time is addressed in Appendix 13 of Appendix A. Additional detail regarding the qualitative assessment of deep time has been added to Sections 1.3 and 3.5 of the Compliance Report.

Section 5.1.1, page 43. This section identifies compliance points for the dose assessment and the GWPLs, but not for uranium chemical toxicity.

EnergySolutions’ Response: Uranium toxicity is available in Appendix 6 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5.1.3, page 44. This section describes three potential disposal configurations. In each configuration, there are 27 layers within the disposal cell. In the first configuration, DU waste is disposed of in 21 layers; in the second configuration, DU waste is disposed of in 17 layers; and in the third configuration, DU waste is disposed of in 7 layers. The Final Report should describe the type of material that will be used to fill the layers and spaces not filled with DU waste.

EnergySolutions’ Response: Waste other than depleted uranium to be placed in the Federal Cell is discussed in Section 2.4 of the main report and Appendix 3 of Appendix A. Furthermore, demonstration of the Federal Cell’s ability to satisfy the regulatory required performance objectives for this non-depleted uranium waste was previously submitted to and approved by the Division as part of the same design for the Class A West Amendment Application (Lundberg, 2012).

Section 5.1.7, page 45. The text provides well drilling and basement construction as examples of inadvertent intrusion, but then states that “such direct activities are unlikely at this site,” implying that there was no need to analyze them. Such activities would be unlikely at any well-sited disposal site; therefore, the fact that these activities are unlikely is not a reason to preclude their analysis, and an analysis of these activities thus should be included in the PA. Please provide additional rationale for excluding these activities since they would be unlikely at any well-sited disposal site but are typically included as part of the analysis.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5.2, page 45. In discussing distribution averaging, the Final Report states:

“In addition, these types of models are characterized by differential equations and multiplicative terms. Averaging is a linear construct that does not translate directly in non-linear systems. Again, care needs to be taken to capture the appropriate systems-level effect when dealing with differential equations and multiplicative terms.”

SC&A agrees with this statement. The Final Report should clarify what “cares” were taken in this PA “to capture the appropriate systems-level effect.”

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5.4.4, page 49. The text at the end of the first paragraph states:

“As the model progresses through time, these radionuclides migrate into other parts of the physical system, and eventually are found in environmental media (air, water, soils) that receptors will encounter.”

The Final Report should provide additional information on how the water pathway is considered in the dose assessment.

EnergySolutions' Response: The discussion of groundwater in Sections 1.3, 3.1, 3.5, and 3.6 of the Compliance Report have been expanded. Additionally, groundwater detail is already available in Appendices 5 and 7 of Appendix A.

Section 6.1.1, page 55. The caption in Figure 5 appears to be incorrect. These are plots of calculated Tc 99 concentrations as a function of time for each realization and are not "mean peak" values.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.1.1, page 57. Similarly, the caption for Figure 6 should be "Statistical Summary of Tc₉₉ Concentrations as a Function of Time."

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.1.2, page 58. The x and y axes on the right-hand graph in Figure 7 should be labeled. The corresponding text should explain the development and interpretation of partial dependence plots, an example of which for 99Tc is shown on the right-hand side of Figure 7.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.1.2, page 58. The Final Report should list which parameters were varied in the sensitivity analysis.

EnergySolutions' Response: Appendix 15 of Appendix A discusses the parameters involved in the sensitivity analysis.

Section 6.2.1, page 60. The document states that "other [waste configuration] options could also be considered." The Final Report should identify which waste configuration EnergySolutions intends to use.

EnergySolutions' Response: Depleted uranium waste disposal configurations under consideration by EnergySolutions are described in Section 2.4 of the main report.

Section 6.2.2, page 63. The x and y axes in Figure 8 should be labeled.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.2.2, page 64. The x and y axes in Figure 9 should be labeled. The text should provide more discussion on how to interpret Figures 7, 8, and 9.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.2.2, page 65. The term "sensitivity index (SI)" on line 8 should be defined.

EnergySolutions' Response: A definition for the term sensitivity index is already provided on page 3 of Appendix 15 of Appendix A.

Section 6.2.2, page 67. The relationship between burrowing animals and the radon escape/production ratio, if any, should be discussed.

EnergySolutions' Response: Burrowing animals is discussed in Section 6.2.2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.3, page 67. The term "hazard quotient" should be defined.

EnergySolutions' Response: EPA defines Hazard Quotient as, "The ratio of the potential exposure to the substance and the level at which no adverse effects are expected. If the HQ is calculated to be equal to or less than 1, then no adverse health effects are expected as a result of exposure. If the HQ is greater than 1, then adverse health effects are possible. The HQ cannot be translated to a probability that adverse health effects will occur and it is unlikely to be proportional to risk. It is especially important to note that an HQ exceeding 1 does not necessarily mean that adverse effects will occur."⁵

Section 6.3, page 67. The Final Report should identify which exposure pathways were evaluated when determining the uranium hazard quotients.

EnergySolutions' Response: Appendices 1, 2, 3, 5, 6, 7, and 11 of Appendix A discuss the exposure pathways incorporated for analysis of uranium hazard quotients.

Section 6.3.1, page 68. The text and Table 7 appear to be inconsistent. The text (line 1) refers to "mean...hazard quotient," while the title of Table 7 refers to "peak mean" and the body of Table 7 refers to "peak."

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.3.1, page 68-69. By definition, Hazard Quotient (HQ) is the ratio of exposure dose (mg/kg-day or mg/m³) divided by RfD mg/kg-day or RfC mg/m³ for the various exposure route. Since there are multiple exposure routes (ingestion, inhalation, dermal contact), their respective HQ must be summed to produce a Hazard Index (HI). It appears that Tables 7 and 8 present HIs rather than HQs, as they are labeled. Please clarify what the HQs (or HIs) in Tables 7 and 8

⁵ U.S. EPA, "National-Scale Air Toxics Assessments: Glossary of Terms." Air Toxics Web site (<http://www.epa.gov/ttn/atw/natamain/gloss1.html>) accessed 30 October 2013, U.S. Environmental Protection Agency.

signify, for each receptor indicated, which exposure pathways were included in the HI and which pathways were excluded, and why.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.3.2, page 70. *The x and y axes in Figure 10 should be labeled. The text should provide more discussion of how the partial dependence plots are interpreted and the type of information that can be abstracted from them.*

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.3.2, page 71. *The document should discuss the significance of the reference to "uranium parents" in the second paragraph. Does this refer to the parents of uranium or the uranium parents of the decay products?*

EnergySolutions' Response: Uranium parents are discussed in Section 6.3.2 of Appendix A . EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.3.2, page 72. *The x and y axes in Figure 11 should be labeled.*

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.4, Table 11, page 76. *Both the table title and the right-hand column title identify the dose as the "peak" population dose. Since population doses are summed over all years, the document should clarify what is meant by "peak."*

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing. Section 6.5, page 77. *The document indicates that 2.1 My was selected as the time for the deep time assessment based on the half-life of the U-238 decay products; however, the U-238 decay products are not included in the deep time assessment. The text should resolve this discrepancy by providing the rationale for the selected approach.*

EnergySolutions' Response: The source term incorporated into the deep-time assessment is described in Appendix 13 of Appendix A.

Section 6.5, page 78. *The second paragraph states that sediment accumulates at about 17 meters (m) per 100 thousand years (ky). According to the Deep Time Assessment (Appendix 13, Section 6.3, page 24), the sedimentation rate for large lakes has a log-normal distribution with a geometric mean of 120 millimeters (mm)/ky and a geometric standard deviation of 1.2. This geometric mean is equivalent to 12 m per 100 ky. The differing values cited in the Final Report and Appendix 13 should be reconciled.*

EnergySolutions’ Response: Geometric standard deviations are discussed in Appendix 13 and Section 6.5 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.5, page 78. The statement, “Sediment core records show significant mixing of sediments,” in the third paragraph should be referenced.

EnergySolutions’ Response: Sediment core references are provided in Section 6.5 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.5.1, page 79. The document should clarify the number meant by a “handful” in the statement in the first paragraph: “Intermediate lakes only occur a handful of times.”

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.5.1, page 80. It might provide a useful perspective to compare the concentrations in Table 13 with the current GWPL for uranium.

EnergySolutions’ Response: While EnergySolutions appreciates the Division’s suggestion as to what might be useful to the reader, EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 7.1, page 83. The beginning of the fourth paragraph in the section states, “Once gullies are involved, the doses increase (groundwater concentrations do not change noticeably).” If groundwater concentrations are not identical with and without the gullies, then the text should explain why not.

EnergySolutions’ Response: The relationship between gullies and groundwater is addressed in Section 7.1 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 7.2, page 85. The Final Report should provide justification for a 500-year compliance period for Tc-99. According to R313-25-8(5)(a), “for the purposes of this performance assessment,” which applies to “the total quantities of concentrated depleted uranium and other wastes,” “the compliance period shall be a minimum of 10,000 years,” and “additional simulations shall be performed for the period where the peak dose occurs and the results shall be analyzed qualitatively.” The first paragraph states that, “Because the groundwater concentration of 99Tc increases with time, the peak of the mean concentration occurs at 500 yrs.” However, Figures 5 and 6 show the concentration of Tc-99 as still increasing at 500 years. The paragraph further states that “The 5,000 simulations provide 5,000 estimates of the peak of the mean concentrations.” However, the 5,000 simulations provide 5,000 estimates of the Tc 99 concentration as a function of time from 0 to 500 years. From these 5,000 realizations, one can calculate the mean dose at any time. The highest mean dose will occur at 500 years, since the

analysis was truncated at that time. SC&A does not believe that this is the generally accepted understanding of the peak of the mean concentration.

EnergySolutions' Response: Sections 1.3, 3.1, and 3.6 of the main report reference groundwater protection limits associated with EnergySolutions' Ground Water Quality Discharge Permit (and UAC R317-6). Furthermore, these sections also discuss the implications associated with demonstration of compliance with the 4 mrem/year groundwater drinking standard of UAC R313-25-19.

Section 7.2, page 85. The second sentence in the second paragraph states, "Infiltration rates might be overestimated." The text should discuss why the estimates for infiltration may be too high.

EnergySolutions' Response: Infiltration rates are described in Section 7.2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 7.2, page 85. The last paragraph states that "the MOP performance objectives are not exceeded in all cases." However, Table 17 shows that the 95th percentile ranch worker dose is 72.3 mrem/yr, which is greater than the 25 mrem/yr performance objective. The text should address this discrepancy.

EnergySolutions' Response: Doses summarized in Table 3-3 of the Compliance Report (which include 95-percentile doses of 110 mrem/year for the Industrial Worker and 72 mrem/year for the Rancher) are specifically associated with inadvertent intrusion scenarios and as such as comparable to the 500 mrem/year dose limit standard. Doses summarized in Table 3-1 of the Compliance Report (which cite 95-percentile doses of 16 mrem/year for the Industrial Worker and 11 mrem/year for the Rancher) are those specifically associated with the Division's referenced 25 mrem/year protection of the general public performance objective. Therefore, the statement from Section 7.2, page 85 is correct, as originally drafted.

4.0 REVIEW OF APPENDIX 1 – "FEP ANALYSIS FOR DISPOSAL OF DEPLETED URANIUM AT THE CLIVE FACILITY," MAY 28, 2011

4.1 GENERAL COMMENTS

Comment 1. Definition of Features, Events, and Processes (FEPs)

For document clarity, the text should include some discussion as to how FEPs are defined.

EnergySolutions' Response: Determination and definition for FEPs is included in Appendix 1 of Appendix A.

4.2 SPECIFIC COMMENTS

Section 4.1.1, page 5. The discussion lists FEPs said to be mentioned in 10 CFR Part 61; however, it is not clear that the items listed are FEPs. Section 4.1.2 refers to similar items as “technical performance objectives.” A clear distinction should be made between FEPs and technical performance objectives.

EnergySolutions’ Response: FEPS are described in Section 4.1.1. of Appendix 1 of Appendix A EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.2, page 7. The discussion states that the PA reflects post-closure conditions, and FEPs related to operations are not considered relevant. It is not clear that this approach is consistent with UAC R315 25-8(4)(c), which states:

“Analysis of the protection of individuals during operations shall include assessments of expected exposures due to routine operations and likely accidents during handling, storage, and disposal of waste.”

In light of this requirement, the document needs to explain, in greater detail, why the protection of individuals during operations was not considered.

EnergySolutions’ Response: As is discussed in Section 3.3 of the main report, demonstration of protection of individuals during operations has been previously submitted and approved by the Division as part of design from EnergySolutions’ Class A West Amendment Application (McCandless, 2012). Disposal of depleted uranium in the Federal Cell requires no revision to existing and approved procedures currently protecting the general public.

Section 6.0, page 9. The text should provide a specific cross-reference to the evaluation of canister degradation and corrosion in the conceptual site model.

EnergySolutions’ Response: Canister degradation and corrosion are discussed in Section 6.0 of Appendix 1 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

5.0 REVIEW OF APPENDIX 2 – “CONCEPTUAL SITE MODEL FOR DISPOSAL OF DEPLETED URANIUM AT THE CLIVE FACILITY,” MAY 28, 2011

5.2 SPECIFIC COMMENTS

Pages vi and vii. Some of the page references for the figures and the table in the table of contents are incorrectly stated.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 1, page 1. The second paragraph mentions a Federal rule (10 CFR 61) relative to radiological performance assessment, but it does not mention the controlling Utah rule(s), created and administered by Utah as an NRC agreement state. The text should frame the discussion within the context of governing Utah rule.

EnergySolutions' Response: Citation to Utah rules has been given preference in the Compliance Report. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 1, page 1. The third paragraph states that the "PA model is intended to...support environmental decision making in light of inherent uncertainties." The text should clarify whether the PA is a National Environmental Policy Act (i.e., NEPA) document or a nuclear licensing document.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 1, page 2. The third paragraph states that the quantitative probabilistic PA model is based on projecting current societal conditions "up to 10,000 years." Utah rule UAC R313-25-8(5)(a) requires quantitative modeling for a minimum of 10,000 years, not a maximum of 10,000 years. Please provide text and modeling, as needed, to address this discrepancy.

EnergySolutions' Response: Regulatory context for a quantitative assessment up to 10,000 years has been added to Section 1.3 of the Compliance Report.

Section 2, page 3. The third paragraph states that the "...focus of the uncertainty analysis in the PA model will be parameter uncertainty." The paragraph should also state how parameter variability was addressed.

EnergySolutions' Response: The method of parameter uncertainty analysis is presented in Appendices 11, 13, and 16 of Appendix A.

Section 2, page 5. The first paragraph on the page says, "However, it is very important to capture correlations between variables in a multiplicative model. Otherwise, system uncertainty is not adequately constrained. GoldSim provides some limited capability to introduce correlation into a PA model, but steps will be taken to evaluate the correlation effects of some variables." The text should provide a reference to the section in the PA where these steps are discussed.

EnergySolutions' Response: Parameter correlation is described in Appendices 3 through 11 and 14 of Appendix A.

Section 3, page 5. The second paragraph states that, "Pending the findings of the PA, DU waste will be stored in a permanent above-ground engineered disposal embankment that is clay-lined with a composite clay and rock cap." The term "pending," as a preposition, means "while awaiting," or "during." The quoted statement is not correct, since DU waste will not be stored as described while awaiting or during "findings of the PA." Assuming that the PA is approved,

DU waste may then potentially be disposed, perhaps as described above. However, before DU is disposed of at the Clive facility, a license amendment (of which the PA is a part) must be approved by the Utah Division of Radiation Control.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing. Although the Performance Assessment evaluates disposal both above- and below-grade, depleted uranium will be disposed below grade to enhance assurance of continued isolation under geologic-time events such as the return of a large lake inundating Clive. Figure 1-2 of the Compliance Report demonstrates that the entire depleted uranium inventory evaluated can be disposed in such a manner.

Section 3.4.2.2, page 11. The last paragraph of this section states that the groundwater "is not potable for humans." The text should clarify whether there are any non-humans for which the groundwater may be potable.

EnergySolutions' Response: Potability is discussed in Section 1.3 of the Compliance Report. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1.2, page 15. Discussions between the DRC and EnergySolutions have resulted in verbal agreements to limit doses to the general public to 25 mrem/yr TEDE. A discussion of these TEDE limits should be added to the information contained in this section.

EnergySolutions' Response: Discussion of the application of a 25 mrem/year TEDE for the general public has been added to Section 1.3 of the Compliance Report.

Section 4.1.4, page 16, of the PA says, "In addition to protecting any member of the public, 10 CFR 61 requires additional assurance of protecting individuals from the consequences of inadvertent intrusion. An inadvertent intruder is someone who is exposed to waste without meaning to, and without realizing it is there (after loss of institutional control). This is distinct from the intentional intruder, who might be interested in deliberately disturbing the site, or extracting materials from it, or who might be driven by curiosity or scientific interest."

This discussion should be framed in the context of applicable Utah rule, not 10 CFR 61. Utah rule UAC R313-25-20, entitled "Protection of Individuals from Inadvertent Intrusion" says, "Design, operation, and closure of the land disposal facility shall ensure protection of any individuals inadvertently intruding into the disposal site and occupying the site or contacting the waste after active institutional controls over the disposal site are removed." While not directly applicable, 10 CFR 61 says essentially the same thing. Therefore, it is not correct to define an inadvertent intruder as someone who is exposed to waste, per se. An inadvertent intruder may "inadvertently" intrude "into the disposal site and" occupy "the site" and be exposed to radiation without direct contact with the waste. In addition to inadvertently intruding into the disposal site, an inadvertent intruder, under Utah rule, is one who is "occupying the site" OR "contacting the waste."

While the intentional intruder, relative to the site, may be interested in “extracting materials from it, or who might be driven by curiosity or scientific interest,” so might an inadvertent intruder. In fact, resource exploitation is one of the common classes of actions considered by the federal government in developing inadvertent intruder scenarios. The discussion in the PA should account for the possibility of inadvertent intruders engaging in resource exploitation (e.g., mining of clay, sand or aragonite materials).

EnergySolutions’ Response: Justification and discussion of protection of the Inadvertent Intruder has been added to Section 1.3 of the Compliance Report.

Section 4.1.4, page 16. *The last paragraph of this section asserts that, “because the definition of inadvertent intruders encompasses exposure of individuals who engage in normal activities without knowing that they are receiving radiation exposure, there is no practical distinction made here between a member of the public (MOP) and inadvertent intruders with regard to exposure/dose assessment.”*

A review of UAC R313-25-19 and UAC R313-25-20 enables making such a practical distinction. Under UAC R313-25-19, entitled “Protection of the General Population from Releases of Radioactivity,” reference is made to releases of “radioactive material” “to the general environment in ground water, surface water, air, soil, plants or animals.” And under UAC R313-25-20, protection is extended to “any individuals inadvertently intruding into the disposal site and occupying the site or contacting the waste.” In the former, radioactive materials or radioactivity is released to the general environment, which in many cases could be offsite, whereas in the latter, individuals must come into the disposal site itself and either occupy it or contact the waste, and it would be there that they could receive a dose of radioactivity. MOPs, unlike inadvertent intruders, do not need to enter the site. MOPs, unlike inadvertent intruders, may be aware of the potential for radioactive exposure, but still receive it. Inadvertent intruders do not have to be exposed to releases of radioactive materials to the environment, but, unlike members of the public, they may expose themselves directly to unreleased sources or shine from unreleased sources as well as releases of radioactive materials to the environment. The text should clarify these significant differences.

EnergySolutions’ Response: Justification and discussion of protection of the Inadvertent Intruder has been added to Section 1.3 of the Compliance Report.

Section 4.2.1, page 17. *The last paragraph claims to reproduce the new section for R313-25-8 as follows:*

“(2)(a) Any facility that proposes to land dispose of significant quantities of depleted uranium, more than one metric ton in total accumulation, after June 1, 2010, shall submit for the Executive Secretary’s review and approval a performance assessment that demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose. Any such

performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period will be a minimum of 10,000 years. Additional simulations will be performed for an analysis for the period where peak dose occurs and the results shall be analyzed qualitatively.”

This is not correct. The correct new section in R313-25-8 is designated as R313-25-8(5)(a), not as R313-25-8(2)(a). The correct new section is also reproduced properly as follows:

“(5)(a) Notwithstanding R313-25-8(1), any facility that proposes to land dispose of significant quantities of concentrated depleted uranium (more than one metric ton in total accumulation) after June 1, 2010, shall submit for the Director's review and approval a performance assessment that demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose. Any such performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years. Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.”

The main difference between the two versions, other than the numbering, is that the correct, up-to-date version refers to “significant quantities of concentrated depleted uranium” (adding the word concentrated). Note that this rule applies to the facility as a whole, not simply to a particular embankment. The text should include the correct reproduction of the rule as well as the correct numbering.

EnergySolutions’ Response: There corresponding references in Section 1.3 of the Compliance Report have been updated to current UAC citations. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.2.2, page 18. This section refers to Utah rule R313-15-1008 as being “Classification and Characteristics of Low-Level Radioactive Waste.” Figure 5 refers also to R313-15-1008. The rule numbers are not correct. The correct rule that should be referenced is UAC R313-15-1009.

The PA says that “Ra-226, a decay product of uranium-238, the principal component of DU, is of direct interest to the disposal of DU waste.” However, Ra-226 is also one of the many “other wastes” mentioned in UAC R313-25-8(5)(a) for which modeling must be performed during not only the compliance period of a minimum of 10,000 years, but also during an extended period of time beyond that, i.e., for a time sufficient for the peak dose to be evaluated through the model, with the results then being analyzed and discussed qualitatively. The text should discuss

ramifications for modeling associated with the Utah rule that includes in-growth of Ra-226 in determining LLW classification and characteristics.

Classification for most radioactive substances involves those whose activity concentrations are maximums at the time of initial classification, and decline via radioactive decay thereafter. However, activity concentrations for Ra-226 are not maximum at the time of LLW classification, but they continue to grow through time until secular equilibrium is attained with the uranium parent(s). This is a situation not analyzed for in the original development of the classification tables. This is a point of importance in considering whether the Director of the DRC should allow for DU disposal at Clive in Utah, where radioactive materials having a classification above Class A are not permitted to be disposed of by law. This factor needs to be discussed in depth. The text should accordingly reference the section of the PA that provides modeling results for Ra-226 and that indicates the point at which the activity concentrations of Ra-226, through radioactive in-growth associated with depleted DU, exceed Class A concentrations, and also the point, if any, at which activity concentrations of Ra-226 exceed Class C concentrations. The text should also provide justification as to why Utah should permit disposal of materials producing substances that, even though initially passing Class A limits, will ultimately lead to the anomalous condition of Ra-226 activity concentrations exceeding Class A limits, and possibly even Class C limits, over time.

EnergySolutions' Response: The corresponding references in Section 1.3 of the Compliance Report have been updated to current UAC citations. The concentration limits in R313-15-1009 apply to classification at the time of disposal. The radiological characteristics (i.e., in-growth) of Ra-226 were well-established at the time its classification limit was set; and once disposed, waste is commingled with other wastes and fill materials, reducing initial concentration. Therefore, hypothetical classification exercises add no value to an assessment of the safety implications of depleted uranium disposal.

Section 4.2.2, page 18. The second paragraph states, "...some radionuclides listed in the tables shown in Figure 7 in addition to the Ra-226 added by Utah (Figure 5)." However, there are no tables in Figure 7; Figure 5 includes a single table. The text should be revised to clarify.

EnergySolutions' Response EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.2.3, page 19, says, "Note that according to the Permit, groundwater at Clive is classified as Class IV, saline ground water, according to UAC R317-6-3 Ground Water Classes, and is highly unlikely to serve as a future water source. As noted in Section 3.4.2.2, the underlying groundwater in the vicinity of the Clive site is of naturally poor quality because of its high salinity and, as a consequence, is not suitable for most human uses, and is not potable for humans."

It is true that the Permit states that groundwater at Clive is classified as Class IV groundwater, which is saline. However, it is not true that "according to the Permit, groundwater at Clive . . . is highly unlikely to serve as a future water source." The permit does not appear to speak to that

speculation. The Licensee should provide appropriate justification for this claim, or make modifications as needed.

The claims that groundwater at Clive, because of its natural high salinity, “...is not suitable for most human uses, and is not potable for humans” are simply not correct. Water of comparable salinity is currently being used, after appropriate treatment, in many Middle Eastern countries as potable water, and it is employed there for many human uses. Saline water is also currently used to provide potable water for people in other parts of the world, including the local region. Saline water is currently being used, for example, here in Utah by Kennecott and a local water distributor to provide potable water for people in the Jordan Valley. Regionally, it is being used in Arizona and California. The text should provide more appropriate, extended discussion of this issue, or it should justify the original statements.

EnergySolutions’ Response: The discussion of groundwater classifications have been added to Section 1.3 of the Compliance Report.

Section 5, page 20, first paragraph. Information in the meteorology section appears to be incomplete and in error. Numerous tornados have been reported in Utah; one web site lists 120 tornados between 1953 and 2012 (<http://www.tornadohistoryproject.com/tornado/Utah/table>). Please provide complete and accurate information.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5, page 20, last paragraph. Information about seismic activity section appears to be incomplete and in error. (See also Section 4.2.) Please provide complete and accurate information.

EnergySolutions’ Response: Seismicity has been included in Section 5 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5, page 21, Containerization. The text states that canister degradation and corrosion are evaluated in the conceptual model. The document should provide a specific cross-reference to this discussion.

EnergySolutions’ Response: Canister degradation and corrosion is discussed in Section 5 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5, page 22, Human Processes. The text states that anthropogenic climate change is among the human process FEPs identified for assessment. The text should provide a specific cross-reference to this assessment.

EnergySolutions’ Response: Section 6.0 of Appendix 1 of Appendix A provides detail as to the manner in which the anthropogenic climate change FEP was assessed.

Section 6, page 22. The text states that the “scope of this CSM is limited to the disposal of DU wastes....” This statement appears to conflict with UAC R313-25-8(5)(a), which requires the PA to demonstrate that performance standards will be met for “depleted uranium and other wastes, including wastes already disposed of....” Please reconcile this apparent inconsistency.

EnergySolutions’ Response: As is described in Section 1.2 of the Compliance Report, a Performance Assessment modeling waste already disposed of in the Class A West Embankment has been submitted and approved by the Division as part of EnergySolutions’ Class A West Amendment Application (McCandless, 2012). Because it employs the same Division-approved cover design, McCandless (2012) also demonstrates compliance with Class A Waste placed above any depleted uranium in the Federal Cell. Additionally, “other wastes” within the depleted uranium canisters (as discussed in Section 2.3 of the Compliance Report and Appendix 4 of Appendix A) is included in the depleted uranium Performance Assessment.

Section 6, page 22. The first paragraph describes DU oxides to be produced from GDPs, but the information is not complete on this matter. Please provide it.

EnergySolutions’ Response: Depleted uranium oxides are discussed in Section 6 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6, page 22. The text should provide a reference for the statement in the third paragraph, “If uranium hexafluoride derived from irradiated reactor returns is introduced to the cascade, the associated fission products and actinides migrate to the depleted end of the cascade, with the U 238.”

EnergySolutions’ Response: Uranium hexafluoride is discussed in Section 6 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.3, page 24. This section refers to depleted uranium oxide from gaseous diffusion plants. The section, however, does not describe the types and quantities of uranium oxide(s) produced or expected to be produced from de-conversion of DUF6 at these plants. This section needs to reference one or more other section(s) in the PA where detailed information about these oxides are presented in the PA, since chemical properties and environmental behavior differ depending on the type of oxide and its relative fractional contribution to the DU waste.

EnergySolutions’ Response: Detailed descriptions of the depleted uranium waste projected to be disposed of (and included in the depleted uranium Performance Assessment) is discussed in Appendix 4 of Appendix A.

Section 6.4, page 25. Depleted uranium already disposed of at the Clive Facility is not accounted for in the DU PA Model. However, Utah code requires demonstration within the PA that performance standards will be met for “depleted uranium and other wastes, including wastes already disposed of....” [UAC R313-25-8(5)(a)]. Reference should be made here to that section

of the PA where depleted uranium already disposed of at the Clive Facility is discussed and evaluated. If such a section does not currently exist, then it needs to be created.

EnergySolutions' Response: As is described in Section 1.2 of the main report, a Performance Assessment modeling waste disposed of in the Class A West Embankment (including depleted uranium) has already been submitted and approved by the Division as part of EnergySolutions' Class A West Amendment Application (McCandless, 2012). Additionally, authorization for historically-disposed depleted uranium was already approved by the Division with the Performance Assessment submitted in support of condition 6 of EnergySolutions' 22 October 1998 License 2300249 (limiting the depleted uranium within a container as $3.7e+05$ pCi/g upon receipt).

Section 6.6, page 26. The second paragraph states that, "The transport of radon in both the saturated and unsaturated zones will be included in the PA model." However, radon is not mentioned in the saturated zone modeling appendix (Appendix 7); the text should provide a specific cross-reference to the discussion of radon transport under saturated conditions.

EnergySolutions' Response: Radon transport is discussed in Appendices 5, 7, and 8 of Appendix A.

Section 7.1.1.1, page 27. The third paragraph states that "Diffusion in the air phase within the UZ below the facility will not be modeled, since the only diffusive species would be radon...." However, Section 6.6 states that "The transport of radon in both the saturated and unsaturated zones will be included in the PA model." The text should resolve these apparently contradictory statements.

EnergySolutions' Response: Radon diffusion is discussed in Section 7.1.1.1 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 7.1.1.2, page 27. The second paragraph states that "A range of values will allow the sensitivity analysis (SA) to determine if this is a sensitive parameter...." The text should provide a specific cross-reference to the discussion of this sensitivity analysis.

EnergySolutions' Response: Sensitivity is discussed in detail in Appendices 14, 15, and 16 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 7.1.3.1, page 28. The first paragraph states that "Over time, cracks, fissures, animal burrows, and plant roots can also provide preferential diffusion pathways that reduce the effectiveness of the engineered barrier." The document should indicate how this was accounted for in the PA model, particularly with respect to the potential release of radon to the surface.

EnergySolutions' Response: Modeling of the impact of the diffusion pathways is described in Appendices 3 and 8 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 7.1.4, page 31, says, “However, in areas where precipitation does not infiltrate to groundwater, black greasewood will not form taproots and will maintain a more shallowly rooted growth form. Excavations of several greasewood plants at the Clive site by SWCA (2011) found roots that did not exceed one meter in depth.”

SWCA (2011) explains that these greasewood roots went down to a compressed clay layer located at that shallow depth, and then spread out laterally. Where there locally is a perching layer such as this clay layer appears to be, one that traps moisture at a shallow level and makes it available for roots, such shallow plant rooting behavior is expected. However, where such a perching layer does not exist, it is expected that greasewood roots may extend to great depths in search of groundwater or capillary-fringe water. As Neptune and Associates (2011) says of the site, “The vegetative survey of the Clive site found that the majority of greasewood plants are less than one meter tall . . . Still, larger plants do occupy parts of the Clive site, especially where precipitation runoff is concentrated, and these plants may extend taproots to exploit deeper water.”

*As the PA implies, greasewood is a phreatophyte. Its scientific name is *Sarcobatus vermiculatus*. Maxwell et al. (2007) state that greasewood is an obligate phreatophyte, whose roots almost always grow into groundwater. Waugh (1998) states of greasewood that it “is an obligate phreatophyte requiring a permanent ground-water supply, and can transpire water from aquifers as deep as 18 meters below the land surface (Nichols 1993).” Nichols (1993) reports greasewood taproots growing to depths equivalent to about 60 feet. Meinzer (1927) states that “Near Grandview, Idaho, H. T. Stearns observed roots of greasewood penetrating the roof of a tunnel 57 feet below the surface.” White (1932) reports greasewood growing at localities where the depth to groundwater is 50 to 60 feet. WSDNR (2011) states that “*Sarcobatus vermiculatus* is an obligate phreatophyte and is able to tap into groundwater at great depth (>10 meters).” Chimner and Cooper (2004) report that xylem water from greasewood plants overlying a groundwater table at a depth of about 13 meters (43 feet) was isotopically similar to xylem water from greasewood at other sites where depth to groundwater ranged from 2 to 13 meters (6 to 43 feet). Harr and Price (1972) report maximum greasewood rooting depths of at least 12.7 m (42 feet).*

When natural soils in the area are disturbed during excavation to procure cover-system materials, these cover-system materials will no longer possess an intact compressed natural clay layer at a depth of 1 meter that acts to pond infiltrating water and limit deeper greasewood rooting. While the radon barrier may provide some local resistance, the radon barrier is susceptible to damage over time via plant rooting, animal burrowing, water-based and wind-based erosion, and violent meteorological events, such as tornados and microbursts. This section should discuss the potential for deeper rooting by greasewood.

EnergySolutions’ Response: Expanded discussion of greasewood bioturbation has been added to Section 2.1.11 of the Compliance Report and is already found in Appendices 8 and 9 of Appendix A.

Section 7.1.5, page 32. *The first paragraph states that “site-specific information about the utilization of the site by specific animal species is likewise limited.” The PA does not include much information relative to burrowing mammals. Such information, however, can be found specifically for the site in SWCA (2011; 2012). SWCA in particular describes burrowing mammals on site, or very near the site, such as coyotes, badgers, kit foxes, burrowing owls, ground squirrels, and deer mice. Additional generic and case-study information is available in the literature. Much more analysis on the potential for burrowing mammals to impact site rock and soil materials is needed, since burrowing mammals may play an important role in cover-system degradation over time. The PA should include extensive analysis about this important topic, including additions to modeling to show effects of burrowing on site conditions.*

Dwyer et al. (2007) state that, “...biointrusion can lead to increased infiltration and preferential flow of surface water through the cover system as well as contribute to the change in the soil layer’s hydraulic properties.” Hakonson (1999; 2002) and Hakonson et al. (1982) indicate that biointrusion by mammals can be problematic at disposal sites and that pocket gophers, for example, can increase rates of infiltration by 200% to 300%. Breshears et al. (2005) report that burrows made by pocket gophers in simulated landfills dramatically increased infiltration rates, i.e., by about one order of magnitude. Badger burrows at the Hanford site are reported to have captured much runoff and allowed the runoff to infiltrate into soils deeper than elsewhere on site. Measurements by researchers of moisture in soils under the burrows after artificial rainfall events demonstrated this impact. “These measurements confirmed that larger mammal burrows can and do cause the deep penetration of precipitation-generated runoff at Hanford” (Link et al. 1995). Hakonson (2002) says, “Erosion and percolation increase dramatically when the vegetation cover is absent in the presence of burrowing.” According to SWCA Environmental Consultants (2012), “A bioturbation barrier will likely be needed that is designed to exclude large and small burrowing mammals (i.e., mice, rats, hares, badgers).” The text should clarify whether additional site-specific information about use of the site by animals and also biointrusion is going to be collected, and if not, document why the limited available site-specific information is sufficient for the PA and the license amendment.

EnergySolutions’ Response: Site-specific information on the impact of burrowing animals has been included in Appendices 3, 9, and 10 of Appendix A. In response to the Division’s future Round 1 Interrogatories, this information will be supplemented with SWCA (2012), which was written during the 2.5 years between when the PA was submitted and this completeness review.

Section 7.1.5, page 32. *The PA does not mention coyotes inhabiting the site. SWCA (2012) noted that, while coyote burrows or dens were not observed directly on the several plots used for their limited sampling events, evidence of coyotes was noted nearby. The presence of coyotes on or near the site indicates the potential for cover damage by the coyotes.*

Coyotes are capable of deep burrowing. In one study, it is reported that minimum depth of 17 dens ranged from 2 to over 5 meters (6 to 16 feet), with an average depth of 2.5 m (8 feet) (Way et al. 2001). This depth is much greater than the depth of the proposed cover system (6.5 feet), so a risk from biointrusion into radon barriers and bulk waste exists.

Bioinvasion by coyotes can badly damage cover systems, possibly allowing a direct path for water to percolate into waste, and permitting the release of radon into the atmosphere, increasing risk to people and the environment. If coyotes get into waste, they may become surficially contaminated by radioactive particles and may spread these radioactive particles to other parts of the environment. Additionally, radioactive materials within the coyotes (e.g., from eating other fossorial mammals) may subsequently adversely impact the environment via excretion of coyotes' urine, feces or other bodily fluids, or, when the coyotes die, through decomposition of their flesh. The cover system needs to provide a high level of protection from intrusion by burrowing animals, including coyotes. The PA should account for this and also document the potential for deep burrowing by coyotes.

EnergySolutions' Response: Site-specific information on the impact of burrowing animals (including coyotes) has been included in Appendices 3, 9, and 10 of Appendix A. In response to the Division's future Round 1 Interrogatories, this information will be supplemented with SWCA (2012), which was written during the 2.5 years between when the PA was submitted and this completeness review.

Section 7.1.5, page 32. The PA does not mention badgers inhabiting the site. SWCA (2012) shows photos documenting that badgers live at the site, and this reference also reports badger burrows at the site. McKenzie et al. (1982) is said to give a burrowing depth for badgers that is greater than 2.0 meters, or 6.6 feet (Hampton 2006). Based on a study of a couple of badgers in Utah and Idaho, Lindzey (1976) reports that one badger observed in the study burrowed to a depth of 2.3 meters (7.5 feet). Reported burrowing depths of 6.6 to 7.5 feet are significantly greater than the depth of the proposed DU cover system soil and rip rap. It is estimated in Eldridge (2004) that each badger creates or enlarges up to 1,000 to 1,700 burrows or pits each year. Badgers do this primarily while searching for fossorial mammals (e.g., ground squirrels, kangaroo rats or deer mice) to eat. Since each pit lasts, on average, about 4 years (see Eldridge 2004), one badger may be responsible for the presence of 4,000 to 6,800 relatively large pits being in existence each year.

Bioinvasion by badgers can potentially cause a number of problems. Bioinvasion can potentially damage cover systems, allow too much water to percolate into LLW, and permit release of radon into the atmosphere, increasing radioactive doses to humans and the environment. If badgers get into LLW, they may become contaminated by radioactive particles and may spread them throughout the environment. Badgers may also ingest radioactive materials by eating other fossorial mammals impacted by waste. They may then spread radioactivity through the environment via urine, feces, and other bodily fluids, and, when the badgers die, via decomposing flesh.

Rock armor cover may by itself provide minimal bioinvasion protection. Many plants and burrowing mammals may be able to penetrate a rock armor cover by migrating through the large interstices or voids existing between its cobbles. Larger fossorial mammals, such as badgers, may be able to remove some or all of the smaller cobbles by digging or burrowing. The PA should account for this and also document the potential for deep burrowing by badgers.

EnergySolutions' Response: Site-specific information on the impact of burrowing animals (including badgers) has been included in Appendices 3, 9, and 10 of Appendix A. In response to the Division's future Round 1 Interrogatories, this information will be supplemented with SWCA (2012), which was written during the 2.5 years between when the PA was submitted and this completeness review.

Section 7.1.5, page 32. The PA does not mention kit foxes inhabiting the site. Kit foxes, which are found in western Utah, among other places, either create or use (in some cases) dens as deep as 2.5 meters (8.2 feet; Tannerfeldt et al. 2003, referencing O'Neal et al. 1987). This depth is considerably deeper than the design depth of the top of radon barrier, and even considerably deeper than the design depth of the top of the bulk waste. Foxes are mentioned on page 3-4 of Section 3.1.6 of the EnergySolutions PA for blended and processed resin LLW, which states, "Other burrowing animals at the site include jackrabbits, mice, and foxes." Jackrabbits do not burrow. The PA, however, should account for fox burrowing into bulk waste.

EnergySolutions' Response: Site-specific information on the impact of burrowing animals (including kit foxes) has been included in Appendices 3, 9, and 10 of Appendix A. In response to the Division's future Round 1 Interrogatories, this information will be supplemented with SWCA (2012), which was written during the 2.5 years between when the PA was submitted and this completeness review.

Section 7.1.5, page 32. The PA does not mention burrowing owls. The EnergySolutions PA for blended waste says, "Furthermore, the presence of badgers and a large family of burrowing owls indicates that the biota can potentially move large volumes of soil." SWCA (2012) also mentions them, and shows a photograph. The PA should document the potential for deeper burrowing by burrowing owls.

EnergySolutions' Response: Site-specific information on the impact of burrowing animals (including burrowing owls) has been included in Appendices 3, 9, and 10 of Appendix A. In response to the Division's future Round 1 Interrogatories, this information will be supplemented with SWCA (2012), which was written during the 2.5 years between when the PA was submitted and this completeness review.

Section 7.1.5, page 32. SWCA Environmental Consultants (SWCA 2012) reports on the species of ground squirrels observed onsite: Spermophilus spp. Suter (1993) and Suter et al. (1993) report ground squirrel burrowing to depths of at least 1.4 meters (4.6 feet), but do not mention species. HERD (1998) reports that ground squirrels in California burrow to depths of at least 66 inches (1.7 meters, or 5.5 feet). These data indicate that the potential depth to which ground squirrels may burrow may be nearly as deep as the proposed cover system soil thickness and deeper than the top of the radon barrier. These data indicate the potential for ground squirrels to biointrude through at least some of the cover-system soils at the site.

Biointrusion by ground squirrels can badly damage cover systems, possibly allowing for more water to percolate into waste, and facilitating the release of radon into the atmosphere, increasing risk to people and the environment. The cover system needs to provide a high level of

protection from intrusion by burrowing animals, including ground squirrels. The PA should account for this.

EnergySolutions' Response: Site-specific information on the impact of burrowing animals (including ground squirrels) has been included in Appendices 3, 9, and 10 of Appendix A. In response to the Division's future Round 1 Interrogatories, this information will be supplemented with SWCA (2012), which was written during the 2.5 years between when the PA was submitted and this completeness review.

Section 7.1.5, page 32. The PA does not talk extensively about deer mice. Yet, according to the SWCA (SWCA 2011; 2012), 83 deer mice and 1 kangaroo rat were trapped during a single biological survey on site.

*Kenagy (1973) reports on the depth of nests of the kangaroo rat, *Dipodomys merriami*, at a site in Owens Valley between the Mohave Desert and the Great Basin. Maximum depth of kangaroo rats that could be located by tracking devices used at this site is reported to have been 1.75 m (5.7 feet). However, many of the kangaroo rats are reported to have stayed in their burrows during the study at considerably greater depths than this maximum depth to which the tracking devices used in the study could read a signal and track them. Different species of kangaroo rats may burrow more deeply or less deeply. The species of kangaroo rat found at the site is not mentioned in the PA. The kangaroo rat captured by SWCA Environmental Consultants (2012) is thought to have been an Ord's Kangaroo rat (see page 23 of SWCA 2012b).*

Arthur and Markham (1986, 1987; see also Bowerman and Redente 1998) note that deer mice penetrated an Idaho National Environmental Laboratory (INEL) cover system having a thickness of 2.4 meters. Many of the mice are reported to have received relatively high radiation doses, some of which are said to have been lethal.

Landeen and Mitchell (1981) found that other types of mice (i.e., pocket mice) at the Hanford site burrowed about 79% deeper in disturbed soils than in native soils. This indicates that, for combinations of some mammals and some soils, biointrusion may be deeper in disturbed soils than in non-disturbed soils.

Based on the foregoing, it appears that the potential for biointrusion exists for both kangaroo rats and deer mice at the site. Kangaroo rats are noted in field observations to have burrowed down to soil depths of at least 1.75 meters (5.7 feet). It is not known how species variation affects burrowing depth. Deer mice can burrow down to at least 2.4 meters (7.9 feet). These are depths for which actual field samples are relatively few. Therefore, greater depths of burrowing could be expected if an entire population were to be evaluated. Furthermore, as reported for one species in one soil by Landeen and Mitchell (1981), burrowing depths may possibly tend to be greater in disturbed soil.

For the Licensee-preferred cover design at the site (see pages 12 and 15), the proposed cover-system soil thickness is several feet. Both kangaroo rats and deer mice have been reported to burrow down into soil fairly deeply. This indicates the potential for biointrusion at the site. The

PA should include discussion of the potential for this from mice and kangaroo rats, and the effects of bioinvasion by mice and kangaroo rats, and all other potential bioinvasions, should be accounted for in the PA model.

EnergySolutions' Response: Site-specific information on the impact of burrowing animals (including deer mice) has been included in Appendices 3, 9, and 10 of Appendix A. In response to the Division's future Round 1 Interrogatories, this information will be supplemented with SWCA (2012), which was written during the 2.5 years between when the PA was submitted and this completeness review.

Section 7.2, page 35. Even though predictions of dose in deep time involve much uncertainty, doses can be discussed qualitatively under certain assumptions. This approach has value in assisting regulators and the general public in understanding how radioactivity values of DU's daughter products (and therefore their potential contribution to dose) tend to increase over time. A simple bounding assumption that could be used would be to assume that site conditions do not deteriorate at all. Annual dose could then be estimated, for example, for an inadvertent intruder working 8 hours per day, 5 days per week, in a basement of a building located over the embankment. The results, though based on quantitative numbers, would need to be assessed qualitatively, because there would be, in fact, dramatic uncertainty associated with the result, and this set of criteria can be communicated to the reader of the PA. Determination of dose at the time of peak dose and qualitative discussion of the results is mandated by Utah rule, and it should be included as one of the PA results.

EnergySolutions' Response: Regulatory discussion of the nature of the qualitative assessment is included in Section 1.3 of the Compliance Report and Appendix 13 of Appendix A.

Section 7.2.1.4, page 39. This section discusses the indirect effects of volcanism in diverting the Bear River from Idaho to the Bonneville basin. The effects of volcanism on the Clive area should be included, or the text should document that there is no possibility for impacts of volcanism on the Clive area over the next 10,000 years.

EnergySolutions' Response: Multiple effects that may potentially impact the Federal Cell, including volcanism, are considered in Appendix 13 of Appendix A.

Figure 7.2.1.5, page 40. The X on the Whittaker biome diagram (which is supposed to represent site conditions) appears to be too high. As it currently is depicted, the scaled precipitation value for the X appears to be in the range of 27–30 cm/yr. Yet average precipitation at Clive is 8.62 in/yr (about 21.9 cm/yr). This appears to change the biome depicted for the site conditions. The placement of the data point for site conditions as presented by the X on the diagram should be modified in the PA.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 7.2.2, page 42. The document says, “When the first lake returns at or above the elevation of Clive, the waste embankment will be treated as destroyed.” This interpretation of results may, under many circumstances, be reasonable. However, if all waste and cover-system materials are located below natural grade level, then it is not likely that the waste would be redistributed into the environment nearly as readily, if at all. The PA model should be re-run under this scenario, with the top of the cover at natural grade level, and the results presented in the text.

EnergySolutions’ Response: Deep time is addressed in Section 7.2.2 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 8.1, page 44. The last sentence of the section states that, “All wastes are assumed to have the characteristics of local Unit 3 sandy soil.” The text should provide the basis for making this assumption, rather than assuming that the DU waste would have the characteristics of DUO3 from SRS and DU3O8 and DUO2 associated with de-conversion of UF6.

EnergySolutions’ Response: Waste characteristics for depleted uranium and the conservatisms of the statement referenced are discussed in Appendices 3 and 4 of Appendix A.

Sections 8.2 and 8.3, page 44. The text should provide a brief description of the liners and cap or provide a specific cross-reference to where descriptions may be found.

EnergySolutions’ Response: The liner and cover design approved for the Class A West Embankment is described in detail in Section 3 of the Class A West Amendment Application (McCandless, 2012). This same Division-approved design is planned for use in the Federal Cell.

Section 8.2, page 45. Paragraph three of the first bulleted item says, “The measured moisture content in the Cover Test Cell at the site provides evidence for an evaporative zone depth greater than 18 in (Envirocare 2005).” However, the DRC in its 2012 report on the covered test cell, clearly demonstrated a lack of substantive evidence for an evaporative zone depth greater than 18 in exists. Substantial evidence, in fact, exists to show that in many studies, coarse-grained material (such as rip rap) placed at the surface of a soil layer acts as an inorganic mulch and greatly reduces or, in some instances, nearly eliminates evaporation. The PA should be modified to account for this.

EnergySolutions’ Response: The impacts of evaporation on the Class A West Embankment has been included in the Performance Assessment submitted and approved by the Division in Attachment 3 of the Class A West Amendment Application (McCandless, 2012). Because the same Division-approved design is planned for the Federal Cell, this analysis also supports the performance of the Federal Cell. Similar GoldSim representation within the depleted uranium Performance Assessment was modeled (see Appendices 3 and 8 of Appendix A).

Section 8.3, page 45. The suppositions in the second bullet about the behavior of smaller mammals and ants should be supported by appropriate references.

EnergySolutions' Response: Small mammals and ants are described in Section 8.3 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 8.2, page 45. The third bulleted item says, "On balance, the evidence suggests that bioturbation and homogenization of the radon barriers will probably occur very slowly relative to the 10,000-year time frame for the PA." No justification is provided for this claim. Moreover, homogenization of the radon barriers is not the only result of biointrusion and bioturbation. This bulleted item should be expanded, and any assertions made should be justified.

EnergySolutions' Response: Bioturbation of the radon barrier is discussed in Section 8.2 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 8.2, page 46, says, "Freeze/thaw cycles will also tend to degrade performance of the cap. This process is anticipated in the design, however, which includes a sacrificial layer to accommodate it (Whetstone, 2000)." However, the sacrificial layer is not necessarily of sufficient thickness in its current design to withstand sustained cold winter temperatures.

At the Cover Test Cell previously built and tested on site, freezing temperatures occurred at a depth of 30 inches for January 2004, which was not an exceptionally cold month. Neither was the month before an exceptionally cold month. In very cold winters, it stands to reason that the zone of freezing may extend even deeper than 30 inches, and this may necessitate even greater design soil layer thickness above the radon barrier to protect it.

In the Cover Test Cell that month, while freezing occurred at a depth of about 30 inches, temperatures only slightly above freezing (e.g., 2°C, or about 36°F) were noted even at a depth of 42 inches, at or near the top of the radon barrier. During that month, mean monthly low air temperatures are reported as having been 11.35°F (see <http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?utdugw>). However, meteorological records show that, in the 56 years between 1951 and 2006, inclusive, there were 13 years (23%) in which mean monthly low air temperatures for January dropped to values lower than 11.35°F (<http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?utdugw>), and sometimes much lower. Likewise, about 25% of December monthly low air temperatures between 1951 and 2006 were colder than those in December 2003, and sometimes much colder. It follows that test results for freezing of the Cover Test Cell in 2004 are not conservatively representative of all freezing temperatures experienced over time.

In January, 1989, monthly low air temperatures plummeted to 0.39°F, which is nearly 11 degrees cooler than in January 2004. With a similar drop of 11 degrees in monthly low air temperature in the future compared to January 2004, it is possible that a radon barrier at the DU embankment could be subjected to below-freezing temperatures, with consequent severe damage.

The PA should discuss the potential for freezing of the radon barrier, which could cause it to undergo severe damage through frost heave.

EnergySolutions’ Response: The adequacy of modeling the impacts of freeze/thaw cycles on the Class A West Embankment have been included in the Performance Assessment submitted and approved by the Division in Attachment 3 of the Class A West Amendment Application (McCandless, 2012). Because the same Division-approved design is planned for the Federal Cell, the analysis demonstrates compliance. Consideration of the disposal of depleted uranium does not impact the Division-approved cover design.

Section 8.2, page 46. As stated in the document, “Subsidence is not expected to be an important process at the Clive facility, since the waste is aggressively compacted in order to prevent this occurrence (EnergySolutions, 2009c). However, the subsidence described in the EnergySolutions reference does not refer to compaction of DU in its drums or canisters, which may behave very differently in the embankment from, for example, compacted bulk waste. Drums of DU-related LLW from SRS or canisters of DU-related LLW from GDPs may have headspace within the associated containers that may not respond to compaction efforts at Clive. However, this headspace may become important as the containers deteriorate over long periods of time, perhaps decades or hundreds of years, and as the headspace is filled in by overlying waste, resulting in differential subsidence. What is missing from the PA is an analysis of stability conditions as this compaction occurs. The analysis is required under UAC R313-25-22 and analysis should be part of the PA.

EnergySolutions’ Response: The impact of waste subsidence on the Class A West Embankment ability to satisfy its performance objectives has been included in the Performance Assessment submitted and approved by the Division in Sections 3.3.3 and 4.3 and Attachment 5 of the Class A West Amendment Application (McCandless, 2012). Because the same Division-approved design is planned for use in the Federal Cell, this analysis also supports the Federal Cell’s performance. In accordance with existing CQA/QC Manual requirements for LLRW disposal, depleted uranium containers, regardless of the type, will require any headspace void to be filled. EnergySolutions does not propose to vary this requirement, in order to provide assurance that embankment stability evaluations remain bounding. Consideration of the disposal of depleted uranium does not impact the use of the Division-approved Class A West Embankment design in the Federal Cell.

Section 9.1.1, page 47. The document states, “Based on laboratory analysis of the contents of DU waste (including all radionuclides in the containers), the species in the disposed inventory include (Beals et al. 2002; EnergySolutions 2009b; Johnson 2010): . . .” This statement is unclear as to which waste it is referring. Does it refer to all DU waste expected to be disposed of including that in the future, or to currently disposed of DU waste, or to DU waste from SRS, or to DU waste from GDPs? Each of these will have different DU-waste species compositions. How is this accounted for in the model? This section needs clarification.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 9.1.2, page 47. The text should describe how “spontaneous fission” is modeled in the PA such that it is “accounted for in terms of [its] dose effects on humans.”

EnergySolutions' Response: Modeling of doses is described in Appendices 4 and 11 of Appendix A.

Section 9.2, page 51. It is stated that, "The disposed DU waste is assumed to be uncontainerized, since standard operations at the site include significant compaction of disposed waste." This appears to be an incorrect assumption. Planned disposal practices at the site include disposal of SRS drums and GDP canisters as well as the DU waste that each type of container holds. Correct information about containers needs to be supplied for the model and for the text in this section. This information is important in considering physical stability of the waste, since any headspace in the containers will eventually allow for partial collapse of the waste and cover above it.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 9.3, page 52. This section discusses use of partition coefficients in the model. However, the text, and presumably the model, either openly or implicitly assume that sorption and exchange processes occur:

- (1) *Under equilibrium conditions, rather than non-equilibrium or time-dependent conditions*
- (2) *Linearly, rather than nonlinearly*
- (3) *Reversibly, rather than irreversibly*
- (4) *Independently of pH, Eh, temperature, and other physical and chemical characteristics of the external environment, rather than dependently*

While choosing such an approach to sorption and exchange processes may be considered by the modeler(s) to be necessary to keep the model sufficiently simple and workable, and data acquisition minimal, it is well known that there are some rather severe limitations to the accuracy of such an approach with respect to radionuclides. For example, as stated by Cygan et al. (2001), "linear and reversible sorption (i.e., KD approach) is rarely observed in soils and groundwaters because of complex geochemical factors that can significantly affect radionuclide transport mechanisms and kinetics (e.g., pH, fluid composition, ionic strength, mineral substrate structure and composition, organic complexation)."

There is thus a great deal of uncertainty involved in model results based on an application of the partition coefficient approach, such as occurs in the PA model. This section should either provide a discussion of this inherent uncertainty, or provide a reference to a relevant discussion found elsewhere in the PA. The discussion of uncertainty should attempt to quantify it. Another section of the PA should address model sensitivity to the value of the partition coefficient used.

EnergySolutions' Response: The selection of sorption coefficients has been previously submitted to and approved by the Division as part of the Attachment 3 to the Class A West Amendment Application (McCandless, 2012). Since the applicable environment considered therein is also applicable to the Federal Cell, the Division's acceptance of the sorption coefficients is also supported for the Federal Cell. Uncertainty in sorption coefficients is discussed in Appendices 4, 5, 6, 7, and 14 of Appendix A.

Section 9.3, page 52. The text provides the partition coefficient concept. It should also provide details on how the retardation factor was calculated and specifically whether moisture content or porosity is used in the unsaturated zone transport calculation.

EnergySolutions' Response: Calculation of retardation factor has been previously submitted to and approved by the Division as part of the Attachment 3 to the Class A West Amendment Application (McCandless, 2012). Since the applicable environment considered therein is also applicable to the Federal Cell, the Division's acceptance of the retardation factors is also supported for the Federal Cell. Additional discussions are present in Appendices 4, 5, and 7 of Appendix A.

Section 10.3, page 56. The text states that "Potential activities of interest...are based on the predominant present day uses of the general area...." As we described in Section 3.1, General Comment 9, the PAWG (see NRC 2000a) expects that an analogue site would be used when there are currently no nearby residents. The applicant should provide the basis for not using an analogue site.

EnergySolutions' Response: Nearby industrial residents are described Section 1.3 of the main report.

Section 10.3.1, page 57. The second paragraph states that "Inputs for developing exposure parameter values under the ranching scenario include...restrictions related to BLM leases...." The document should explain why it is appropriate to include Bureau of Land Management (BLM) restrictions, given the potential for BLM policies to change in the future over the next 10,000 years.

EnergySolutions' Response: BLM leases are discussed in Section 10.3.1 of Appendix 2 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 11, page 62. The first paragraph states that "...process-level models may be developed." The text should clarify whether process-level models were, in fact, developed and integrated fully into the overall model; it should describe how the conceptual site model was actually implemented.

EnergySolutions' Response: Process modeling is addressed in Appendices 5, 6, 7, 8, 9, and 13 of Appendix A.

6.0 REVIEW OF APPENDIX 4 – "RADIOACTIVE WASTE INVENTORY FOR THE CLIVE DU PA," MAY 28, 2011.

6.1 GENERAL COMMENTS

Comment 1. Clarification of Metrics: When the appendix cites a material mass, the material comprising the mass should be stated. For example, on page 6 (line 2), the text states, "...weight

(total of 7,886,738 pounds corresponding to a mass of 3,577 Mg).” The document should indicate whether this is 3,577 Mg of DU, DUO₃, or DUO₂.

EnergySolutions’ Response: EnergySolutions appreciates the recommendation. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 2. Overlooked Reference: The list of references does not include the following document (DOE 2003):

Recycled Uranium, United States Production, Enrichment and Utilization. DOE/SO-0003. U.S. Department of Energy. May 2003.

This document and its supporting references may contain useful information on the levels of actinides and fission product contaminants in materials at the three gaseous diffusion plants.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

6.2 SPECIFIC COMMENTS

Section 2.2.2, page 5. The first paragraph mentions samples analyzed by the Savannah River Technology Center (SRTC) and by BWXT Services, Inc., for uranium, fission, and transuranic radionuclides. The last sentence of the paragraph provides the references for the results from SRTC, but not for BWXT Services, Inc.; the document should also provide a specific cross-reference to the results of the BWXT analysis.

EnergySolutions’ Response: Results from the BWXT assessment are included in Appendix 4 of Appendix A.

Section 2.2.2, page 6. The document states that “In January of 2010 EnergySolutions collected 15 samples that were analyzed for uranium isotopes (Table 14, in the Appendix). In April 2010 EnergySolutions collected 11 samples that were analyzed for uranium isotopes and 99Tc (Table 15, in the Appendix).” The number of samples should be reversed; Table 14 shows 11 samples for January 2010, and Table 15 shows 15 samples for April 2010.

EnergySolutions’ Response: EnergySolutions appreciates the recommendation. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 2.3.2, page 7. The document states that “Little information is available at this time regarding the exact nature and extent of the contamination within the contaminated DU population.” Based on Comment 2 above (see DOE 2003), SC&A believes that this statement is not accurate. Additional information is available to augment the analysis.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.1.2, page 10. The text states, “However, different sampling events for 99Tc and U indicate potentially different measurement types between sampling events.” The meaning of this statement is not clear. What are different measurement types? How is this judgment made?

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.2.1, page 12. We believe that the subscripts in the denominator of equation 1 should be *i* (eye).

EnergySolutions’ Response: EnergySolutions appreciates the recommendation. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.2.2, page 14. The document states:

“In general, the differences this causes in uranium activity concentrations are fairly small relative to the likely effect on the PA model results, however, this will be tested in the model evaluation and sensitivity analysis.”

The text should provide a specific cross-reference to the sensitivity analyses.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.2.3, page 16. The text states:

“If, given these relatively broad distributions, the uranium isotopes are not sensitive to any PA model endpoint, then the need to refine these distributions will be less.”

The text should indicate whether any analyses were conducted to determine if the uranium isotope distributions significantly affected the PA results.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.3, page 17. The text states:

“The effect of the inclusion of these data has been tested during model evaluation and is reported as part of the sensitivity analysis.”

The text should provide a specific cross-reference indicating where the results are reported.

EnergySolutions’ Response: Sections 6.1.2, 6.2.2, and 6.3.2 of Appendix A address results of the sensitivity analysis. EnergySolutions appreciates the recommendation. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.3, page 18. *The text should describe how the information contained in the box plots in Figure 3 (and later in Figure 5) should be interpreted. What statistical parameters do the boxes display?*

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.3, page 19. *The document states:*

“Given the mobility of 99Tc and the width of the input distribution defined above, it is reasonable to expect that concentration of 99Tc will be a sensitive parameter.”

The text should indicate whether this expectation was tested and, if so, where the results are reported.

EnergySolutions' Response: Sections 6.1.2, 6.2.2, and 6.3.2 of Appendix A address results of the sensitivity analysis. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.3, page 20. *The intent of the dashed lines in Figure 4 should be defined.*

EnergySolutions' Response: EnergySolutions appreciates the recommendation. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.4, page 20. *The introductory paragraph in this section states:*

“As noted in Section 2.1, there are other potential contaminants in the SRS DU, including decay, activation and fission products (see Table 3). Given the only source of data for these radionuclides in SRS-2002, the concentrations are very low, and are unlikely to significantly contribute to the PA, however, input distributions for the mean concentrations of each of these radionuclides are developed and included in the PA to confirm that this is the case.”

To test the supposition that the contaminant radionuclides are unlikely to significantly contribute to PA, one might suppose that doses were assessed with and without these contaminants. The text does not indicate whether such a comparison was made. The document should state how the PA confirmed that the contaminants did not contribute significantly to the PA.

EnergySolutions' Response: Sections 6.1.2, 6.2.2, and 6.3.2 of Appendix A address results of the sensitivity analysis. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.5, page 21. *It is stated here:*

“The exact nature of the DU oxides that will be generated by the deconversion plants at Portsmouth and Paducah will not be known until their production, so this PA relies on

the best information available to develop estimates. What is known is that the oxides will be primarily U₃O₈, and that they will be shipped and disposed in used DUF6 cylinders, some of which will contain residual contamination from reactor returns.”

It is assumed by the Licensee within the PA that the radioactive waste from GDPs will primarily be U₃O₈. However, the exact nature of the oxides produced at the GDPs, as stated, is not known. A number of sources suggest that the deconverted DU material may also contain UO₂. At an NRC Website (NRC 2012), it says, “What will happen to the waste products from the de-conversion process? De-conversion permits the recovery of fluoride compounds . . . as the fluorine is extracted, the uranium is converted to an oxide (either U₃O₈ or UO₂).” Even the PA (2011), on page 21 of Appendix 4, says, “Note that UO₂ . . . may make up a small amount of the GDP DU.”

UO₂ formed by some processes is known to be pyrophoric when finely divided. Finely divided uranium oxide materials may be created during processing, or they may form as a result of movement and abrasion during shipping and waste emplacement.

Pyrophoric wastes, of course, may present some hazards. Disposal of pyrophoric wastes, unless they are treated, prepared and packaged to be nonflammable, is forbidden by rule in Utah [R313-15-1009(2)(a)(vii)].

An ORNL document (Thein and Bereolos 2000) says, “UO₂ may even be pyrophoric when the particle size is very fine.” A U.S. Air Force translation of Budnikov et al. (1963) says, “Finely dispersed UO₂ has pyrophoric properties, it burns to U₃O₈.” Clayton and Aronson (1958) indicate that whether or not UO₂ is pyrophoric depends on the process used in chemically preparing it. Eidson and Beals (2010) state, “Finely divided UO₂ is pyrophoric, oxidizing in air to a variety of oxide phases including U₃O₈ as the most stable phase.”

Gupta and Singh (2003) warn, “When dealing with uranium powder or some other powder in a finely divided form, it should be borne in mind that one is handling pyrophoric materials and that it is absolutely necessary to exercise the corresponding control and implement precautions in every stage of production and processing . . .”

Either the Licensee must make provisions for exclusion of UO₂ from the waste, or the PA should justify disposal of waste containing UO₂ at the site. Factors to consider include development of finely divided particles and possible pyrophorism during physical transport by rail or road, placement in an embankment, or geochemical modification subsequent to burial.

EnergySolutions’ Response: As part of its Class A West Amendment Application (and condition 16.D of the associated License UT 2300249), EnergySolutions is prohibited from managing pyrophoric radioactive waste. Licensing of a Federal Cell with the Division-approved Class A West Embankment design does not alter the appropriateness of this condition. Development and submission of the depleted uranium Performance Assessment does not change this limitation.

Section 3.5.2.3, page 23. Please provide a complete reference for “(personal communication, Tammy Stapleton, April 2011).”

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

7.0 REVIEW OF APPENDIX 5 – “UNSATURATED ZONE MODELING FOR THE CLIVE PA,” MAY 28, 2011

7.2 SPECIFIC COMMENTS

Section 2, page 7. The Final Report (first paragraph, page 55) states that “the waste is more concentrated [when placed lower in the embankment] since it is arranged into a smaller volume, thereby decreasing the duration of breakthrough at the well, and increasing its amplitude.” Appendix 5 should provide a schematic similar to Appendix 7, Figure 1, for the saturated zone modeling that shows the different arrangements of the wastes as a function of the three burial depths.

EnergySolutions’ Response: EnergySolutions appreciates the Division’s recommendation. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.1, page 11. The text indicates that the distribution of recharge rates is based on 18 years of historical data. The text should explain the rationale for not adjusting the distribution to include potential climatic changes (wetter) and subsequent impacts to precipitation. Studies at Yucca Mountain have suggested significant climate changes over the next 10,000 years (e.g., BSC 2004).

EnergySolutions’ Response: While included in this Compliance Report as part of qualitatively informing the Performance Assessment of the Federal Cell, EnergySolutions agrees with NRC cautions and recognizes that regulatory compliance should include limited,

“consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation”(NRC, 2000).

Furthermore,

“[t]hese events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose.” (NRC, 2000).

As such, EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.2, page 15. The text at the end of the fourth paragraph states, “Since the upper filter layer is assumed to have been silted up and is therefore ineffective at diverting infiltrating water, it is assigned a lateral flow of 0 cm/yr (0 in/yr).” The document should clarify why, after the upper flow barriers are compromised, water will not collect above the clay liner (“bathtub effect”) and provide a driving force to increase the infiltration rates above those predicted by HELP and UNSAT-H.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5.1.5 and 5.1.6, page 27. Please provide additional justification for the modeled post-installation upper and lower radon barriers since the values used are orders of magnitude lower than that indicated as being appropriate in NUREG guidance (see Benson et al., 2011).

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 8.0, page 30. The document should provide the mass-balance information for both the flow and contaminant transport from the model simulations.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 8.3, page 37. The last sentence in the section states, “Numerical testing demonstrated that the geometric zoning produces stable solutions for the top slope and side slope models with the Runge-Kutta method up to flow rates of 5 cm/year.” The text should provide a specific reference to where this work is presented.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 9.2.1, page 49. The text states, “Air-phase advection is not included in the Clive DU PA Model. It is assumed that the advective flux of gases is negligible compared to the diffusive gas flux.” The document should provide additional justification for this statement, since it is a major assumption in predicting radon flux back to the surface. If a total pressure gradient exists in a soil as a result of external forces, such as atmospheric pumping or diurnal temperature changes, gases, especially when considering dispersion, will experience net flow, e.g., from points of higher to lower pressure. Furthermore, it has been shown that relatively small gradients in total pressure can result in advective gas fluxes that are much larger than diffusive gas fluxes (Thorstenson and Pollock 1989; Massmann and Farrier 1992; Weisbrod et al. 2009; Ganot et al. 2012).

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

8.0 REVIEW OF APPENDIX 6 – “RADIONUCLIDE GEOCHEMICAL MODELING FOR THE CLIVE DU PA,” MAY 28, 2011

8.1 GENERAL COMMENTS

Comment 1. Up-to-Date References: Appendix 6 uses data developed for the Yucca Mountain Site Characterization Project's Total System Performance Assessment to define solubilities for several species. The source document is LANL 1997. There are more recent Yucca Mountain studies that should be considered to be sure that the most current sources are considered. This includes “Dissolved Concentration Limits of Radioactive Elements,” ANL-WIS-MD-000010, Revision 05, July 2005 (Bechtel SAIC 2005).

EnergySolutions' Response: EnergySolutions appreciates the suggestion. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 2. Reactions with Water: This appendix does not consider reactions of depleted uranium oxides with water. Please provide justification for not considering reactions of depleted uranium oxides with water. Particularly due to the potential to create flammable, explosive or pressurizing gases, such as hydrogen DUO₃ is an example of depleted uranium oxide that is potentially prone to production of pressurizing gases, even at ambient temperatures. As stated by Thein and Bereolos (2000):

There has been a continuing concern that moisture and other volatiles theoretically can produce pressurizing gases during long-term, sealed storage via radiolysis. Reduction of this potential source of pressurization is a primary reason for treating the uranium oxides. Heating uranium oxide will reduce moisture content to less than 0.5 wt % and similarly reduce equivalent quantities of residual species (e.g., hydrates), which might produce pressurizing gases. The 0.5 wt % specification is a generally accepted limit that is reasonable to achieve and for which no negative effects have been identified. Reducing the amount of moisture present also reduces the potential for and rate of container corrosion.

Free water is eliminated during heating at temperatures above 100°C (i.e., simple evaporation in a vented vessel). The three principal uranium oxides (UO₂, UO₃, and U₃O₈) all form hydrates. However, UO₂ and U₃O₈ form hydrates only when prepared via a precipitation reaction. On the other hand, UO₃ can form hydrates directly through reaction with H₂O between temperatures of 5 and 75°C (Vdovenko 1960).

It is not presently known if DUO₂ and DU₃O₈ present in the proposed LLW will be formed during de-conversion at the GDPs via a precipitation reaction and therefore be susceptible to hydrate formation and gas production if buried in containers at Clive. However, it is known that

the SRS depleted uranium LLW is in the form of UO₃. It can therefore presumably “form hydrates directly through reaction with H₂O between temperatures of 5 and 75°C (Vdovenko 1960).” Subsurface temperatures at Clive are expected to be between temperatures of 5°C and 75°C. If UO₃ is buried at Clive, it will ultimately be exposed to soil moisture. This could occur in the unsaturated portion of the vadose zone, the saturated portion of the vadose zone (i.e., the capillary fringe, which, in fine-grained materials such as fine silts or clays, may be as high as 5–10 feet above the water table), or the saturated zone (located beneath the water table). During prolonged inundation, as during a large-scale intermontane lake level rise, the porous media surrounding buried UO₃ would ultimately be saturated. This would occur even in the initially unsaturated portion of the vadose zone, which would become saturated over time. Since exposure to moisture leads to hydrate formation, and hydrate formation is associated with production of potentially hazardous gases via radiolysis, it follows that the PA should discuss how this problem can be obviated.

EnergySolutions’ Response: As part of the application of EnergySolutions’ current Division-approved procedure for waste disposal in the Class A West Embankment with CLSM, disposal of depleted uranium in the Federal Cell will not be sealed in an air-tight condition. Therefore, any gases that may be formed after disposal of depleted uranium will be allowed to diffuse through the Federal Cell without the risk of increase pressurization or accumulation.

Comment 3. DU Solubility in Water and SRS Waste: The DU oxide DUO₃, under oxidizing conditions, is moderately soluble in water (Weiner 2008). DUO₃ dissolved in groundwater will move offsite given enough time. Complexes of uranium with water and some other minerals such as sulfate and carbonate can also be fairly mobile in groundwater. The Utah limit on uranium in groundwater is 30 ug/L, comparable to about 27 pCi/L. The uranium in a plume that has moved downgradient from the embankment over time will decay to form radon-222 in areas where no cover-system exists to protect the general public or inadvertent intruders from exposure. As such, DUO₃ in general, and SRS waste specifically, does not appear to be suitable for long-term subsurface burial at Clive. The PA should discuss this issue and justify why UO₃ should be allowed to be disposed of at the Clive LLW Disposal Facility.

EnergySolutions’ Response: The mobility of depleted uranium under various geochemical conditions is considered in Appendix 6 of Appendix A. Additionally, radon pore-space diffusion has been shown to be approximately 4 orders of magnitude lower in the presence of highly saturated media (Figure 5 of NUREG/CR-3409). Because the aquifer is in a saturated condition, it is extremely unlikely that radon formed within the aquifer would upwardly diffuse into the atmosphere.

In a related study by Schramke, Janet (2006), it was concluded that,

“if the uranium oxides U_3O_8 or UO_2 are placed in [the Class A West Embankment], interaction with infiltrating water is likely to result in replacement of the oxide phases by more-stable, less-soluble secondary solids. . . Therefore, as a consequence of the formation of increasingly stable phases, the uranium solids present in the [Class A West Embankment] would be expected to become less soluble with time. The solubilities of these phases would provide an upper limit for uranium concentrations in the leachate regardless of the total mass of uranium in the disposal cell. The [Class A West Embankment] is located above the water table in an arid environment. The [Class A West Embankment] design includes a clay liner and leachate collection system that will minimize the transport of waste constituents to the site groundwater. The site soils consist of fine-grained materials that are dominated by clay and carbonate minerals. Uranium in solution is known to be attenuated by sorption on clay minerals (Giblin 1980, Ames et al. 1983, Giammar 2001), carbonate minerals (Voudrias and Means 1993, Brown et al. 1999) and soil organic matter (Meunier et al 1989), which will limit the concentration of uranium in leachate that reaches the groundwater below the [Class A West Embankment]. Once the leachate travels to the groundwater, the uranium concentration will be decreased by dilution and dispersion as well as by sorption on the clay minerals, carbonates, organic matter, and other minerals present in the aquifer solids. In summary, the following processes at the [Class A West Embankment] would substantially reduce uranium concentrations at a groundwater point of exposure to levels considerably below the solubility of U_3O_8 :

- *Formation of more-stable, less-soluble uranium phases within the disposal cell;*
- *Uranium adsorption by clays, carbonates, and organic matter in the vadose zone;*
- *Dilution by mixing of leachate with native groundwater; and*
- *Uranium adsorption on aquifer materials in the saturated zone.”*

8.2 SPECIFIC COMMENTS

Section 1.0, Table 3, page 2. The notation “U” should be defined. SC&A presumes it refers to a uniform distribution with the indicated minimum and maximum.

EnergySolutions’ Response: EnergySolutions appreciates the Division’s recommendation. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 2.0, page 2. Please provide clarification as to whether the fill placed between the waste containers before the cell is closed would be radioactive bulk LLW or non-radioactive earthen material.

EnergySolutions’ Response: As is discussed in Section 2.4 of the Compliance Report and Appendices 2, 3, and 4 of Appendix A, the Federal Cell will accept Class A low level radioactive

waste (including some of the same backfill as described in Section 4.3 of the Class A West Amendment Application). Section 3.3 of the Compliance Report describes how containers of depleted uranium will be disposal in CLSM within the Federal Cell so that voids within and between the containers are filled.

Section 4.1.11, page 15. Please provide a reference to the section of the PA that covers transport of technetium in groundwater at the site. Please also provide additional information on the role that waste acceptance criteria may play to exclude sources of DU having elevated concentrations of technetium-99.

EnergySolutions' Response: Groundwater migration of technetium-99 from the Division-approved Class A West Embankment has been addressed in Attachment 3 of the Class A West Amendment Application (McCandless, 2012) and from the Federal Cell in Appendices 5, 6, and 11 of Appendix A. Additionally, Section 3.1.3 of the Compliance Report suggests that, *“since the technetium-99 disposal concentrations are already limited to 1,720 pCi/g under the Class A West side slope, EnergySolutions proposes similar limitations be applied to the Federal Cell to include a disposal concentration limit for Tc99 of 23,800 pCi/g under the Federal Cell top slope.”*

Section 5.0, page 17. The first sentence of the last paragraph states, “The potential for colloidal transport of actinides at the Clive facility is not incorporated into the PA model.” The text then refers to actinide intrinsic colloids, which comprise one type of colloid. The text should discuss the potential for other types of colloids and colloidal-forming constituents in the waste (e.g., ligands).

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5.0, page 18. The last two sentences of the first paragraph state:

“Retention of colloids is favored at high ionic strength, low pH and in impermeable rock. The high ionic strength conditions in the saturated zone at Clive are counter to conditions considered favorable for colloid transport.”

The text should provide citations for the statement that retention of colloids is favored in high ionic strength solutions.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 5.0, page 18. The first sentence in the second paragraph states:

“In many cases the solubility of radionuclide species used in the transport model was based to some extent on the data provided in the proposed Yucca Mountain Project (LANL 1997) and the Nevada National Security Site (NNSS, formerly the Nevada Test Site) (Sandia 2001) modeling.”

The discussion should also include the solubility and speciation work with radionuclides in high ionic strength brines that has been performed (and is currently ongoing) to support the Waste Isolation Pilot Plant.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

9.0 REVIEW OF APPENDIX 7 – “SATURATED ZONE MODELING FOR THE CLIVE DU PA,” MAY 28, 2011

9.1 GENERAL COMMENTS

Comment 1. Vertical Hydraulic Conductivity and Gradient: Please provide additional discussion on how vertical components of hydraulic conductivity and vertical gradients are considered in the PA.

EnergySolutions' Response: Vertical conductivity and gradients are addressed in Appendices 3, 5, and 7 of Appendix A.

9.2 SPECIFIC COMMENTS

Section 3.1, page 3. Typically, hydraulic conductivity has a log-normal distribution, as opposed to the normal distribution assigned in the model. The applicant should provide the Excel® spreadsheet prepared by R. Sobocinski, the random-effects analysis, and any other information that supports the derivation of normal distribution for the hydraulic conductivity.

EnergySolutions' Response: Distribution shape justification for the Federal Cell's saturated zone is documented in the Revised Hydrogeologic Report (EnergySolutions, 2012a).

Section 3.3, page 4. The applicant should provide any factors taken into consideration when developing the distribution of hydraulic gradients from off-normal conditions (e.g., impacts by increased infiltration due to climatic changes, or gully erosion/plant or animal penetration of the liner).

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.1, page 7. The text in the last paragraph on the page states:

“An aquifer thickness for each of the four locations was calculated as the difference between the recorded elevation of the water table and the elevation of the bottom of the shallow aquifer. Since the four locations do not quite form a square, triangulation was used to calculate an average thickness across the region.”

The document should explain the rationale for this approach and provide any information that supports the assumption that uniform mixing is likely to occur over the “aquifer thickness” described, i.e., to a depth of 16 or more feet beneath the waste unit. This assumption is important since there is a direct linear relationship between the thickness of the aquifer (vertical extent of plume) and the concentrations arriving at the monitoring well.

EnergySolutions’ Response: Aquifer thickness beneath the Federal Cell’s saturated zone have been documented in the Revised Hydrogeologic Report (EnergySolutions, 2012a). Even so, EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.2, page 11. The text in the second paragraph states, “Only longitudinal dispersion will be considered for this discussion because of the geometry of the transport pathway.” The applicant should provide the longitudinal dispersivity value used in the model, as well as any studies (e.g., grid convergence) or calculations that demonstrate the grid spacings are sufficiently small.

The applicant should also provide the mass-balance information for both the flow and contaminant transport from the model simulations.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

10.0 REVIEW OF APPENDIX 10 – “EROSION MODELING FOR THE CLIVE PA,” MAY 28, 2011

10.1 GENERAL COMMENTS

Comment 1. Below-Grade Disposal: Please provide a discussion of how the performance of the system may change if the top of the cover system was set at or below natural grade, particularly with respect to gully formation, radon releases, and the ability to meet groundwater GWPL’s.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 2. Gully Screening Model: As stated in Section 4.0, “The purpose of the initial gully model in the Clive PA model is to determine whether gullies and fans are significant contributors to dose and whether a more sophisticated erosion model is needed. A simple screening-type gully model was developed with the advice of Dr. Willgoose.” Similarly, the Final Report on the Clive DU PA states in Section 4.1.2.9, “The gully model is a simplistic model of gully erosion and landscape evolution. For example, the model assumes that 1) a gully forms instantly and doesn’t change with time, 2) that between 1 and 20 gullies only are allowed to form, and 3) that gullies do not interact with other model processes such as biotic transport (e.g., no plants grow in a gully). This stylized model was used to provide a basis for discussion of whether or not gully

formation is an important consideration in this waste disposal system, and to evaluate the consequences of human activities that inadvertently cause doses to future humans.” In Section 6.2.1 of the Final Report, it is shown that the presence of gullies increases the peak mean dose to a rancher from 4.37 to 20.9 mrem/y TEDE, and is due to thinning of the cover layers (cap and fill materials) and possible direct exposure of the DU waste. Based on this information, it would appear that gully formation is an important consideration in evaluating the waste disposal system. The report should explain why a more sophisticated erosion model is not needed, including how the assumed 1 to 20 gullies can be reconciled with the actual number of gullies expected to form during a minimum of 10,000 years. If a more sophisticated erosion model is developed, the report needs to describe the new model, including how it will be implemented in the PA and its effect on the peak mean dose to a rancher or other relevant scenarios.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

10.2 SPECIFIC COMMENTS

Section 4, page 5. The text in the first bullet states, “Gullies are assumed to form instantaneously, from the time of loss of institutional control.” In Section 5.1.2 of the Final Report (page 43), the text indicates that the institutional control period of 100 years is assumed for the dose calculations. The document should indicate when gullies are instantaneously formed for the PA.

EnergySolutions’ Response: EnergySolutions agrees that the intent of the cited statement from Section 5.1.2 of Appendix A is that gullies are instantaneously formed following the loss of institutional control.

Section 4, page 5. Please provide additional rationale for excluding potentially important biological processes in considering gully formation. For instance, burrowing of animals within gullies since presumably the gullies could be penetrated more readily in areas of rip rap erosion.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 6.2, page 17. The second sentence in the first paragraph states, “In the current Clive PA model, waste is buried only under the top slope, so the quantity of concern is the distance from the ridge that the gully gets into the waste.” The text should clarify whether this is the case for all three burial scenarios.

EnergySolutions’ Response: EnergySolutions agrees that the intent of the cited statement from Section 6.2 of Appendix 10 of Appendix A is that the depleted uranium Performance Assessment models burial of depleted uranium only beneath the top slopes for all three depth scenarios summarized in Section 2.4 of the main report.

11.0 REVIEW OF APPENDIX 11 – “DOSE ASSESSMENT FOR THE CLIVE DU PA,” MAY 28, 2011

11.2 SPECIFIC COMMENTS

Section 3.1, page 10. To be consistent with other sections of the PA, “2.5 million years” should be changed to “2.1 million years.”

EnergySolutions’ Response: EnergySolutions agrees that the intent of the cited statement from Section 3.1 of Appendix 11 of Appendix A is 2.1 million years. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.1, page 11. The document should provide a basis for the statement that “the assumption that future land use and receptors will be similar to today’s is likely conservative (i.e., protective).”

EnergySolutions’ Response: EnergySolutions recognizes the Division’s request for expanded discussion in Section 3.1 of Appendix 11 of Appendix A. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.2, pages 12 and 13. The text states that “screening-level” calculations will be performed to determine what quantity of plant material and volume of water would need to be consumed to exceed the radiation dose performance objective. Provide a specific cross-reference to the results of these “screening-level” calculations.

EnergySolutions’ Response: Screening level calculations addressing plant and water ingestion are discussed in Section 5.1.5, 5.1.6, and 5.4.5 and Appendices 1, 9, and 11 of Appendix A.

Section 3.3.1, page 16; Section 3.3.3, page 18. A de minimis dose value is developed based on EPA’s de minimis risk level and dose equivalence. Given that the Energy Policy Act of 1992 contained provisions revoking the NRC’s 1986 and 1990 Below Regulatory Concern Policy Statements, the applicant should provide the justification for proposing a de minimis (i.e., below regulatory concern) dose value.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.4.3, page 22. With regard to the dose conversion factors (DCFs), the text should clarify what is meant by the phrase “proof-of-principle uncertainty distributions.”

EnergySolutions’ Response: As is noted in Section 3.4.3 of Appendix 11 of Appendix A, the term “proof-of-principle uncertainty distributions” related to evaluation of the appropriateness of use of the distribution and uncertainties of Kocher’s radiation effectiveness factors to the depleted uranium Performance Assessment’s use of dose conversion factors. In doing so, it was assumed

that for the carcinogenic effects of radiation, that the radiation effectiveness factors are equivalent to the relative biological effectiveness, which is in turn equivalent to radiation weighting factors. Since the radiation effectiveness factors account for the fact that some types of radioactive decay result in more biological damage than others.

In the depleted uranium Performance Assessment, the radiation-type specific radiation effectiveness factors were used as modifying distributions to the dose conversion factor point estimates presented in NRC's FGR 13. As the radiation effectiveness factors are radiation type specific, they are generally applicable to the predominant radiation characteristics of the particular radionuclide of concern. As part of the analysis reported in Appendix A, the validity of this assumption is confirmed. EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.4.5, page 25. With regard to the uranium toxicity analysis, the text should clarify what is meant by the phrase "a proof-of-principle exercise."

EnergySolutions' Response: As is noted in Section 3.4.5 of Appendix 11 of Appendix A, the term "proof-of-principle exercise" relates to the potential non-radiation related toxicity of depleted uranium. Oral toxicity criteria for uranium are published by EPA in relation to the Superfund Program (EPA, 2011) and by EPA's Office of Water in relation to drinking water standards (EPA, 2000). However, since there is a five-fold difference between these criteria, both were employed in the depleted uranium Performance Assessment to determine the sensitivity of uranium health effect results to differences in these recommended toxicity criteria for uranium. As part of the analysis reported in Appendix A, the validity of this assumption is confirmed.

EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 3.4.5, page 25. Instead of simply referencing EPA documents, the PA needs to provide a brief description of the Superfund and drinking water uranium RfDs. For example, are the RfDs for soluble or insoluble uranium salts, or both? This appendix states that there is a five-fold difference between the two RfDs; a brief description of why there is this difference would be helpful. Also, what was the basis for assigning a 50/50 probability to each RfD? Why not simply assign 100% probability to the Superfund RfD, since it is the more recent, or 100% probability to the drinking water RfD, since it is the more limiting?

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 4.5, page 30. The text does not describe how "non-standard" receptors (e.g., teenagers, children, infants, pregnant women, Native Americans) were addressed. The text should address such non-standard receptors or explain why they do not need to be addressed.

EnergySolutions' Response: EnergySolutions recognizes the Division's request for expanded discussion in Section 4.5 of Appendix 11 of Appendix A. However, the comment does not

identify incompleteness. If requested, EnergySolutions will consider expanding the discussion of Section 4.5 of Appendix 11 of Appendix A as part of its responses to the Division's future Round 1 Interrogatories.

12.0 REVIEW OF APPENDIX 12 – “DECISION ANALYSIS METHODOLOGY FOR ASSESSING ALARA COLLECTIVE RADIATION DOSES AND RISKS,” MAY 30, 2011

12.2 SPECIFIC COMMENTS

Section 1, page 1. The third and fourth paragraphs refer to the “Exposure and Dose Documentation” white paper. The applicant should clarify which reference is meant; we assume it is the “Dose Assessment for the Clive DU PA” (May 28, 2011) white paper (Appendix 11). Please confirm or clarify.

EnergySolutions’ Response: The reference, as clarified above, is correct.

Section 1, page 1. The fourth paragraph refers to the ALARA regulation as “a second decision rule;” however, a first decision rule has not been identified.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 1, page 1; Section 2, page 2. In addition to the DOE and NRC documents listed in Section 1 and ICRP Publication 26 (ICRP 1977) discussed in Section 2, ICRP Publication 101b (ICRP 2006) provides a good description of the ALARA concept, including a history of its evolution. ICRP 101b describes ALARA as an “optimization” process. It should be ascertained that the information contained in this appendix is consistent with ICRP 2006.

EnergySolutions’ Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Section 2, page 3. As discussed in Section 3.1, General Comment 1 for the Final Report, the government has indicated that the use of discount factors other than the 3% and 7% may be necessary when intergenerational consequences are involved [see NUREG/BR-0058 (NRC 2004) and OMB Circular A-4 (OMB 2003)]. In addition, NUREG-1757 (NRC 2006) replaces NUREG-1727 (NRC 2000b), as stated in the abstract for NUREG-1757.

EnergySolutions’ Response EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

13.0 REVIEW OF APPENDIX 15 – SENSITIVITY ANALYSIS METHODS (“MACHINE LEARNING FOR SENSITIVITY ANALYSIS OF PROBABILISTIC ENVIRONMENTAL MODELS,” MAY 29, 2011)

13.1 GENERAL COMMENTS

Comment 1. Relevance to PA: The document, *Machine Learning for Sensitivity Analysis of Probabilistic Environmental Models (May 29, 2011)*, is a generic presentation describing various approaches to sensitivity analyses. As such, it is not a useful document by itself to support the sensitivity analyses described in Section 6.0 of the Final Report. The sensitivity analysis methods report should be expanded to discuss the sensitivity index and the partial dependence plots for specific parameters modeled in the DU PA.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

14.0 REVIEW OF APPENDIX 16 – “MODEL PARAMETERS FOR THE CLIVE DU PA MODEL VERSION 1.0,” MAY 28, 2011

14.2 SPECIFIC COMMENTS

Section 3.2, Table 5, page 5. The comment associated with Dose _Simulation _Duration states, “User can set this value, up to 10,000 yr, per UAC R313-28-8.” UAC R313-25-8(5)(a) states that “the compliance period shall be a minimum of 10,000 years” (emphasis added), not a maximum of 10,000 years.

EnergySolutions' Response: The regulatory basis for use of a 10,000 year Period of Performance is addressed in Section 1.3 of the main report.

15.0 SECTION 4.1, FIGURE 1, PAGE 7. THE TEXT OF FIGURE 1 INDICATES THAT THE BRANCHING FRACTIONS WERE OBTAINED FROM “THE NUCLEAR WALLET CARDS (TULI, 2005).” THE REPORT SHOULD INCLUDE A REFERENCE SECTION, WITH A COMPLETE REFERENCE FOR TULI 2005. APPENDIX 17 – QUALITY ASSURANCE PROJECT PLAN

15.1 GENERAL COMMENTS

Comment 1. Missing Approvals: The signature page of Document No. 06245-001 available on the web is incomplete in that the indicated signatures are not provided and the signature page does not include approval by the State of Utah. The document should indicate that all necessary approvals have been obtained. This comment also applies to Appendices A, B, and C.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 2. Lack of Page Numbers: There no page numbers in the document. Page numbers should be added.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Comment 3. GoldSim Model Calibration: The only GoldSim model calibration appears to be that done to counteract numerical dispersion on air diffusion (Appendix 5, Section 9.4.3). Please provide a discussion of the role that model calibration has taken in substantiating that GoldSim adequately simulates the physical, chemical and biological site processes.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

15.2 SPECIFIC COMMENTS

Section 5.0, Table 2. Several scheduled completion dates are listed as TBD. Please indicate when the tasks with TBD dates were completed and that other scheduled tasks with specific completion dates have been completed.

EnergySolutions' Response EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

Appendix B, Section 2.6. Please provide the verification and benchmarking exercises that were designed to test the GoldSim abstractions against results obtained from process-level analytical and/or numerical models, including (but not limited to) all of the simulated fate and transport pathways, input/output links to external models (e.g., HELP, atmospheric modeling), probabilistic components and dose assessments.

EnergySolutions' Response: EnergySolutions does not consider this comment to be relevant to completeness. It will be addressed during the substantive review of the filing.

APPENDIX C

Responses to February 28, 2014 Round 1 Interrogatories



**RESPONSES TO 28 FEBRUARY 2014 – ROUND 1 INTERROGATORIES
UTAH LLRW DISPOSAL LICENSE RML UT 2300249
CONDITION 35 COMPLIANCE REPORT**

March 31, 2014

**For
Utah Division of Radiation Control
195 North 1950 West
Salt Lake City, UT 84114-4850**

**EnergySolutions, LLC
423 West 300 South, Suite 200
Salt Lake City, UT 84101**

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1. INTRODUCTION

EnergySolutions, headquartered in Salt Lake City, Utah is a worldwide leader in the safe recycling, processing and disposal of nuclear material, providing innovations and technologies to the U.S. Department of Energy (DOE), commercial utilities, and medical and research facilities. At its Clive Facility, located 75 highway miles west of Salt Lake City, EnergySolutions operates a commercial treatment, storage and disposal facility for Class A low-level radioactive waste and Class A low-level mixed waste.

Historically, EnergySolutions' authorization for disposal of depleted uranium (DU) was approved by the Utah Division of Radiation Control at a concentration of 110,000 pCi/g beginning with License amendment 2 of Utah Radioactive Material License UT2300249, (approved December 3, 1990). This concentration was later increased to the specific activity of depleted uranium; i.e., pure form; with approval of the Performance Assessment submitted in support of the October 22, 1998 License renewal (limiting the depleted uranium within a container to no greater than 370,000 pCi/g, upon receipt). Under this License authorization, approximately 18,400 Ci of depleted uranium were safely disposed at Clive between 1990 and 2010.

In 2010, the Utah Radiation Control Board initiated rulemaking to require a site-specific analysis before authorizing the disposal of additional large quantities of depleted uranium. This rulemaking also applies to 3,577 metric tons (5,408 drums) of uranium trioxide (DUO₃) waste received by EnergySolutions from the Savannah River Site (SRS) in December 2009. In compliance with the depleted uranium Performance Assessment prerequisite, EnergySolutions is temporarily holding these drums in storage (awaiting Director approval of this depleted uranium Performance Assessment). In the future, EnergySolutions is also considering disposal of significant quantities of depleted uranium from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky.

As is illustrated in Figure 1-1, EnergySolutions is evaluating a new Federal Cell, using an evapotranspirative cover design equivalent to that under consideration by the Division for the Class A West Embankment, as the ultimate destination for significant quantities of depleted uranium. As initially submitted in 2009, the Federal Cell was named the "Class A South" cell, with a revised application and completeness review response package dated June 9, 2009 (EnergySolutions, 2009). EnergySolutions' records show that the Division indicated interrogatories on this design were under preparation, but not received prior to its withdrawal on May 2, 2011. The former Class A South cell included a clay isolation barrier as well as a proposed system for monitoring groundwater beneath this barrier; in order to differentiate the source of any potential groundwater contamination as being from Class A or 11e.(2) wastes. The former Class A South cell design was subjected to these additional buffer zone and monitoring requirements due to long-term stewardship being split between the State of Utah and DOE. The Federal Cell will be entirely within DOE stewardship; therefore, the additional requirements will not apply.



Figure 1-1, EnergySolutions' Proposed Federal Cell Location



On June 1, 2011, (in compliance with Condition 35.B of its Radioactive Material License UT2300249), EnergySolutions submitted to the Division the Report, “*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*,” documenting the depleted uranium Performance Assessment. In response, EnergySolutions received on October 25, 2013 from the Utah Department of Environmental Quality “*Task 1: Preliminary Completeness Review*.” Following examination of the Preliminary Completeness Review, EnergySolutions submitted revision 1 of its depleted uranium Performance Assessment Report titled, “*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*,” (EnergySolutions, 2013a).

On February 28, 2014, EnergySolutions received Round 1 Interrogatories from the Division, requesting clarification and additional information to support the Division’s continued review of EnergySolutions’ depleted uranium Performance Assessment. As a result of ongoing research EnergySolutions has conducted regarding cover design and in review of the Round 1 Interrogatories, EnergySolutions has chosen to revise the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. As a result, EnergySolutions is revising its depleted uranium Performance Assessment GoldSim model, accordingly. In parallel to constructing the revised GoldSim model to address the performance of the evapotranspirative cover, EnergySolutions has prepared responses contained herein to the Round 1 Interrogatories of February 28, 2014.

In order to facilitate public access during the public review and comment period, EnergySolutions will provide the Division with a complete, self-contained Report with the final revised GoldSim model, responses to Preliminary Completeness Review, and responses to the Division’s other rounds of Interrogatories.

2. RESPONSES TO 28 FEBRUARY 2014 - ROUND 1 INTERROGATORIES

Responses to the Division’s Round 1 Interrogatories, requesting clarification and additional information to support the Division’s continued review of EnergySolutions’ depleted uranium Performance Assessment, are presented herein. As part of the review and response preparation for the Round 1 Interrogatories, EnergySolutions has revised the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. Refer to drawing series 14004, attached. In parallel to revising GoldSim model to address the performance of the evapotranspirative cover, EnergySolutions responds herein to the Round 1 Interrogatories of February 28, 2014.

1. INTERROGATORY CR R313-25-19-01/1: INTERGENERATIONAL CONSEQUENCES

Please follow the policy of the U.S. Nuclear Regulatory Commission (NRC) in determining dollar values per person-rem and discount rates, or explain why that policy would not apply.

EnergySolutions’ Response: Revised ALARA modeling is being performed that will include the NRC dollar per-person/rem value (NRC, 1995; NRC, 2004). Additionally, sensitivity to a range of reasonable discount rates is being explored as suggested in NRC (2004). The NRC (2004) guidance is being referenced in the Final Report and the text is being revised to discuss NRC policy on the subjects of dollar per-person/rem value and intergenerational consequences. A discussion of the intergenerational impacts will also be included.

2. INTERROGATORY CR R313-25-8(5)(A)-02/1: DEEP TIME

Provide further information on how the length of the deep time assessment (2.1 million years (My)) was determined.

EnergySolutions’ Response: Radioactive decay and ingrowth in a given decay chain is calculated using the Bateman equation,

$$N_i = \lambda_1 \lambda_2 \cdots \lambda_{i-1} N_{1(0)} \sum_{j=1}^i \frac{e^{-\lambda_j t}}{\prod_{k \neq j} (\lambda_k - \lambda_j)}$$

Where:

λ_i is the decay coefficient for each member i in the chain (where $\lambda = \ln(2)/T_{1/2}$, $T_{1/2}$ being the half-life) [T^{-1}],

t is time [T],

N_i is the abundance of each member i at time t , and

$N_{1(0)}$ is the abundance of the initial parent at $t = 0$.

The starting amount of the initial parent, U-238, is arbitrary for the purposes of determining secular equilibrium, since the time at which the abundance of progeny (decay products) stops increasing is being sought. This is the time at which all progeny are at maximum abundance, which is the time of interest for deep time modeling.

The information required to perform the Bateman equation calculations is simply the identification of members of the decay chain and the half-lives for each. These data are inputs to the GoldSim Clive DU PA Model, as documented in the \Materials container. The decay chains are illustrated in the container \Materials\DecayChains, with the uranium series shown here:

Short-lived members of the chain are not modeled for contaminant transport,

Uranium Series, simplified

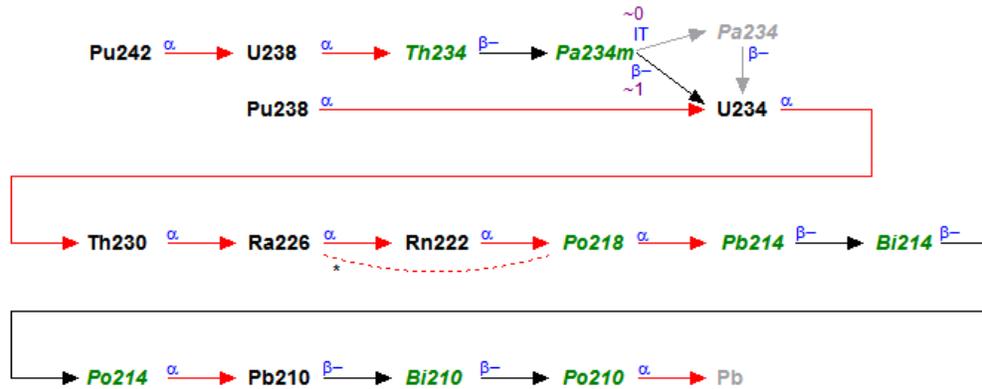


Figure 2-02/1, Uranium-238 Decay Series

however this matters not for the determination of the time of secular equilibrium. The half-lives and direct progeny for each member of the chain are implemented in the Species element, in the \Materials container, a screen shot of which is shown.

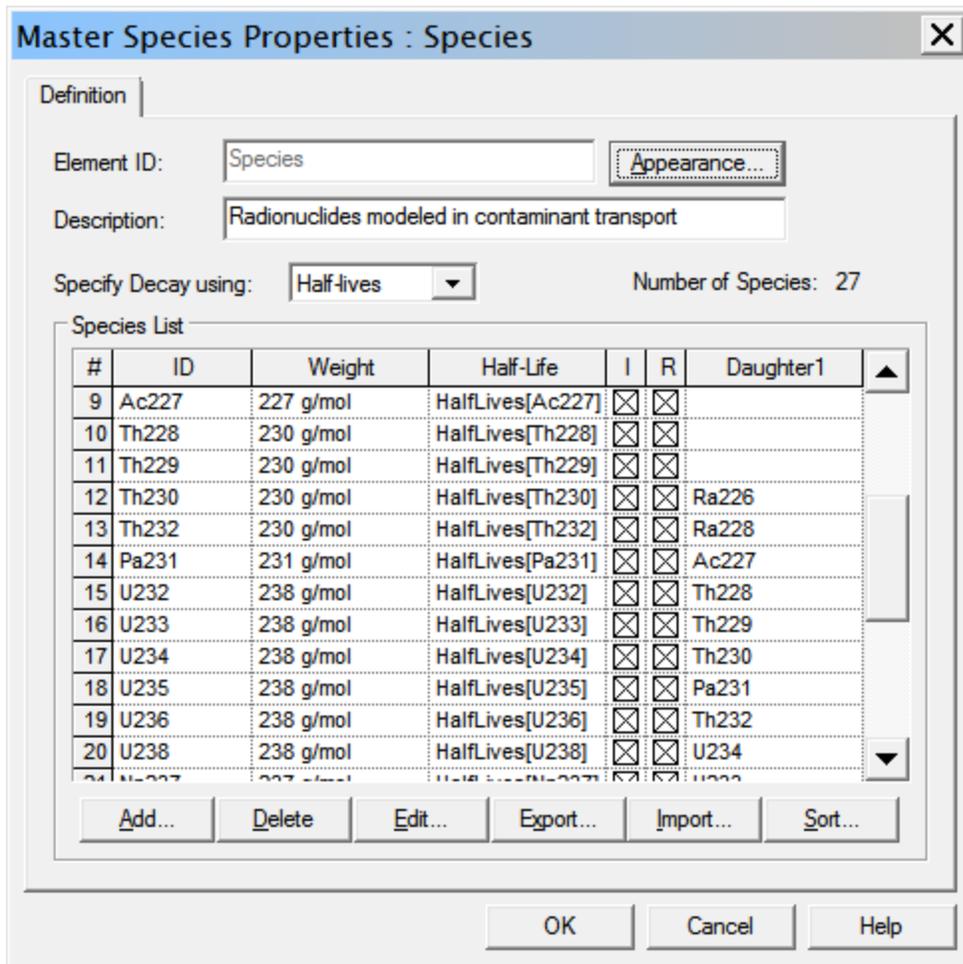


Figure 2-02/2, GoldSim \Material Screen Shot

The GoldSim software uses this information to solve the Bateman equation internally, thereby producing values for abundance of all members of the chain at any time. In order to illustrate this, a special calculation is executed in the Clive DU PA Model in the \DeepTimeScenarios container (see box on upper right part of the page in that container, labeled “A study of the decay and ingrowth from U-238”). Two result elements in that box show the abundance of all modeled radionuclides, having started with 1 g of U-238 in the “UnitInventoryU238” cell. One result element shows abundance in units of mass (g), and the other in units of activity (Ci). The latter is shown here and illustrates how all members of the chain gradually come into equilibrium with the U-238 parent. Therefore, they all achieve the same activity. Radon is the exception, due to how its E/P ratio is implemented in this model, but this has no implications for the determination of secular equilibrium.

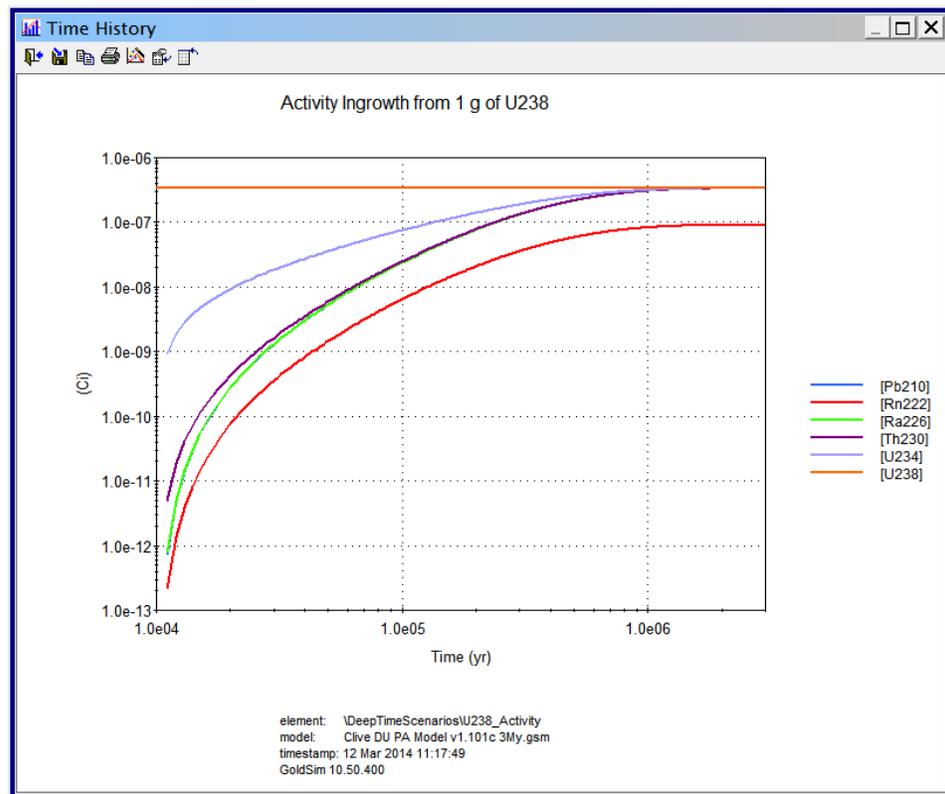


Figure 2-02/3, GoldSim \DeepTimeScenarios Screenshot

As can be seen in this graph of activity over time, secular equilibrium is reached at just over 2 My. At 2.1 My, the abundance of the last modeled member of the chain, Pb-210, is equal to that of ^{238}U , within less than one half of one percent.

While one could carry the calculation out further to achieve a greater degree of accuracy, there is no benefit in doing so for decision-making purposes. Note that for the purposes of illustration here, the model time has been extended to 3 My, as reflected in the Time axis.

The text in the FRV1 Executive Summary, page 5 is being changed as follows to reflect that the decay products reach secular equilibrium with the major parent, U-238, and further explanation is being provided along the lines presented above.

[FRV1, Executive Summary, page 5, third sentence:]

“Peak activity of the waste occurs when the progeny of the principal parent, ^{238}U (with a half-life that is approximately the age of the earth—over 4 billion years), reach secular equilibrium. This occurs at roughly 2.1 My from the time of isotopic separation, and the model evaluates the

potential future of the site in this context. At 2.1 My the abundance of the last modeled member of the chain, ^{210}Pb , is equal to that of ^{238}U , within less than one half of one percent. While one could carry the calculation out further to achieve a greater degree of accuracy, there is no benefit in doing so for decision-making purposes.”

3. INTERROGATORY CR R313-25-8(5)(A)-03/1: DEEP TIME – SEDIMENT AND LAKE CONCENTRATIONS

1. Explain why FRV1 does not provide any health and environmental concentration limits for future lake water or sediments for comparison.
2. Resolve discrepancies between the concentration values given in Table 14 and the concentrations shown in FRV1 Figure 13.
3. Provide the basis for presenting only the U-238 sediment concentrations (rather than the full U-238 decay series), as well as the basis for concluding that these concentrations are “small.”
4. Indicate why the soil criteria in 40 CFR Part 192 should not apply to the deep time assessment.

EnergySolutions’ Response:

1. The purpose of the deep time analysis is to provide a “*qualitative analysis with simulations*”. Although the intent of this requirement could be debated, calculating doses in deep time is neither required nor informative. ICRP states that “*doses and risks, as measures of health detriment, cannot be forecast with any certainty for periods beyond around several hundreds of years into the future*” (ICRP, 1998). Also, DOE (DOE 1997) has stated: “. . . *DOE recommends that quantitative assessments of collective dose to support ALARA efforts be limited to a few hundred years.*” And, the National Academy of Public Administration (NAPA), in a report for DOE (NAPA 1997), considered the “*near future*” to be 2 to 4 generations, and the “*distant future*” to be 500 to 1,000 years. Deep time analysis is interesting for gaining a sense of what might happen, but is not considered very useful for quantitative results, and based on clear guidance in the regulatory language. As noted in the interrogatory, health limits are not provided for future lake water or sediments, and this is because they are not considered useful. Environmental concentration limits are also health-based, so the same applies.
2. Discrepancies between the concentration values given in Table 14 and the concentrations shown in FRV1 Figure 13 are being resolved. The full resolution involves generation of revised Figures 12 and 13 that include the QA notes in the Figures’ footers, a clarification that both these figures show the 3-m waste burial option, and a modification of values in Tables 13 and 14 to coincide with the values in the Figures. This is being addressed with the results of the next version of the GoldSim PA model.

3. The Clive DU PA Model provides concentrations for sediments and water for all modeled radionuclides, including those in the uranium decay chains. These can all be accessed from the Control Panel dashboard, by choosing the button for “Deep Time Scenarios” results. The time history graphs of concentrations show all radionuclides, not just uranium. The next version of the report includes results for these other radionuclides. Also, clarification is being provided for why the uranium concentrations are considered “small” – statements about the concentrations is being clarified with comparison to current background concentrations.
4. It is not clear why 40 CFR 192 is applicable to this Performance Assessment. However, there are at least 2 related sections of 40 CFR 192 that are considered in this response.

§ 192.00 Applicability. This subpart applies to the control of residual radioactive material at designated processing or depository sites under section 108 of the Uranium Mill Tailings Radiation Control Act of 1978 (henceforth designated “the Act”), and to restoration of such sites following any use of subsurface minerals under section 104(h) of the Act.

§ 192.02 Standards. Control of residual radioactive materials and their listed constituents shall be designed 1 to: (a) Be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and, (b) Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not: (1) Exceed an average 2 release rate of 20 picocuries per square meter per second, or (2) Increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter. (c) Provide reasonable assurance of conformance with the following groundwater protection provisions:

Section 192.02 indicates the applicability of 40 CFR 192, which seems to suggest it is not applicable to the DU waste, and Section 192.02 indicates that effectiveness is limited to 1,000 years. In which case, the soil criteria of 40 CRF 192 do not seem to be applicable to deep time assessment, or to the DU PA more generally.

4. INTERROGATORY CR R313-25-8(4)-04/1: REFERENCES

Ensure that links to references online are working at the time of submittal and that they do not bring users to sites that require entry of a username and passcode.

EnergySolutions’ Response: As the current documents are now nearly three years old and numerous comments have been made that will require document revision,

all online reference links in the Final Report and its appendices will be checked again before submission of the next revised draft. Please note that many of the references in the documents are copyrighted journal articles or books. It is illegal to provide these documents to those who have not paid a fee, thus links were provided to abstracts or publishers of the copyrighted works.

5. INTERROGATORY CR R313-25-7(2)-05/1: RADON BARRIER

Explain why the model does not consider the effects of a compromised radon barrier.

EnergySolutions' Response: SCWA has conducted detailed analysis demonstrating negligible degradation of the Evapotranspirative Cover's radon barrier from animal borrow and root penetration (EnergySolutions, 2013d). As a result of their analysis, SWCA concluded,

“The proposed biointrusion barrier and capillary breaks in the [Evapotranspirative] cover have been demonstrated to effectively deter or limit penetration by deep rooting plants [native to Clive] into protective [clay] layers” (pg 45).

Similarly, SWCA's analysis concluded that the

“preferred [Evapotranspirative] cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively minimize or eliminate biointrusion by small mammals [native to Clive],” (pg. 30).

The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two orders of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

A compromised radon barrier need not be modeled at this time because the ET Cover design will limit infiltration down to the radon barrier. With no infiltration

down to that level, the naturalization of the radon barrier will have no effect on performance.

The topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. An expanded assessment of the radon barrier and assigned physical properties in models of cover performance must be carefully designed for applicability to the climate and hydrogeological setting of the Clive disposal facility.

Confidence in the assessment of radon barrier performance can be enhanced through sensitivity and uncertainty analyses of the models. Modeling the uncertainty in cover performance involves alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty). Enhanced investigations of these components of uncertainty require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling.

There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. To provide a more comprehensive sensitivity analysis for infiltration modeling, it should not be based on selective and non-systematic changes in physical properties of cover materials. Instead what is required would be refined modeling of closure cover performance using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into the probabilistic performance assessment model.

6. INTERROGATORY CR R313-25-7(2)-06/1: GULLY MODEL ASSUMPTIONS

Add a cross-reference in the Executive Summary to the discussion on gully model assumptions in the Erosion Modeling report.

EnergySolutions' Response: The editorial suggestion is noted and the Executive Summary is being revised.

7. INTERROGATORY CR R313-25-8(4)(B)-07/1: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS

Identify the intrusion barriers in the disposal cell design and explain why typical NRC intrusion scenarios usually underestimate the performance of the disposal system and under what unusual circumstances the performance of the facility/site will not be underestimated. Evaluate other suggested scenarios in addition to the usual NRC intrusion scenarios.

EnergySolutions' Response: The intruder barriers of EnergySolutions Federal Cell are the same as its licensed Low Level Radioactive Waste Disposal Facility, which are those defined in UAC R313-25-2 as,

“a sufficient depth of cover over the waste that inhibits contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in R313-25, or engineered structures that provide equivalent protection to the inadvertent intruder.”

UAC R313-25-20 requires assurance of protecting individuals from the consequences of inadvertent intrusion into disposed waste. An inadvertent intruder is someone who is exposed to waste unintentionally and without realizing it is there (after loss of institutional control). This is distinct from an intentional intruder, who might be interested in deliberately disturbing the site, or extracting materials from it, or who might be driven by curiosity or scientific interest.

“Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.” [UAC R313-25-20]

While an unlimited number of hypothetical inadvertent intruder scenarios could be developed, Division requirements limit such development to include, *“Identification of the known natural resources at the disposal site whose exploitation could result in inadvertent intrusion into the wastes after removal of active institutional control.”* UAC R313-25-7(8). Of similarly sentiment, NRC's Performance Assessment Working Group (PAWG) notes that,

“the overall intent [of exposure scenario development guidance] is to discourage excessive speculation about future events and the PAWG does not intend for analysts to model long-term transient or dynamic site conditions, or to assign probabilities to natural occurrences. . . The parameter ranges and model assumptions selected for the LLW performance assessment should be sufficient to capture the variability in natural conditions, processes, and events. . . Therefore, PAWG

recommends that new site conditions that may arise directly from significant changes to existing natural conditions, processes, and events do not need to be quantified in LLW performance assessment modeling . . . With respect to human behavior, it may be assumed that current local land-use practices and other human behaviors continue unchanged throughout the duration of the analysis. For instance, it is reasonable to assume that current local well-drilling techniques and/or water use practices will be followed at all times in the future.” (NUREG-1573).

NRC further supports the importance of selecting appropriate inadvertent intruder scenarios that reflect current practices and site environments in its guidance to Regulators reviewing performance assessments to,

“[1] verify that conceptual models for the biosphere include consistent and defensible assumptions based on regional practices and characteristics (i.e., conditions known to exist or expected to exist at the site or surrounding region); [2] verify that intermediate results (e.g., fluxes, travel times) are physically reasonable;. . . [3] evaluate the types of scenarios . . . considered in the intruder analysis and confirm that the scenarios considered are appropriate for the site; [4]verify that assumptions and parameters used in defining the exposed intruder, including location and behavior of the intruder, timing of the intrusion, and exposure pathways, are consistent with the current regional practices [emphasis added]; and [5] if a garden is assumed in the scenario [implying it is not always required], verify that the garden size is appropriate and consistent with regional practices” NRC (2007).

Traditional generic exposure scenarios evaluating potential inadvertent intruder doses (in compliance with UAC R313-25-20) are described in NRC’s draft Environmental Impact Statement supporting 10 CFR 61 (NRC 1981) and the Update of Part 61 Impacts Analysis Methodology (NRC 1986). The methodology described therein includes evaluation of exposure pathways within a group of four inadvertent intruder scenarios including intruder discovery, intruder drilling, intruder construction, and intruder agriculture. These inadvertent intrusion scenarios represent a potential series of events that are initiated by the successful completion of a water supply well. However, NRC further notes that,

“it would be unreasonable to expect the inadvertent intruder to initiate housing construction at a comparatively isolated location before assuring that water for home and garden use will be available. Thus, this scenario (intruder-driller) is assumed to precede the following three scenarios” (NRC, 1986).

The intruder-drilling scenario is assumed to be an initiating event for the intruder-construction and intruder-agriculture scenarios (NRC 1986, Section 4.1.1.1). This scenario assumes that waste is brought to the ground surface in a mixture with cover material, unsaturated zone material, and drilling mud and is then contained in a mud pit used by the driller. The driller (a separate individual from that in any subsequent exposure scenario) may be exposed by direct gamma radiation from the waste mixture in the mud pit (NRC, 1986). Attributes of this scenario such as the dimensions of the mud pit and depth of water above the cuttings are described in Section 4.2.1 of NRC (1986).

The intruder-discovery scenario described in Section 4.2.3 of NRC (1981) involves external exposure to discoverable wastes that are clearly distinguishable from natural materials. The dose assessment methodology described in NRC (1981) was updated in NUREG/CR-4370 (NRC, 1986). Exposure to the intruder-discoverer is assumed to be limited to the topmost waste layer, since the intruder “*would likely stop excavating before digging too deep into the rest of the waste*” (NRC 1986, Section 4.2.3). The intruder-discovery scenario for stable waste streams in the first 500 years after closure is assumed to preempt the intruder-agriculture scenario (and, presumably, the intruder-construction scenario) because construction and inhabitation of a home will not occur once the waste has been discovered and recognized (NRC 1986, Section 4.2.3).

The intruder-construction scenario involves direct intrusion into disposed wastes for activities associated with the construction of a house {(e.g., installing utilities, excavating basements, and similar activities [as described in Section 4.2.2 of NRC (1986)]}. However, because there is no historic evidence of prior residential construction at the Clive site, the extreme salinity of Clive’s soils, the non-potable groundwater, the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the inadvertent intruder-construction scenario is not considered “*reasonable*” for the Clive site nor included in this updated site-specific Performance Assessment.

The intruder-agriculture scenario assumes an individual is living in the home built under the intruder-construction scenario, and is also exposed from gardening activities involving the waste/soil mixture excavated during construction (NRC 1986, Section 4.2.4). As with the inadvertent intruder-construction scenario, the lack of historic evidence of prior residential agriculture at the Clive site, the extreme salinity of Clive’s soils, the non-potable groundwater, the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the inadvertent intruder-agriculture scenario is not considered “*reasonable*” for the Clive site nor included in this Report’s site-specific Performance Assessment.

As part of an unrelated investigation, NRC staff specifically asked the Division to “*provide further information on its position that the onsite residential and*

agricultural intruder pathways for the [EnergySolutions] site are unrealistic.” In response, Division staff:

“stated that onsite residential and/or farming scenarios at the [EnergySolutions] facility are unrealistic for several reasons. First, the site conditions of low precipitation (i.e., approximately 5-6 inches/year) and high evapotranspiration rates (i.e., approximately 40 - 50 inches/year). Also, there is a lack of suitable irrigation water . . . and the soil is extremely saline. Secondly, Tooele County has designated this part of the county as Heavy Industry and Hazardous Waste Zones which bars any such residential and/or farming uses” (NRC, 2005).

The Division’s judgment of the unrealistic nature of farming or residential intruder scenarios is consistent with the requirements of UAC R313-25-7(8).

As a groundwater quality standard, non-degradation has been demonstrated using groundwater protection levels based on a potential dose of 4 mrem/year. In establishing this standard, certain assumptions were made regarding human consumption. For highly saline sources of groundwater, the consideration of untreated consumption in evaluating health protection determinations can be particularly critical and is consistent with the discretion described in NUREG-1573. Consequently, for performance assessment purposes, considering site-specific data regarding groundwater quality, uses, and reasonable receptor pathways is an appropriate approach and is consistent with prior and current performance assessment approvals for the facility.

A similar memorandum to Staff by the U.S. Nuclear Regulatory Commission encourages that *“the proposed rule should clearly indicate that the intruder assessment should be based on intrusion scenarios that are realistic and consistent with expected activities in and around the disposal site at the time of site closure.”* (SECY-13-075).

The Division’s clarifications are also consistent with NUREG-1573,

“Consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior [beyond what is currently evident at the site] should be limited so as to avoid unnecessary speculation.” (NUREG-1573, October 2000, p. 3-10).

Archeological surveys of the Clive area performed in 1981 support this determination, (EnergySolutions, 2013c). This survey found no evidence of long-term residential or agricultural resource sites. A similar cultural and archaeological resource survey was conducted in 2001 on a land adjacent south to Section 32 (EnergySolutions, 2013c). In addition to the new survey, Sagebrush’s

(2001) report also summarized five additional cultural resource inventories performed within a mile of the subject area, between the original 1981 and 2001 studies. In all surveys, Sagebrush reported no paleontological, prehistoric, or historic resources were discovered in the survey area. In fact, no evidence has been discovered that suggests the Clive facility has ever been inhabited or developed for agriculture by permanent residents in the past (probably due to unfavorable conditions for human habitation).

In compliance with UAC R313-25-20 and Division directive, EnergySolutions has included credible inadvertent intrusion scenarios in this Performance Assessment. However, since (1) Clive's groundwater is not potable and will not support a residence or agriculture, (2) the expense of treating Clive's groundwater with conventional technologies as well as low aquifer yield is preventing current industrial occupants from using such treatment; (3) Clive's geology holds no mineral resources of value, and (4) Clive's current practices and county-zoning limit use of the area to only ranching and periodic recreational uses, the Depleted Uranium Performance Assessment includes scenarios of inadvertent intrusion reflecting current conditions surrounding the site (as documented in Appendices 1 and 2). Therefore, incorporation of additional inadvertent intruder scenarios is unsupported.

8. INTERROGATORY CR R313-25-8(4)(A)-08/1: GROUNDWATER CONCENTRATION ENDPOINTS

Explain why six different models are considered for the dose and groundwater concentration endpoints rather than three.

EnergySolutions' Response: The six different dose and concentration endpoints referenced in the Executive Summary are:

- 1) depleted uranium waste below 3m of other material and no gullies modeled,
- 2) depleted uranium waste below 3m of other material and gullies modeled,
- 3) depleted uranium waste below 5m of other material and no gullies modeled,
- 4) depleted uranium waste below 5m of other material and gullies modeled,
- 5) depleted uranium waste below 10m of other material and no gullies modeled,
and
- 6) depleted uranium waste below 10m of other material and gullies modeled.

These six variations of the model were run to capture the differences between the disposal depths (top of waste at 3, 5, and 10 m bgs), as well as the presence or absence of gullies, again for the three disposal depths. This results in a matrix of disposal depths (3) times gully state (2), making 6 cases.

The text is being modified as follows to clarify this distinction:

[end of paragraph following numbered bullets on page 6 of the FRV1]

“Consequently, six different models are considered for the dose endpoints. Dose results for ranch workers are presented in Tables ES-1 (without gullies) and ES-2 (with gullies). Doses to ranch workers are more than an order of magnitude greater than doses to hunters and OHV enthusiasts. Groundwater results for 99Tc in Table ES-3, and are not affected by the presence or absence of gullies in the Clive DU PA Model v1.0.”

9. INTERROGATORY CR R313-25-19-09/1: DEFINITION OF ALARA

Change the citation for the definition of ALARA from 10 CFR 61.42 to 10 CFR 20.1003.

EnergySolutions’ Response: Section 1.3 of FRV1 is being revised as indicated. This change is being made in the final version of the report. The reference to 10 CFR 61.42 is being maintained for traceability from Utah code through 10 CFR 61 to the original NRC definition, and the text is being changed to reflect that the original ALARA definition is contained in 10 CFR 20.1003.

10. INTERROGATORY CR R313-22-32(2)-10/1: EFFECT OF BIOLOGICALS ON RADIONUCLIDE TRANSPORT

Provide support for the statement that the severity of the “...effect [of plants, ants, and burrowing mammals] on radionuclides transport might be small.”

EnergySolutions’ Response: The intent of this statement is to point out that the effects of biologically-induced transport would be expected to be less for deeply-buried waste than for shallower waste. This occurs because plant roots and animal burrows are most concentrated at the ground surface, and gradually lessen as a function of depth, therefore their influence in the realm of contaminant transport also decreases with depth. In the Clive DU PA Model v1.0 biotic effects are not linked to gully formation.

The text in FRV1 Section 4.1.2.8 is being modified as follows to clarify the concept that more deeply-buried waste is being subject to less biotically-induced contaminant transport than wastes that are buried closer to the surface.

[modified text for Section 4.1.2.8, p. 32 in FRV1]

4.1.2.8 Biologically-Induced Contaminant Transport

“Biological organisms play an important role in soil mixing processes, and therefore are potentially important mediators of transport of buried wastes from deeper layers to shallower layers or the soil surface. Three

broad categories are evaluated for their potential effect on the redistribution of radionuclides at the Clive facility: plants, ants, and burrowing mammals. The impact of these flora and fauna will be limited largely to the top several meters, as their potential influence as contaminant transport mechanisms is greater in the cover layers than in the underlying waste, although contaminant concentrations are lower in the cover layers. Details for all three categories can be found in the Biological Modeling white paper (Appendix 9)."

11. INTERROGATORY CR R313-25-20-11/1: INADVERTENT HUMAN INTRUDER

Ensure that the text correctly reflects the language of UAC R313-25-20.

EnergySolutions' Response: Section 4.1.2.10.1 of FRV1 is being revised as requested and Section 5.1.7 is being referenced to clarify the interpretation of the UAC R313-25-20 definition.

Please refer to Section 5.1.7 of the Final Report where the definition of IHI as specifically applied in the PA is described:

"Inadvertent intrusion is often used in terms of direct but inadvertent access to the waste (e.g. through well drilling or basement construction), for which the initiator is exposed. However, such direct activities are unlikely at this site. The types of activities here do not result in direct exposure to the waste by the initiator, but potentially to future receptors."

12. INTERROGATORY CR R313-25-20-12/1: SELECTION OF INTRUSION SCENARIOS

Address inadvertent human intruder exposure scenarios that are likely to result in the greatest doses to members of the public.

EnergySolutions' Response: As explained in the response to Interrogatory CR R313-25-8(4)(B)-07/1, likelihood of maximum dose is not a criterion for inadvertent intruder scenario selection within the Depleted Uranium Performance Assessment.

13. INTERROGATORY CR R313-25-7-13/1: REFERENCE FOR LONG-TERM CLIMATIC CYCLES

Provide a reference for the statement about the likelihood of long-term climatic cycles of 100 thousand years (ky).

EnergySolutions' Response: The following references are being included in the text to support the statement, "Given that long-term climatic cycles of 100 ky are considered very likely...."

Hays, J.D., J. Imbrie, and N.J. Shackleton, 1976, Variations in the Earth's orbit; Pacemaker of the Ice Ages, *Science*, Vol. 194, No. 4270, pp. 1121-1132. (see p. 1126.)

Shackleton, N.J., 2000, The 100,000-year Ice-Age cycle identified and found to lag temperature, carbon dioxide, and orbital eccentricity, *Science*, Vol. 289(5486), pp. 1897-1902.

14. INTERROGATORY CR R313-25-8(4)(D)-14/1: SEDIMENT MIXING

Clarify the statement "*probably leads to conservative results*" to indicate those cases in which conservative results would not be obtained.

EnergySolutions' Response: As described in *Deep Time Assessment for the Clive DU PA*, May 30, 2011, the sources of sediment from the formation and presence of lakes are sediments resulting from precipitation/biological processes and sediment that is mechanically and chemically eroded and transported; the majority of the lake sediment will originate from erosional processes during transgressive and regressive lake fluctuations near the elevation of the Clive site.

In the conceptual model for future lakes, the return of a large lake disperses the contents of the waste embankment through wave action. The model assumes that the waste is fully mixed with the accumulated sediment during each lake cycle (intermediate and deep lakes). This assumption is considered conservative because it leads to the highest concentrations of waste in the near-surface sediments in the first new lake with continual remixing of waste/sediment in successive lake cycles. Assuming burial of some fraction of the waste by future lake sediment would be a less conservative assumption.

The extent of mixing of previous sediment with new sediment is not understood, hence an assumption that the sediments completely mix is conservative, since it retains some of the waste near the surface rather than burying all of it under the successive cycles of lake sedimentation.

In addition, sediment mixing was associated here with lake cycles. However, the system is aggrading from windblown deposition. No credit was taken for covering the waste site with windblown deposition. Instead, an assumption was made that all forms of sedimentation would be fully mixed with the DU waste. This seems quite conservative considering the site will be covered by rounds of windblown deposition during non-lake periods, which is expected to be quite long for this current 100k-yr cycle. Recent literature indicates that the conditions are

not conducive for development of a lake at Clive in this cycle, in which case the site will be under windblown sediment before a lake comes back.

15. INTERROGATORY CR R317-6-6.3(Q)-15/1: URANIUM CHEMICAL TOXICITY

Provide the spatial compliance points for uranium chemical toxicity.

EnergySolutions' Response: Ingestion of groundwater at the Clive site is not identified as a potential exposure pathway, so dose and risk from uranium toxicity are not evaluated for this pathway, and there are no GW compliance points for uranium toxicity. In addition, naturally occurring uranium concentration in shallow groundwater exceed EPA MCLs with or without the disposal of DU.

16. INTERROGATORY CR R313-25-8(4)(A)-16/1: RADON PRODUCTION AND BURROWING ANIMALS

Discuss the relationship between burrowing animals in the cover system and the radon escape/production ratio, if any. Provide the values used in the Conceptual Site Model with regard to the waste form, porosity, and surface area and escape/production ratios for both the Savannah River Site (SRS) and gaseous diffusion plant (GDP) waste sources of DU.

EnergySolutions' Response: There is no relationship between the radon E/P ratio and animal burrowing. The E/P ratio defines the fraction of radon (Rn-222) produced by alpha decay of Ra-226 that “escapes” from a solid form (e.g. a crystalline matrix) into a location where the radon can freely migrate away. This would be into interstitial air or water adjacent to the solid in which the ²²⁶Ra was present. This has no relationship to the distance from waste to the ground surface, as it represents phenomena on the scale of millimeters.

The input distribution used for the E/P ratio is defined in the Clive DU PA Model v1.0 element \Processes\AirTransport\EPRatio_Radon, and is tabulated in the Model Parameters document (Clive PA Model Parameters.pdf), Table 5.1, p. 18. This E/P ratio distribution is used for all materials in the model.

17. INTERROGATORY CR R317-6-6.3(Q)-17/1: URANIUM PARENTS

Clarify the reference to “*uranium parents.*”

EnergySolutions' Response: Uranium hazard quotient is tied directly to uranium, and no other radionuclides except parent nuclides which decay to uranium will influence this endpoint.

Only parents of uranium could affect the concentrations of uranium. The presence of uranium progeny and other radionuclides not related to uranium is irrelevant. The text is being modified as follows to clarify this.

[Section 6.3.2, page 71, second paragraph, first sentence:]

“The uranium hazard quotient is tied directly to uranium, and no other radionuclides except parents of U, including Am, Pu, and Np, which occur only in relatively insignificant quantities, could influence this endpoint.”

18. INTERROGATORY CR R313-25-8(5)(A)-18/1: SEDIMENT ACCUMULATION

Resolve the discrepancy between the values for sediment accumulation cited in FRV1 and the Deep Time Assessment report.

EnergySolutions’ Response: There is no discrepancy, but further clarification is being made.

The sedimentation rate of 17 meters per 100 ky discussed in FRV1, Section 6.5, page 78 refers to the rate of total sediment accumulation which includes both aerial deposition and lake sedimentation. The sedimentation rate of 120 millimeters/ky (12 meters per 100 ky) discussed in Section 6.3, page 24 of the Deep Time Assessment report refers to the sedimentation rate for deep lakes only. The text is being revised to provide clarification.

Note that the sedimentation rates for aerial deposition were not used in the model prior to the formation of the first intermediate or deep lake; instead an assumption was made that the next lake would destroy the disposal mound. See the responses to Interrogatories 129 and 131 for a discussion of uncertainty in lake erosion and the use of analog studies in the Lake Bonneville basin to constrain the depth of lake erosion.

However, recent research suggests that it is unlikely that a lake will inundate Clive in the current 100ky glacial cycle. The higher levels of CO₂ in the atmosphere coupled with the expected insolation levels make it very unlikely that a large lake can form (see response to Interrogatory # 123). Aeolian sedimentation rates at Clive are expected to be between 0.1 and 3 mm/yr during the current inter-pluvial period based on analogue measurements at dry pluvial lake sites throughout the world and in the arid SW United States. Based on these data, the total thickness of aeolian deposits could be 5 m or greater if the current inter-glacial lasts for 50 ky; the embankment could be completely covered if the first lake does not occur for 150 ka, which would be the case if there is no large lake in the next glacial cycle. The conservative assumption of complete erosion of the embankment with mixing of DU inventory becomes unlikely given the

combination of partial to complete burial of the Clive site by aeolian deposition and more realistic assumptions of lake erosion.

Note that the historical record provided in the subject report (FRV1) indicates that not all glacial cycles produce large lakes. Given current conditions, it seems reasonable that a large lake will not occur in this glacial cycle.

The deep time model is being updated to address sediment mixing, and further research is being performed to quantify aeolian deposition rates to better support the deep time modeling.

19. INTERROGATORY CR R313-25-8(5)(A)-19/1: REFERENCE FOR SEDIMENT CORE RECORDS

Provide a reference from technical peer-reviewed literature for the sediment core records.

EnergySolutions' Response: As is addressed in detail in Sections 3.1 through 3.3 of Appendix 13, Deep Time Assessment – references to the evaluation of sediment cores can be found in:

- Oviatt, C. G., Thompson, R. S., Kauffman, D. S., Bright, J., and R. M. Forester, 1999. Reinterpretation of the Burmester core, Bonneville Basin, Utah. *Quaternary Research*, 52: 180-184.

Evidence of significant mixing of sediment is seen in sediment core records and an analysis of a pit wall at the Clive site. Sediment core evidence can be found in an analysis of the Burmester core (Eardley et al., 1973, and, Oviatt et al., 1999) and the Knolls core (Appendix B of the Deep Time Assessment Report; C.G. Oviatt, unpublished data). The pit wall analysis can be found in Appendix B of the Deep Time Assessment Report (C.G. Oviatt, unpublished data). Neither the pit wall nor the Knolls core data have been published previously.

20. INTERROGATORY CR R317-6-2.1-20/1: GROUNDWATER CONCENTRATIONS

Explain why groundwater concentrations are not identical with and without the formation of gullies in the cover system.

EnergySolutions' Response: As is noted in Section 7.1 of Appendix A of the Report, “*once gullies are involved, the doses increase (groundwater concentrations do not change noticeably).*” Since proximity to waste dominates projected doses, the thinning of the cover due to gullies and the possibility of bringing waste to the surface increases the resulting doses. Additionally, the addition of gullies also results in local changes to the cover system. However,

when modeled across the entire Federal Cell cover, minor local changes in infiltration result in extremely minor variations in point-of-compliance groundwater concentrations.

The groundwater concentrations are not related to the presence/absence of gullies in the Clive DU PA Model v1.0. The text is being modified as follows for clarity.

[Section 7.1, p. 83, fourth paragraph of section, first sentence:]

“Once gullies are involved, the doses increase (groundwater concentrations do not change).”

21. INTERROGATORY CR R313-25-8(4)(D)-21/1: INFILTRATION RATES

Explain why infiltration rates may be overestimated.

EnergySolutions’ Response: This discussion is already included in Section 4.1.2.4.1 where it states the following:

“Comparisons of HELP modeling results with results from mechanistic unsaturated zone modeling programs such as UNSAT-H and HYDRUS at arid and semi-arid sites suggest that the HELP model will generally overestimate the vertical flow rates through waste cell covers (Meyer et al. 1996, Khire et al. 1997, Albright et al. 2002). These model comparisons indicate that the vertical flow rates through the CAS cell calculated using the HELP model are likely to be overestimated in the PA Model.”

Text on page 85 is being changed. Original text: *“Infiltration rates might be overestimated, and 99Tc inventory concentrations might be overestimated.”* New text: *“Infiltration rates might be overestimated (refer to Section 4.1.2.4.1), and 99Tc inventory concentrations might be overestimated.”*

22. INTERROGATORY CR R313-25-7-22/1: DEFINITION OF FEPS

Clarify the distinction between *“features, events, and processes”* (FEPS) and *“technical performance objectives.”*

EnergySolutions’ Response: The list in Section 4.1.1 is intended to be a list of objectives, not FEPS. These objectives were erroneously referred to as FEPS in the text. The text *“The types of FEPS mentioned in 10 CFR 61 include:”* is being revised to *“The types of objectives mentioned in 10 CFR 61 include:”* Further, the bullet item *“releases of radionuclides via pathways in air, water, surface water, plant uptake, or exhumation by burrowing animals,”* is being revised to *“limitation of releases of radionuclides via pathways in air, water, surface water, plant uptake, or exhumation by burrowing animals,”*.

The list in Section 4.1.2 was derived from Utah Administrative Code (UAC) Rules 313-25-8 and provides a summary of the performance objectives of R313-25. For clarification the text in Section 4.1.2, “*Notable technical performance objectives of near-surface disposal sites established of UAC Rule R313-25 include:*” is being revised to “*Notable performance objectives of near-surface disposal sites established of UAC Rule R313-25 include:*”.

23. INTERROGATORY CR R313-25-7(2)-23/1: CANISTER DEGRADATION AND CORROSION

Provide a specific cross-reference to the evaluation of canister degradation and corrosion in the Conceptual Site Model.

EnergySolutions’ Response: Although canister degradation and corrosion were identified as applicable FEPs, the Clive DU PA Model takes no credit for either. Instead, it is assumed that waste packages, including the 48 Y DU cylinders, provide no containment of the DU waste, and that it is all immediately available for environmental transport. This is discussed in Section 8.1 of the Conceptual Site Model Report. A cross-reference is being provided back to the FEP Analysis report in the final version.

24. INTERROGATORY CR R313-15-101(1)-24/1: UTAH REGULATIONS

Frame the discussion in the context of the governing Utah rule and correct errors in quoting Utah rules.

EnergySolutions’ Response: Governing Utah rules (i.e., UAC R313-25-8(5)(a)) are being cited in addition to NRC rules in sections 1, 1.3, and 4.2.1 of the Conceptual Site Model and these corrections are also being made in Section 1.3 of FRV1.

25. INTERROGATORY CR R313-25-7(9)-25/1: DISPOSITION OF CONTAMINANTS IN UF₆

Provide a reference for the discussion of the results occurring when contaminated uranium hexafluoride (UF₆) is introduced to the cascade.

EnergySolutions’ Response: The text is being changed as follows to reflect that only some of the contaminants end up in the U-238 tails. This is clearly the case, as radiochemical analysis has identified their presence in the DUF₆ (Hightower et al. 2000). The cause of their presence in the DUF₆ is not particularly relevant. What is relevant is that it is found there.

[section 6, page 22, last sentence (before section 6.1):]

“If uranium hexafluoride derived from irradiated reactor returns is introduced to the cascade, some of the associated fission products and actinides migrate to the depleted end of the cascade, with the U-238. Some contaminants also remain fixed to the inside walls of the DU feed cylinders, which are reused for collecting tails. These “heels” will remain in the cylinders through the process of deconversion, since they are again reused for collecting the U₃O₈ product.”

26. INTERROGATORY CR R313-25-8(4)(A)-26/1: RADON DIFFUSION IN THE UNSATURATED ZONE

Clarify whether diffusion of radon in the air phase in the unsaturated zone is included in the PA model. If it is not, justify why its omission is protective of human health and the environment. Also, describe and justify what site-specific investigation was performed at Clive to determine the applicable air phase tortuosity model.

EnergySolutions’ Response: The text in Section 6.6, page 26, of the Conceptual Site Model white paper is being modified as shown below to clarify that the transport of radon in the saturated and in the unsaturated zone from the waste to the ground surface is included in the PA model, resolving the apparent inconsistency.

[section 6.6, second sentence, second paragraph:]

“The transport of radon in the saturated zone and in the unsaturated zone from the waste to the ground surface is included in the PA model.”

No site-specific investigation of air phase tortuosity was performed, since no laboratory is offering to conduct radon diffusion measurements since the shut-down of Kirk Nielson’s lab (personal communication, Kirk Nielson to John Tauxe). The analysis is therefore dependent on models proposed in the literature.

27. INTERROGATORY CR R313-25-8(4)(A)-27/1: DIFFUSION PATHWAY MODELING

Clarify how the PA model accounts for the impact of diffusion pathways.

EnergySolutions’ Response: Indeed the Clive DU PA Model v1.0 does not model the effects of cracks, fissures, animal burrows, and plant roots on diffusive contaminant transport. The text is being modified as follows to clarify this.

[Conceptual Site Model report , Section 7.1.3.1, page 28, first paragraph:]

“Contaminants released from the waste (or generated by decay of parents in any location) may be transported via the air pathway by migration of gaseous species through soil pore space. Over time, cracks, fissures, animal burrows, and plant roots can also provide preferential pathways that reduce the effectiveness of the engineered barrier. These effects are difficult to quantify and are not modeled in the Clive DU PA Model v1.0. Efforts at quantification could be included as part of future cover modeling as part of PA maintenance.”

28. INTERROGATORY CR R313-25-8(4)(A)-28/1: BIOTURBATION EFFECTS AND CONSEQUENCES

Provide references to support the statement that bioturbation and homogenization of the radon barriers will probably occur very slowly relative to the 10,000-year time frame for the PA, and address other effects and consequences of biointrusion and bioturbation.

EnergySolutions’ Response: Detailed analysis conducted by SCWA demonstrating negligible degradation of the Evapotranspirative Cover’s radon barrier from animal borrow and root penetration has previously been conducted (Appendix C of *EnergySolutions*, 2013d). As a result of their analysis, SWCA concluded,

“The proposed biointrusion barrier and capillary breaks in the [Evapotranspirative] cover have been demonstrated to effectively deter or limit penetration by deep rooting plants [native to Clive] into protective [clay] layers” (pg 45).

Similarly, SWCA’s analysis concluded that the

“preferred [Evapotranspirative] cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively minimize or eliminate biointrusion by small mammals [native to Clive],” (pg. 30).

The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (*EnergySolutions*, 2014) for the ET cover design. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two order of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

Text in the Compliance Report will be revised to remove reference to jackrabbits in the discussion of burrowing mammals. The current PA model evaluates mammals burrowing to a depth of 2 m based on the likely average vertical extent of multiple badger excavations (Kennedy et. al, 1985). The distribution of mammal burrow density used in the current PA model is based on actual burrow survey data collected by SWCA in each plot. The modeled distribution of excavated soil volumes is based on measurements of burrow mounds by SWCA in randomly selected ¼-hectare sections of each plot, and included 25 mouse/vole/rat burrows, 98 kangaroo rat burrows, and 1 badger burrow (Table 15 in the Biologically-Induced Transport Report).

Because of the scarcity of ground squirrel and badger burrows on site, all mammals were lumped into a single category for the purpose of developing distributions in the PA for mammal burrowing. As part of PA maintenance, the model will be updated with separate distributions for soil movement by small mammals (deer mice, kangaroo rats, and ground squirrels) which occur frequently on the site, and large mammals (badger, coyote, kit fox) which occur in much lower densities at Clive and the surrounding area. Because of the low frequency of large mammal burrows within the surveyed Clive plots, data collected by SWCA within the Clive plots is not sufficient to develop burrow volume and burrow density distributions for the larger mammal category. Therefore, these distributions will be based on review of literature for these species.

Hakonson (1986) found that rock armor layers are effective in preventing burrowing by mammals due to several factors, including the weight of the cobbles compared to the weight of the small mammals included in his evaluation, and the non-cohesiveness of the gravel which makes structural maintenance of the burrow problematic. Larger mammals such as badgers may be able to move the cobbles more easily than smaller mammals such as mice and kangaroo rats, but the structural instability of the burrows would remain, making the in-filled gravel and cobbles unsuitable for burrowing.

29. INTERROGATORY CR R313-25-8(5)(A)-29/1: LIMITATION TO CURRENT CONDITIONS OF SOCIETY AND THE ENVIRONMENT

Explain and justify why Bureau of Land Management (BLM) restrictions should be included in the inadvertent intruder analysis, given the likelihood that they will

change over the compliance period of the PA (i.e., 10,000 years). Explain why other future land uses and FEPs were omitted.

EnergySolutions' Response: As is outlined in Appendix 1, “*Clive Du Pa FEP Analysis*” those features, events, and processes not representative of conditions currently observable at the site were eliminated from the Performance Assessment, as unnecessarily speculative. As is reflected in U.S. NRC guidance to staff,

“Given the significant uncertainties inherent in these long timeframes [“the period from the end of the compliance period through 10,000 years”], and to ensure a reasonable analysis, this performance assessment should reflect changes in features, events, and processes of the natural environment such as climatology, geology, and geomorphology only if scientific information compelling such changes from the compliance period is available.” (NRC, SRM- SECY-2013-075, February 2014).

This is further echoed by NRC’s PAWG in NUREG-1573,

“The applicant should apply a current conditions philosophy to determine which pathways are to be evaluated. That is to say that current regional land use and other local conditions in place at the time of the analysis will strongly influence pathways that are considered to be significant.” (NREUG-1573).

Therefore, inclusion of a recreational scenario based on current BLM land management in the Depleted Uranium Performance Assessment is appropriate.

As a general principle, Performance Assessment modeling into the distant future requires projection of current conditions or knowledge. This has been a commonly accepted practice for Performance Assessment modeling for many years, and is the only way to avoid unnecessary speculation on the future.

Application of this basic approach addresses the need to project into the future based on current conditions, and implies that BLM restrictions should be considered for the ranching scenario, that scenarios such as seawater aquaculture are not current in this area (partly because the groundwater is much more saline than seawater), resource mining does not occur in the close vicinity of Clive but does occur in some of the hills that are not too distant, and there is no water resource management in the general area.

30. INTERROGATORY CR R313-25-8(5)(A)-30/1: INCLUSION OF SRS-2002 DATA IN THE SENSITIVITY ANALYSIS

Provide a cross-reference in the text to the results of DU waste characterization, including the SRS-2002 data (Beals et al. 2002), in the sensitivity analysis.

EnergySolutions' Response: The wording in the Waste Inventory white paper is being changed. The intention of these white papers is to provide information on the development of input distributions, and not to comment on the results of the modeling. Consequently, the sentence is being changed to acknowledge that the “*effect of the inclusion of these data will be tested during model evaluation and will be reported as part of the sensitivity analysis*”.

Note that no inventory distribution was identified as sensitive using the global sensitivity methods that were applied to the DU PA model. See response to Interrogatories #31, #32, #54 and #55 (and others).

31. INTERROGATORY CR R313-25-8(5)(A)-31/1: Tc-99 CONTENT IN THE WASTE AND INCLUSION IN THE SENSITIVITY ANALYSIS

Indicate whether (and where) the expectation that the concentration of Tc-99 will be a sensitive parameter was tested. Alternatively, explain and justify what other evidence is available that led to this conclusion. Perform additional characterization of the SRS waste proposed for disposal in terms of Tc-99 content and provide the results for agency review, or explain and justify why additional sampling and laboratory analysis are not needed.

EnergySolutions' Response: The cited language is being removed from the Waste Inventory white paper.

However, the Tc-99 inventory was included in the global sensitivity analysis and was not identified as a sensitive parameter (variable) for any endpoint of interest. This implies that other variables that are included in the assessment of dose to various receptors contain uncertainty that swamps the uncertainty effect from the inventory distribution. Further explanation is being provided in an updated sensitivity analysis results section or appendix to the main report. And, since the issue of inventory of Tc-99 is considered important here, further analysis is being performed to show how the dose results change as a function of changes in only the Tc-99 concentrations. In addition, the sampling performed in 2002 is documented in other SRS reports as consisting of a random selection of drums, from which samples were collected from the top of the material in the drums because the process by which the material was produced was always the same. The representativeness of the sampling of the drums is clear given random mixing of material in the drums during shipping and the random selection of drums for sampling by EnergySolutions.

Overall, considering the lack of sensitivity of the model results to the Tc-99 inventory, and the representativeness of the samples for the entire waste stream, no further characterization of the SRS waste is considered necessary from a technical perspective. Also see response to Interrogatory #48.

32. INTERROGATORY CR R313-25-8(4)(A)-32/1: EFFECT OF OTHER POTENTIAL CONTAMINANTS ON PA

State how the PA confirmed that other potential contaminants in the DU did not contribute significantly to doses and indicate whether they were included in the sensitivity analysis.

EnergySolutions' Response: Justification for the suite of isotopes, including distributions of depleted uranium and fission product concentrations from the Savannah River site that are included in the Depleted Uranium Performance Assessment is presented in Section 3.0 of Appendix 4, "*Radioactive Waste Inventory for the Clive DU PA.*" Each radionuclide's contribution to dose is computed as:

$$\begin{aligned} \text{Dose Contribution}_{\text{nuclide}} &= (\text{Concentration})_{\text{nuclide}} \\ &\times (\text{Media Volume Up-taken}) \\ &\times (\text{Dose Conversion Factor})_{\text{nuclide}} \end{aligned}$$

The sensitivity of dose contribution is linear to changes in isotopic concentration at the point of uptake or external exposure.

The sensitivity analysis performed on this model, the results of which are presented in the Report, is a global sensitivity analysis. All input parameters (variables) are changed simultaneously to determine which are most important predictors (most sensitive inputs) for the model outputs. The inventory terms have not shown to be sensitive parameters (variables) for any of the dose or risk outputs. This implies that the greater uncertainties that are important to the model output are in other parts of the model. This also implies that reduction of inventory uncertainty through collection of more information will have only a small effect on the results. In many ways this should not be surprising considering the amount of data available for the inventory in this case, compared to the amount of information available for, for example, the radon emanation factor, $K_{d,s}$, solubilities, or plant concentration ratios, etc. Further explanation of the approach taken to sensitivity analysis and model evaluation, and of the results is being presented in a new section or appendix to the Report.

33. INTERROGATORY CR R315-101-5.3(6)-33/1: CLARIFICATION OF THE PHRASE “PROOF-OF-PRINCIPLE EXERCISE” AND SENSITIVITY TO URANIUM ORAL REFERENCE DOSE FACTORS

Clarify the meaning of the phrase “*proof-of-principle exercise*” with regard to the uranium toxicity analysis and explain how the sensitivity of the PA to different uranium oral reference dose factors was determined.

EnergySolutions’ Response: The term “*proof of principle*” was applied to assessment of the effect of uncertainty in the uranium oral reference dose (RfDo) on chemical hazard results because this assessment was limited to consideration of the differences in the two RfDo values published by EPA. To improve clarity, the first sentence of paragraph two of Section 3.4.5 of the Final Report is being revised:

“A limited evaluation of the effect of uncertainty in the value of the uranium oral RfD on chemical hazard results is included in this assessment.”

Values for toxicity criteria such as the RfDo represent science policy decisions by EPA, and this assessment only evaluated the significance of selecting one or the other of these values. A broader assessment of the effect of uncertainty in the uranium RfDo would include uncertainties related to the policy assumptions, toxicological models, and dose-response data underlying both RfDo values.

The sensitivity of the mean uranium hazard quotient (HQ) for each scenario to the stochastic input distributions was evaluated in the same manner as sensitivity analyses for other PA endpoints. Methods applied for the sensitivity analyses are described in Appendix 15 (Sensitivity Analysis Methods) of the Final Report. In the case of the uranium RfDo, the input distribution was defined as an equal probability of either 0.0006 mg/kg-day or 0.003 mg/kg-day. As shown in Figures 10 and 11 of the Final Report, uncertainty in the values of inputs other than the RfDo accounted for approximately 94% (3m model; no gullies) and 92% (3m model; with gullies) of the variability in the mean ranch worker uranium HQ. The fivefold difference in the value of the RfDo, and uncertainty in all other stochastic inputs leading to the ranch worker HQ, contributed less than 6% and 8%, respectively, to the variability in the ranch worker HQ results.

34. INTERROGATORY CR R313-25-8(5)(A)-34/1: INTENT OF THE PA

Revise the text to correct the statement about the intent of the PA.

EnergySolutions’ Response: The intent of the Depleted Uranium Performance Assessment is to satisfy the requirements of UAC R313-25-8(5)(a) which states,

“ . . . a performance assessment [must] . . . demonstrate that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose.”

Additionally, the purpose of PA in general is manifold, as a decision tool for regulators and site operators, in addition to evaluating regulatory compliance. The purpose of the PA Model is likewise manifold, in that it informs the PA, and in effect represents the site. By experimenting with the PA Model, decisions regarding facility design and the acceptance of candidate waste streams can be informed, while simultaneously evaluating compliance. The text is being modified as follows to clarify the role of PA and PA modeling.

[FRV1 Section 2.1, p. 21, second paragraph following numbered list:]

“The role of PA in a regulatory context is often restricted to the narrow use of evaluating compliance. In the present case, the Clive DU PA Model v1.0 can be used to evaluate compliance—and inform a PA document that presents the argument that demonstrates compliance—with 10 CFR 61 Subpart C and the corresponding provisions of the Utah Administrative Code. In addition to that role, however, and because of the long-term nature of the analysis, the intent of the Model is not necessarily to estimate actual long-term human health impacts or risks from a closed facility. Rather, the purpose is to provide a robust analysis that can examine and identify the key elements and components of the site, the engineered system, and the environmental setting that could contribute to potential long-term impacts. Because of the time-scales of the analysis and the associated uncertainty in knowledge of characteristics of the site, the waste inventory, the engineered system and its potential to degrade over time, and changing environmental conditions, a critical part of the PA process is also the consideration of uncertainty and evaluation of model and parameter sensitivity in interpretation of PA modeling results.”

35. INTERROGATORY CR R313-25-19-35/1: REFERENCE FOR COST PER PERSON-REM

Add the reference for the cited NRC estimate of the cost per person-rem.

EnergySolutions’ Response: The text is being revised to reflect the appropriate reference, which is DOE:

DOE (US Department of Energy). 1997. Applying the ALARA Process for Radiation Protection of the Public and Environmental Compliance with 10 CFR

Part 834 and DOE 5400.5 ALARA Program Requirements, Volume 1 Discussion, DOE-STD-ALARA1draft. United States Department of Energy, Washington DC. April 1997.

This correct reference is provided on Page 39 in Section 4.1.2.11, and is being added to the first paragraph on page 16.

36. INTERROGATORY CR R313-25-8(4)(A)-36/1: ANT NEST EXTRAPOLATIONS

Specify the documents meant in the phrase “*reported in the literature*” with regard to ant nest characteristics.

EnergySolutions’ Response: As detailed in Section 4.3 and 4.4 of the Biological Transport white paper (Appendix 9 of the Clive PA Model Report), nest volume distributions and maximum nest depth for Pogonomyrmex ants at Clive are based on correlations with nest surface area calculated from data collected at NNSS and detailed in Neptune, 2006. The text is being revised to reference Neptune (2006) and refer the reader to Appendix 9 of the PA Model Report.

37. INTERROGATORY CR R313-25-8(5)(A)-37/1: DISTRIBUTION AVERAGING

Describe the means of capturing “*the appropriate systems-level effect*” from the use of differential equations and multiplicative terms in the PA and describe what specific steps, model inputs, and model assumptions were modified for this purpose.

EnergySolutions’ Response: References is being provided to the model inputs for which additional “care” was taken. The text is being revised to provide clarity in the intent here.

The underlying issue is that spatio-temporal scaling (upscaling) is necessary for the contaminant transport modeling performed for the Clive DU PA. The probabilistic simulations for the PA modeling involve randomly selecting values from all input distributions (outside of the exposure parameters), and then applying those values to the entire spatio-temporal domain of the model. Data that represent points in time and/or space cannot be used directly in this type of model. The data range and variance is too broad for the large spatial or temporal effects that are being modeled.

Upscaling in this context is a form of averaging to the time steps and spatial scale of a specific modeling application. This also means that the input distributions represent expected values and their uncertainty, which provides the basis for uncertainty analysis for the model.

However, averaging (expectation) is a linear operator, which means that the immediate response needs to be a linear function of the input. For example, animal burrow depth directly impacts movement of soil (and hence contaminants). Averaging over animal burrow depth data would result in narrowing the distribution of the data, and hence reducing the shallower and deeper effects. In this case the deeper effects matter the most.

Accordingly, the model is reformed by averaging the amount of burrow volume in each GoldSim cell for the depth interval of the model. Averaging is still performed, but at a different level. This discretized approach can also be adapted to continuous variables as necessary (using expectation of a function). The white papers in the appendices attached to the model describe the specific approaches taken for each input parameter (variable) in the model.

Consideration has been given during model development to appropriate upscaling for each parameter. Sometimes simple averaging is applied, but sometimes greater consideration needs to be given to the response, and adjustments are made to get closer to a linear response in the immediate dependent variable.

38. INTERROGATORY CR R313-25-8(5)(A)-38/1: FIGURES 5 AND 11 IN FRV1

Correct the caption for Figure 5 to reflect the nature of the plots and describe how Figure 5 demonstrates compliance with R313-25-8(5)(a).

EnergySolutions' Response: The caption for Figure 5 is being corrected to read as follows:

[FRV1, Figure 5, p.56]

Figure 5. Time history of ⁹⁹Tc well concentrations; 1,000 realizations shown.

The groundwater permit for the facility requires that groundwater concentrations be kept within specified concentration limits for 500 years, and specifies no concentration limits after 500 years.

The reason there is no groundwater drinking water exposure pathway shown on Figure 11 is that this exposure pathway is not credible. Groundwater salinities are such that the water is not potable, and it is not considered a drinking water source by the State of Utah. While water from the deeper aquifer near the mountain front is treated and used, water from the shallow, upper-unconfined aquifer is not used for anything, including dust suppression. As such, the lack of potable groundwater sources is exemplified by the fact that there is no current use of groundwater for this purpose, despite the presence of industry (including the Clive Site itself) and

a permanent resident at the rest area on Interstate 80. Drinking water requirements for persons at these and other locations in the basin are satisfied using water delivered by truck.

Since groundwater is not a source of drinking water, the drinking water exposure pathway does not exist, and groundwater concentrations are not evaluated for this purpose. There is therefore no need to evaluate groundwater concentrations for 10,000 years.

Also see response to Interrogatory #15.

39. INTERROGATORY CR R313-25-8(5)(A)-39/1: FIGURE 6 CAPTION

Correct the caption for Figure 6 to reflect the nature of the plots.

EnergySolutions' Response: The caption for Figure 6 is being corrected to read as follows:

[FRV1, Figure 6, p.57]

Figure 6. Time history of ⁹⁹Tc well concentrations: statistical summary of the 1,000 realizations shown in Figure 5.

40. INTERROGATORY CR R313-25-8(5)(A)-40/1: FIGURES 7, 8, 9, 10, AND 11

Label the axes for Figures 7, 8, 9, 10, and 11 and provide more discussion in the text on how to interpret the figures.

EnergySolutions' Response: The style of these plots is under revision, recognizing the challenge of presenting a lot of information in a small space. Specifically, axes labels are being added to the partial dependence plots. Furthermore, more text is also being included regarding the interpretation of these plots in the next version. In addition, the reader is being referred to section 2.4.2 of the Sensitivity Analysis white paper. More of the information from this section 2.4.2 is being included in the explanations presented in the revised Final Report.

41. INTERROGATORY CR R315-101-5.3(6)-41/1: TABLE 7

Resolve the discrepancy between the descriptive text and the title and content of Table 7.

EnergySolutions' Response: The text in the Final Report is being modified as follows:

[FVR1, Section 6.3.1, p. 68, first sentence:]

“The uranium hazard results are summarized in two tables: Table 7 shows the statistics for peak uranium hazard quotient for all receptors, without the gully screening calculations, for the cases of waste emplaced at 3 m, 5 m, and 10 m below the embankment cover.”

[FVR1, Section 6.3.1, p. 68, caption to Table 7:]

Table 7. Peak uranium hazard quotient, without consideration of gullies: statistical summary

The same issue exists with Table 8, so that is being changed as well.

[FVR1, Section 6.3.1, p. 68, caption to Table 8:]

Table 8. Peak uranium hazard quotient, with gully screening calculation: statistical summary

42. INTERROGATORY CR R315-101-5.3(6)-42/1: HAZARD QUOTIENT IN TABLES 7 AND 8

Resolve the discrepancy between the titles and content of Tables 7 and 8, in terms of whether they present the Hazard Quotient (HQ) or the Hazard Index (HI) and clarify what they signify for each receptor, the exposure pathways included and excluded, and the rationale for including or excluding them.

EnergySolutions’ Response: As defined in the Definitions Table in Chapter 8 of EPA (1989), an HI is “*the sum of more than one hazard quotient for multiple substances and/or multiple exposure pathways.*” Although the use of the term HI in environmental risk assessment is more commonly used to refer to summation of HQs for multiple substances it is also applicable by this definition to the summation of uranium HQs for multiple exposure pathways.

Section 6.3 of the Final Report is being renamed “*Receptor Uranium Hazard Indices*”. The first sentence of Section 6.3 is being revised to state:

“Uranium hazard indices (HIs) within 10,000 yr are calculated for each receptor scenario as the sum of hazard quotients (HQs) for the ingestion exposure pathways defined in Table 1, and are compared to EPA’s standard HI threshold of 1.0.”

The text of Section 6.3 of the Final Report, Tables 7 through 10, and Figures 10 and 11, is being edited to replace the term hazard quotient with hazard index.

43. INTERROGATORY CR R313-25-19-43/1: PEAK DOSE IN TABLE 11

Clarify the meaning of the term “*peak*” in the context of Table 11. Explain why this information has relevance to the regulatory requirement in R313-25-19, which sets dose limits for “*any member of the public*” (i.e., in the singular).

EnergySolutions’ Response: Cumulative doses are monotonically increasing, so that the “peak” (maximum) cumulative population dose (or, rather, the total effective dose equivalent, or TEDE) must necessarily occur at the time equal to the duration of the time of interest.

The Table title is being changed by removing the word “Peak”. It is not applicable here. The values in the table should represent statistics from the distribution of the cumulative population doses. However, per Interrogatory #88, and in light of upcoming changes to the model (ET cover), this table is being revised and corrections are being made in the text to reflect what is represented in this table.

Doses to individuals, which indeed are required explicitly in R313-25-19, are covered in the previous sections of the FRV1. The interpretation of the ALARA principle followed here is that all doses are to be kept ALARA, in what amounts to a cost/benefit analysis. The reason for doing so is to evaluate changes that might be made to the facility, (e.g. design, waste acceptance), which are incurred at some cost. To the extent that these changes would result in the benefit of reducing doses in the future, a decision is to be made about whether they are worth instituting. In order to include all potential receptors who might benefit from reduced doses, the appropriate method is to evaluate the population dose, which is the sum of all doses to all individuals through the performance period.

44. INTERROGATORY CR R313-25-8(5)(A)-44/1: OCCURRENCE OF INTERMEDIATE LAKES

Clarify the number meant by the term “*handful*” when referring to the occurrence of intermediate lakes. Describe intermediate lakes in terms of past or future total surface area and potential inundation of the Clive site.

EnergySolutions’ Response: In general, the spatial aspect of intermediate lakes that is of interest is whether the shore reaches the elevation of Clive. The total areal extent of these lakes is not accounted for in the present model, as this is not relevant to the issue of the site’s potential inundation.

Intermediate lakes are modeled as a Poisson process with a rate of 0 to 7.5 lakes per 100 ky. The text indicated is being changed as:

“intermediate lakes only occur on average 3 times per 100 ky.”

Please refer to the following existing sections in the Deep Time Assessment white paper for further details regarding timing. Clarification is being added to the main text of the report.

Section 3.3, p. 10, para. 1

“For modeling purposes, a distinction is made between shallow, intermediate and large lakes. Large lakes are assumed to be similar to Lake Bonneville, occurring no more than once per 100 ky glacial cycle. Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur [at Clive].”

Section 4.1.1.1, p. 14, para. 1

“The Great Salt Lake represents the current condition of a lake in the Bonneville Basin. Lakes such as this are likely to exist for periods of time during all future climatic cycles, but lakes that do not reach the elevation of the DU waste embankment at Clive will not affect the waste embankment, so they need are not modeled explicitly. However, it is assumed that during the 100 ky climatic cycles, larger lakes will occur, including lakes that reach the elevation of the DU waste embankment at Clive. Although a definitive distinction is not made, lakes that reach the elevation of Clive but do not develop into a large lake are considered intermediate lakes. These intermediate lakes are also assumed to be large enough that their wave action will destroy the waste embankment. Intermediate lakes might occur during the transgression and regression phases of a large lake, or might occur during a glacial cycle that does not produce a large lake, perhaps in conjunction with glacial cycles that are shorter and less severe than the 100 ky year glacial cycles previously discussed (for example, potentially the current 100 ky cycle).”

Section 6.2, p. 23, para. 1 and 2

“In order to reflect the slow decrease in temperature over the 100 ky cycle, the occurrence time for intermediate lakes is modeled as a Poisson process with a rate that increases linearly over the cycle time, from a rate of 0 to 7.5 lakes per 100 ky. This process produces an average of about 3 intermediate lakes per 100 ky. There is little recorded basis for this number, but it matches reasonably with the heuristic model of Section 5.0, and was chosen so that long-term sedimentation rates matched the average from previous lake cycles, as estimated from the sedimentation of individual lakes developed in Section 6.3.”

“There is virtually no information for the duration of intermediate lakes, due to the high mixing rate of shallow lake sediments, which makes dating of times within a single stratigraphic layer of a shallow lake sediment core extremely difficult. Thus, a distribution was chosen to roughly calibrate with the heuristic model: lognormal with geometric mean of 500 y and geometric standard deviation of 1.5.”

45. INTERROGATORY CR R313-25-7(2)-45/1: INACCURATE CROSS-REFERENCE

Change the text to cite the correct location for the list of relevant radionuclides.

EnergySolutions’ Response: The proper reference should be to Table 4. The text of the Conceptual Site Model white paper is being changed as follows:

[Conceptual Site Model white paper, section 4.2.2, p.18, second paragraph, second sentence:]

“The wastes under consideration for disposal in the present PA, however, contain more than simply isotopes of uranium, potentially including some radionuclides listed in the tables shown in Figure 4 in addition to the Ra -226 added by Utah (Figure 5).”

46. INTERROGATORY CR R313-25-7(1)-46/1: TORNADOS

Provide complete and accurate information on tornados in Utah and discuss their potential impact on the long-term integrity of the embankment cover.

EnergySolutions’ Response: Although not explicitly stated in the Erosion Modeling report, tornados are addressed. As quoted in the Basis for Interrogatory, tornados are considered a potential triggering event for gully formation. Therefore, the gully analysis encompasses potential impact from a tornado strike on the embankment.

This scenario must further be considered in terms of its very low probability. Tornados are rare phenomena in the State of Utah primarily due to the lack of atmospheric moisture and the presence of mountainous terrain. Utah tornadoes are much weaker and smaller than their central U.S. counterparts. Utah tornadoes stay on the ground for an average of only a few minutes and their path widths are usually one-eighth of a mile or less. As has previously been reported to the Division,

“The probability of tornado occurrence in Utah is 14 tornados in 61 years (NWC, 2013). Five tornadoes were observed in Tooele County for the

period 1847–2010 (Brough, et al., 2010). Based on this historic record, the probability of a tornado strike at any one point in Tooele County is extremely low.

Because NRC (and the Division) deems insignificant impact to a closed embankment's ability to perform, NUREG-0706 estimates the bounding consequences of a tornado striking an actively operating cell, by modeling a tornado's impact to a uranium mill. In the NUREG-0706 bounding case, 12.6 tons of yellowcake is assumed to be entrained in the vortex, the vortex dissipates at the site boundary, all of the yellowcake is reparable in size, and the cloud is dispersed as a volume source by the prevailing winds. The model predicts a maximum exposure at 2.5 miles from the mill, where the 50-year dose commitment is estimated to be 0.83 micro-rem. At the fence line (1,600 feet) the dose is estimated to be 0.22 micro-rem.

While severe winds on the order of 35 m/s have been recorded in the Clive vicinity, the occurrence is infrequent and the duration is short. Using the same method as NUREG-0706, (i.e., an order of magnitude increase in airborne concentrations during severe wind conditions that occur approximately one percent of the time), the time-weighted average off-site exposure will increase by only 10 percent. This will result in a maximum additional annual collective TEDE of less than 1 mrem to any possible nearby population groups.

Depleted uranium wastes considered by EnergySolutions in this Performance Assessment have average activities considerably less than those modeled by NRC in NUREG-0706. As a result, the expected TEDE at receptor locations is bounded by NUREG-0706. Since there are no nearby population groups, this very small potential dose is even more insignificant.” (Section 7 of EnergySolutions, 2013c, pg 7-7)

Although the probability of a tornado strike on the Clive facility is low, it need not be discounted completely. An unbiased way to include tornado activity as a part of local weather patterns is to rely on the records from meteorological sampling stations, as is being done. These stations record all manner of wind events, from straight-line winds to dust devils to tornados, should they occur. It is essentially a random sampling of natural weather processes, and the record is used in the atmospheric dispersion modeling at the site. In this fashion, tornados are not excluded from the analysis, and are included to the extent that they are recorded to occur. In addition to tornados as weather phenomena that contribute to atmospheric dispersion, they are implicitly included in their effects on erosion, since gully formation can be caused by severe tornados.

47. INTERROGATORY CR R313-25-7(1)-47/1: SELECTION OF BIOME

Correct the placement of the X on the Whittaker Biome Diagram to accurately represent site conditions.

EnergySolutions' Response: The 'X' is not located in the correct place in Figure 7 of the CSM Report. This is being corrected in a revision of the CSM Report. Correct placement of the X will shift its location to the Temperate Grassland and Desert biome near its intersection with the Woodland Shrubland and Subtropical Desert Biomes. Figure 7 is being revised to show the correct placement of the Clive Site within the biome diagram. No revisions to associated text are needed.

48. INTERROGATORY CR R313-25-7(9)-48/1: SOURCE AND COMPOSITION OF DU WASTE

Clarify the source of the DU waste considered in the analysis and how the PA accounts for potentially different radionuclide species compositions. Address concerns with the three sources of information on the characteristics of the DU waste.

EnergySolutions' Response:

General Comment. Every effort was made to find and use all information regarding the characteristics of DU currently proposed for storage at Clive, as well as future sources of waste. Deficiencies of SRS 2002 data are well documented in the Waste Inventory Report. The available SRS data were used when no other information was available (i.e., to also represent the GDP waste). Data from the SRS 2002, the State of Utah, 2010 and *EnergySolutions* (2010) was summarized in such a way to capture the variations between studies as well as within studies. This method results in considerably more uncertainty than if the all the results were pooled to estimate confidence around the overall mean value treating all the data as random samples. This characterizes the distributions for the mean value of the components of the waste inventory in a conservative manner compared to random allocation, but represents the between study variability. The use of the SRS data as a surrogate for the GDP waste is described in the Waste Inventory paper. Consequently, the specific statement called out in the Interrogatory [“Based on laboratory analysis of the contents of DU waste (including all radionuclides in the containers), the species in the disposed inventory include (Beals et al. 2002; *EnergySolutions* 2009b; Johnson 2010):....”] refers to all the waste.

Comment 1, part a. There is no evidence to indicate that the barrels sampled in 2002 were not randomly sampled. Furthermore; information indicates that the barrels stored at Savannah contain similar materials produced by similar processes. Assuming this is the case the sample size provides data that adequately represents the waste concentrations. The following document will be added to the

references: Loftin, S.G., and McWhorter, D.L., 2002, Sampling Plan for Depleted Uranium Trioxide Drums”, InterOffice Memorandum, Westinghouse Savannah River Company. This document makes clear that the drums contain similar material produced from the same process over a roughly 30-year period (1950s to the late 1980s). The drums appear to have been selected essentially at random, and the waste mixture is homogeneous because the UO_3 was mixed prior to placing it in the drums. Because of the previous mixing drums were sampled from the top of each drum. Details are being added to the Waste Inventory paper. However, the drums appear to have been sampled at random, and the process by which the waste was produced appears to have been constant throughout the 30-year period of operation.

Comment 1, part b. Regarding the MDA level used in the Ra-226 measurements, at the time of the 2002 measurements this level was specified as being 1/10 the waste acceptance criteria level – presumably low enough to produce detectable results below the acceptance level. If any new samples are collected, they will specify a MDA value of 15 pCi/g. However; given that the Ra-226 is a product of U-238 decay, and the DU waste is pure uranium at the outset (other than the fission contaminants), uranium data has accurately been coupled with the established methods for modeling the decay chain of uranium suffice for accurate characterization of Ra-226.

Regarding I-129, while none was detected in the 33 samples, an input distribution of the mean value was set based on the MDA values. For 0 of 33 samples to not exceed the MDA, it is likely that the true mean is considerably lower and possibly zero. Nonetheless, with the input based on the MDA, I-129 was not found to be a contributor towards any impacts on groundwater. Therefore; it seems unlikely that additional samples with lower detection limits would change any conclusions. However, an approach is being evaluated that applies scaling factors to I-129 based on Tc-99 concentrations. If the scaling factor approach is considered appropriate, then a different distribution of I-129 will be used in the model. See response to Interrogatory #95.

Comment 1, part c. The term “statistically weaker” may not be applicable, it is not clear exactly how that term might be used. Inputs with fewer sample sizes are not “statistically weaker” than inputs with greater sample sizes, but they likely have wider confidence intervals, or the mean has greater uncertainty. The statistical methods account for different sample sizes by acknowledging the differences in uncertainty.

Comment 1, part d. With regards to the 2002 SRS uranium data, EnergySolutions’ best effort suggest that the data needed (sample mass) to convert the 2002 results to activity concentration does not exist and therefore this cannot be resolved. Furthermore, it is not clear that EnergySolutions has the

authority to demand additional samples be taken and analyzed by the Department of Energy. In 2010, EnergySolutions sought to fill this information gap by collecting 26 additional samples. Efforts could be made at collecting more samples from the SRS drums for uranium analysis, but the uranium inventory is not a sensitive parameter, in which case probably little will be gained by doing so.

Comment 2, part a. Drum samples collected in 2010 by EnergySolutions were randomly chosen. Additionally, inadvertently the barrels of waste were very likely re-randomized during the loading and unloading (i.e. we have no knowledge that the barrels were deliberately kept in any sequential order throughout the transport, and based on the 2002 sampling plan it appears that the drums have never been organized in a way that would allow for systematic sampling). With regard to the State of Utah 2010, data collection the Memorandum indicates that a simple random sampling methodology was followed. The barrels selected for shipment from SRS were NOT preferentially selected based on the qualities of their content – such preferential selection would not have been possible since there is no prior knowledge that some drums contain, in some way different material than other drums. Therefore; no information suggests that the samples are not independent and identically distributed (i.e., randomly selected with similar expectations for each drum and sample).

Comment 2, part b. The uranium isotope data was estimated using the range of isotope proportions measured in the SRS 2002 study, coupled with the combined concentrations measured in 2010. In the Waste Inventory document, it is suggested that if this partitioning distribution is found to be a sensitive parameter, additional sampling may be warranted. However, it was not found to be sensitive. The available data all relate to the same waste stream. Some inherent sampling and measurement variability should be expected, but otherwise the samples represent the same waste stream, in which case all available data are considered useful.

Comment 3, part a. While the Johnson, 2010 memorandum references the EPA Waste Sampling Guidance (530-D-02-002), there is not sufficient information to see exactly how it was applied to the Utah sampling plan. The sample size calculations used in this collection effort are outlined in a letter to Dane Finerfrock from John Hultquist (January 21, 2010). From the letter, it is clear that the sample sizes were based on the goal of providing a specified degree of confidence for estimates of the proportion of drums with Tc-99 concentrations qualified that would qualify it as a Class A waste. There are many statistical problems with the approach that was taken to sample size determination, which Neptune documented in a memorandum to EnergySolutions in January 2010. The wrong statistical formula was used for answering the important question of the concentration of uranium in the DU waste. Sampling to answer a question based on proportions (proportion of what was never clear in the State sampling plan) is

very different than answering the question of concentration or mean concentration. The State took far more samples than were needed to address the issue of concentration estimation if Type I and Type II errors had been applied in the DQO process evaluation of a relatively homogeneous waste stream. Using proportions as the end goal, is not the same as sampling to determine the average concentration for the waste inventory. The sample size used by the State of Utah is likely much higher than that would be recommended to estimate mean concentrations for a homogenous waste source. Other information about the details of the actual sampling procedure and drum selection is not discussed.

With regards to characterizing the waste inventory, a priori there is no ideal sample size needed to run the PA model. The samples sizes used to characterize inventory concentrations are accounted for in the width of the distributions. After the fact, it might be concluded that a given input has great impact on the end result by performing a sensitivity analysis. However, the sensitivity analysis results for the current model indicate that the output results are not sensitive to the inventory distributions.

Discussion

The Division's concerns about the representativeness of the samples used to characterize the waste inventory are understandable. However, none of the inventory distributions are sensitive, and they are all as "wide" as they can be given the data. To this end, the following actions are proposed.

- Specific sensitivity analysis (one-at-a-time) is being developed for select dose rates and hazard quotients focusing on inventory distributions as inputs. Initially, this effort will analyze data from existing model runs (after implementing the ET cover). This would provide information about the relative impacts of the inventory amounts and identify conditions where greater certainty is needed. This item relates to the comments raised in CR R313-25-8(5)(a)-30/1, CR R313-25-8(5)(a)-31/1 and CR R313-25-8(4)(a)-32/1.
- This sensitivity analysis will include evaluating the effect of ignoring some data sources.

49. INTERROGATORY CR R313-25-7(9)-49/1: COMPOSITION OF MATERIAL MASS

Clarify the material comprising masses discussed in the text.

EnergySolutions' Response: The weight reference was calculated from information provided on the Uniform Low-Level Radioactive Waste Manifest – Forms 540 and 541. On these forms, the material description (Form 540, box 11)

is listed as “RQ, UN 3221, Radioactive material, low specific activity (LSA-II), 7, Fissile Exempted.” In the Radiological Description (Form 541, box 15) uranium component is described as “U-(dep).” Therefore this material is assumed to be DU Waste as described in the Waste Inventory Report.

The mass of the empty drums is assumed to be approximately 108 Mg, so the total waste mass is:

3,577 Mg of drummed waste - 108 Mg drum mass = 3,469 Mg of DU waste

which is a mix of uranium isotopes and contaminants, and where the uranium is assumed to be in the form of DUO₃. Calculations are performed within the GoldSim model to attribute the total mass to the separate radionuclides, based on the available concentration data (i.e., based on the input distributions created from the available laboratory data).

Text clarifying how this is done is being added to the Waste Inventory Document.

50. INTERROGATORY CR R313-25-7(9)-50/1: SAMPLES COLLECTED

Correct the numbers given in the text for samples collected in January and April 2010 to match the corresponding tables.

EnergySolutions’ Response: Section 2.2.2 of the Waste Inventory report is being revised to read:

“In January of 2010, EnergySolutions collected 11 samples that were analyzed for uranium isotopes (Table 14, in the Appendix). In April 2010 EnergySolutions collected 15 samples that were analyzed for uranium isotopes and ⁹⁹Tc (Table 15, in the Appendix).”

As confirmed by checking the original sampling reports, 11 samples were collected in the January 2010 event and 15 samples were collected in the April 2010 event. The text referenced above is being corrected.

51. INTERROGATORY CR R313-25-7(9)-51/1: NATURE OF CONTAMINATION

Refer to other existing analyses for information on the nature and extent of contamination within the contaminated DU population for the GDPs.

EnergySolutions’ Response: As with EnergySolutions’ other historic performance assessment, the revised depleted uranium Performance Assessment accounts for variations in depleted uranium concentrations by modeling individual radionuclides at Class A limits (without taking credit for waste form or

packaging). Therefore, the analysis is bounding and includes variances suggested by the references provided by the Division.

These references, and additional references that have been made available since submittal of the report in June 2011, are being consulted for additional information. The radionuclide content of the GDP DU is being modified in accordance with the information from those references found to provide new useful information.

Documents that are being evaluated to further characterize this source term, include:

- BJC (Bechtel Jacobs Company LLC), 2000, Recycled Uranium Mass Balance Project Oak Ridge Gaseous Diffusion Plant Site Report, BJC/OR-584, June 2000.
- BJC, 2000, Recycled Uranium Mass Balance Project Paducah Gaseous Diffusion Plant Site Report, BJC/PGDP-167, 14 Jun 2000.
- BJC, 2000, Recycled Uranium Mass Balance Project Portsmouth, Ohio Site Report, BJC/PORTS-139/R1, 19 Jun 2000.
- Croff, A.G., J.R. Hightower, D.W. Lee, G.E. Michaels, N.L. Ranek, and J.R. Trabalka, 2000, Assessment of Preferred Depleted Uranium Disposal Forms, ORNL/TM 2000/161, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Jun 2000.
- Croff, A.G., J.R. Hightower, and N.L. Ranek, 2000, Evaluation of the Acceptability of Potential Depleted Uranium Hexafluoride Conversion Products at the Envirocare Disposal Site, ORNL/TM 2000/355, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Dec 2000.
- DOE (U.S. Department of Energy), 1999, Final Plan for the Conversion of Depleted Uranium Hexafluoride, DOE/SO-0003, U.S. DOE Office of Nuclear Energy, Science and Technology, Jul 1999.
- DOE, 1999, Final Programmatic Environmental Impact Statement for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride, DOE/EIS-0269, U.S. DOE Office of Nuclear Energy, Science and Technology, Apr 1999.
- DOE, 2000, Recycled Uranium, United States Production, Enrichment and Utilization, DOE/SO-0003, U.S. DOE, Aug 2000.

- DOE, 2003 Recycled Uranium, The Flow and Characteristics of Recycled Uranium Throughout the DOE Complex 1952 1999, DOE/EH-0617, U.S. DOE, May 2003.
- Haselwood Enterprises, Inc., 2000, Recycled Uranium Mass Balance Project Y 12 National Security Complex Site Report, Y/LB 16,036, Rev. 1, U.S. Dept. of Energy, Oak Ridge, TN, Dec 2000.
- Henson Technical Projects, LLC, 2006, Contents Categorization of Paducah DUF6 Cylinders Using Cylinder History Cards – Phase II, Draft for UDS Review, DUF6 G G STU 003, Uranium Disposition Services, LLC, Lexington, KY, Sep 2006
- Hightower, J.R. and J.R. Trabalka, 2000, Depleted Uranium Storage and Disposal Trade Study: Summary Report, ORNL/TM 2000/10, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Feb 2000.
- Hightower, J.R., L.R. Dole, D.W. Lee, G.E. Michaels, M.I. Morris, D.G. O’Conner, S.J. Pawel, R.L. Schmoyer, L.D. Trowbridge, and V.S. White, 2000, Strategy for Characterizing Transuranics and Technetium Contamination in Depleted UF6 Cylinders, ORNL/TM 2000/242, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Oct 2000.
- INEEL (Idaho National Engineering and Environmental Laboratory), 2000, Idaho National Engineering and Environmental Laboratory Site Report on the Production and Use of Recycled Uranium, INEEL/EXT 2000 00959, INEEL, Idaho Falls, ID, Sep 2000.
- INL (Idaho National Laboratory), 2010, Analyzing Losses: Transuranics Into Waste and Fission Products Into Recycled Fuel, 11th Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, INL/CON 10 20136, INL, Nov 2010
- Picel, K., R. Johnson, J. Peterson, K. Keil, A. Kolhoff, H. Spector, and J. DeVaughn, Evaluation of Uranium Enrichment/Depletion and Recycled Uranium Residuals in Soils and Groundwater at the Harshaw FUSRAP Site, Paper 9336, Waste Management 2009 Conference, Mar 2009.
- UDS (Uranium Disposition Services, LLC), 2009, Waste Management Plan, DUF6 UDS PLN 005, rev. 2, UDS, Lexington, KY, Jan 2009

52. INTERROGATORY CR R313-25-7(9)-52/1: MEASUREMENT TYPES FOR SAMPLING EVENTS

Clarify the reference for “*different measurement types between sampling events.*”

EnergySolutions’ Response: Clarification is being provided.

The concern for U-238 is that the 3 different sampling events exhibit different behavior as shown on Figure 1. Also, Figure 3 shows differences for the Tc-99 data for its three sampling events.

While available site knowledge and historical information suggest that the SRS waste is from similar processes and is similar in composition, the sampling events were treated as if they were sampling different populations. The reason for treating the sampling events as if they were sampling different populations was the differences between concentration data for the different sampling events. The text in question was an attempt to acknowledge that the data indicate differences that are more likely explained by different measurement methods (sampling and analysis) than any other reason, given the waste has not been changed in more than a decade. The text is being clarified to change the term “*measurement types*” to “*sampling and analysis methods*”.

The statistical approach was to treat each sample independently within a sampling event, and to treat the sampling events as representing separate populations. The bootstrap simulations, hence, involved bootstrapping both within and across sampling events. This approach maximized the uncertainty that was carried into the distribution of the mean.

53. INTERROGATORY CR R313-25-7(9)-53/1: SUBSCRIPTS IN EQUATION 1

Correct the subscripts in the denominator of equation 1.

EnergySolutions’ Response: Clarification of the meaning of c_i and c_j in the “where” block is being added. The “where” block for equation (1) of the Waste Inventory white paper is being modified to read as follows:

$$A_i = \frac{c_i}{\sum_j c_j} \times 100$$

where

A_i = activity % of uranium component i ,

c_i = activity concentration for uranium component of interest i , and

c_j = activity concentration for all enumerated uranium components j , which indexes $^{233+234}\text{U}$, $^{235+236}\text{U}$, and ^{238}U .

54. INTERROGATORY CR R313-25-7(9)-54/1: PARTITIONING IN THE SENSITIVITY ANALYSIS

Provide a specific cross-reference to the discussion of partitioning in the sensitivity analyses.

EnergySolutions' Response: The text in Section 3.2.1, page 14, of the Waste Inventory report is being changed to:

“In general, the differences this causes in uranium activity concentrations are fairly small relative to the likely effect on the PA model results, however, this will be tested in the model evaluation and sensitivity analysis (see Section 6 of the Clive DU PA Model Report).”

The sensitivity analysis performed on this model and presented in the report is a global sensitivity analysis. All input parameters (variables) are changed simultaneously to determine which are most important predictors (most sensitive inputs) for the model output. The uranium inventory has not shown to be a sensitive parameter for any of the dose or risk outputs.

55. INTERROGATORY CR R313-25-8(5)(A)-55/1: URANIUM ISOTOPE DISTRIBUTIONS

Indicate whether analyses were conducted to determine if the uranium isotope distributions significantly affected the results of the PA.

EnergySolutions' Response: All stochastic inputs into the model are included in the global sensitivity analysis. This includes the radionuclide-specific abundances that make up DU waste, as represented by the GoldSim Stochastic element `\Inventory\SRS_DU_Inventory\ActivityConc_SRS_DUWaste`, in the Clive DU PA Model v1.0. The activity concentration of each radionuclide in DU waste, including all isotopes of uranium, is defined probabilistically through this element.

Note that the Waste Inventory white paper, like all topical white papers, is developed for model inputs and approaches, with no regard to results. Model

results are summarized in the Final Report (FRV1). As shown in Section 6 of the Final Report, no model endpoints (e.g. doses to various receptors, and groundwater concentrations) were sensitive to the uncertainties in inventory, and by extension to uranium isotopic abundances.

The global sensitivity analysis methods used effectively consider changes in all input parameters simultaneously to determine which inputs are most important for the model output. Details are provided in the Sensitivity Analysis white paper.

56. INTERROGATORY CR R313-25-7(9)-56/1: INTERPRETATION OF BOX PLOTS

Interpret the information contained in the box plots in Figures 3 and 5, including the statistical parameters they display.

EnergySolutions' Response: Where the box-plots are first used and referenced on page 17, the following text is being added either within the text, or as a footnote, or as part of the figure caption.

“The box-plots shown in Figures 3 and 5 are standard typical box-plots (Tukey, 1977) used to illustrate and summarize the distribution of groups of data. The top, middle and bottom lines indicate the 75th, 50th (median) and 25th percentile of the data. The vertical lines “whiskers” extend to the largest or smallest point within 1.5 times the interquartile range (75th – 25th percentiles) of the 25th and 75th percentiles. Results falling outside the whiskers are considered to be outliers. This indicates that there is a reasonable chance they are from a different distribution. With several groups of data, box-plots can be used to informally compare the central values (median), spread or variances (width of the boxes) or distributions (symmetry).”

This reference is being added to the References section:

Tukey, John (1977). Exploratory Data Analysis. Addison-Wesley

57. INTERROGATORY CR R313-25-7(9)-57/1: DASHED LINES IN FIGURE 4

Explain the purpose of the dashed lines in Figure 4.

EnergySolutions’ Response: In Section 3.3, the caption is being edited to include an explanation of the dashed vertical lines. The new caption reads,

“Distribution of Tc-99 mean values. Red lines indicate mean values of Utah-2010, ES-2010 and SRS-2002 results. The dashed lines indicate the 5th and 95th percentiles of the mean values of the resampled data.”

To clarify, the resampled data represent the final simulated distribution (from the bootstrapping algorithm that was used). So, these are the 5th and 95th percentiles of the final distribution. The intent of these lines is to show where the original data means fall relative to the final distribution.

58. INTERROGATORY CR R313-25-7(9)-58/1: REFERENCE FOR PERSONAL COMMUNICATION

Provide complete information for personal communication citations in the reference list.

EnergySolutions’ Response: The text is being edited as follows:

[Waste Inventory white paper, p. 23, second-to-last paragraph, last sentence:]

“These cylinders are also considered unlikely to be contaminated (personal communication, Tammy Stapleton, Uranium Disposition Services, LLC, to John Tauxe, Neptune and Company, Inc., 3 May 2011).”

[Waste Inventory white paper, p. 24, first paragraph, third sentence:]

“Using expert opinion, this is estimated at less than 1%, with a best guess at no more than 10 cylinders contaminated (personal communication, Tammy Stapleton, Uranium Disposition Services, LLC, to John Tauxe, Neptune and Company, Inc., 3 May 2011).”

Most style manuals suggest that a personal communication should not appear in the reference list, but rather remain only a parenthetical reference in the text. Nevertheless, the reference section is being revised as,

Stapleton, Tammy, Uranium Disposition Services, LLC, personal communication via telephone to John Tauxe, Neptune and Company, Inc., 3 May 2011.

59. INTERROGATORY CR R313-25-7(2)-59/1: BATHTUB EFFECT

Clarify why, after the upper flow barriers are compromised, water will not collect above the clay liner and drive infiltration rates above those predicted by models.

EnergySolutions' Response: Because of the large differences between the cover layers in permeability the potential for the bathtub effect is being evaluated for both the rip rap and ET cover designs.

For this review of the model, which includes the rip-rap design, it is assumed that the “*top clay liner*” referred to in the Interrogatory is the top clay liner below the waste zone and not one of the radon barriers. The saturated hydraulic conductivity of this liner is too high to result in ponding (bathtub effect). The highest average annual infiltration estimated for the top slope of this waste cover is 0.11 inches/year (Whetstone, 2007, Section 3.4.1) which is equivalent to a hydraulic conductivity rate of $9E^{-11}$ m/s (assuming Darcy’s Law flow and a unit gradient such that flux = K_{sat}). This infiltration rate of 0.11 inches/year is calculated using HELP which is generally considered to over-estimate infiltration (see Section 4.1.2.4.1). [This is being addressed in the ET cover model using HYDRUS instead of HELP.] The saturated hydraulic conductivity of the clay liner below the waste is reported to be $1.0E^{-6}$ cm/s ($1.0E^{-8}$ m/s) in the Unsaturated Zone Model report (p. 5), which is 100 times greater than the infiltration rate so the bathtub effect is not possible. Any increase in saturated hydraulic conductivity of the clay liner below the waste due to naturalization will make the bathtub effect even less likely.

Note that the quoted text in the Interrogatory is not from Section 4.1, page 5, but rather from Section 3.2, page 15, of the Unsaturated Zone Model report.

60. INTERROGATORY CR R313-25-7(3)-60/1: MODELED RADON BARRIERS

Provide additional justification for the modeled post-installation upper and lower radon barriers.

EnergySolutions' Response: As is provided in response to Interrogatories CR R313-25-7(2)-05/1 the Evapotranspirative Cover is designed to protect the radon barrier from the impacts of burrowing insects, animals, and vegetation root systems. Similarly, analysis conducted by Hansen, Allen, and Luce in 2013 concluded,

“The frost depths calculated as part of this analysis give results that are in line with the depths of cover and frost protection proposed in the EnergySolutions ET Cover system design. The proposed radon barrier begins at depths ranging from 30-inches to 42-inches which provides frost

protection for the calculated 100-year frost penetration depth of 22.4 inches to 27.8 inches for the top slope and side slope, respectively.”
(Appendix E of EnergySolutions, 2013d)

The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design’s use on the Class A West Embankment. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two order of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

This interrogatory is closely linked to the Benson et al (2011) report published by the NRC, and is similar to Interrogatory CR R313-25-8(5)(A)-176/1. The Benson et al. (2011) reference is a credible report that emphasizes cover properties in general, not the specific cover types and materials proposed for the Clive site and the local climatic setting. The recommendations from the report, by itself, are not sufficient justification to require redesigning the cover system nor is it contradictory with the steady state infiltration rates developed from the HELP modeling. In fact, Benson et al. (2011) state *“If available, a site-specific saturated hydraulic conductivity that reflects in-service conditions should be used for performance predictions.”* Although site-specific hydraulic conductivities have not been measured, the site-specific estimates are considered to be more credible than the generic values in Benson et al. (2011).

With regard to the influence of biointrusion on model parameters, also refer to the response to Interrogatory CR R313-25-8(4)(A)-108/1 on biointrusion.

The topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. An expanded assessment of cover design components and assigned physical properties in models of cover

performance must be carefully designed for applicability to the climate and hydrogeological setting of the Clive disposal facility.

This interrogatory spans two topics: alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty). Enhanced investigations of these components of uncertainty require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling.

There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. If a more comprehensive sensitivity analysis is needed for the infiltration modeling, it should not be based on selective and non-systematic changes in physical properties of cover materials. Instead what is required would be refined modeling of closure cover performance using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into the probabilistic performance assessment model.

61. INTERROGATORY CR R313-25-8(4)(A)-61/1: MASS-BALANCE INFORMATION

Provide the mass-balance information for both the flow and contaminant transport from the model simulations.

EnergySolutions' Response: The mass balance of water flow is not in question, since it is up to GoldSim to assure that all flows are properly accounted for. GoldSim performs no solutions whatsoever to the hydraulics of the model. In the case of the unsaturated zone, the water flow through the vertical column is defined based on external calculations. Since there are no numerical calculations in GoldSim with respect to water flow calculations, mass balance of water has no mass balance error.

The Contaminant Transport Module is a mass transport model. That is, it tracks the mass of the species as it moves them through the pathway network. However, GoldSim does not automatically impose a mass balance on the transport media that it is moving between pathways (e.g., water). Mass balances for transport media must be specifically imposed by the user. In practice, this simply means that when specifying the media volumes and media flow rates for Cells (and other pathways), you must be careful to ensure that there is a flow balance. For some systems, ensuring a flow balance may be quite straightforward. For example, if the Cells represented portions of a saturated aquifer, the volume of water in each Cell remains constant, and you need to only ensure that the flows between Cells are consistent. (From GoldSim 2010, p. 150)

The mass balance of contaminants (radionuclides) is determined internally by the GoldSim software as part of its proprietary solution algorithms. The internal solver accounts for advective flows, diffusion in air and water (where applicable), partitioning between air, water, and solid phases, as well as radioactive decay and ingrowth. The modeler and the user are not privy to the internal mass balance calculations, but a good indication of how well the model is doing can be had by experimenting with the settings for solution precision, which are accessible to the user. Using the GoldSim interface, go to Model | Options dialog, and select the Contaminant Transport tab. Under the first set of options, General Options, there is a drop-down box where the user can set the solution precision, in qualitative terms: low, medium, and high. If choosing a higher solution precision does not result in substantially different results, then the user has an indication that the mass balance is acceptable, since refining the precision does not improve the calculation.

62. INTERROGATORY CR R313-25-7(2)-62/1: NUMERICAL TESTING OF RUNGE-KUTTA METHOD

Provide a reference for the statement about numerical testing with regard to the Runge-Kutta method and describe the bases for the conclusion that stable solutions were produced.

EnergySolutions' Response: The Runge-Kutta solution method applied to this problem was extensively tested and verified, using test models in both GoldSim and Microsoft Excel. A more extensive documentation of this testing will be provided as an appendix to a revision to the Unsaturated Zone Modeling white paper.

63. INTERROGATORY CR R313-25-8(4)(A)-63/1: AIR-PHASE ADVECTION

Provide additional explanation and justification for the exclusion of air-phase advection from the PA model.

EnergySolutions' Response: In the Clive DU PA volatile radionuclides are transported by aqueous advection and aqueous and gaseous diffusion. Fluctuations in barometric pressure at a site with an open ground surface have been shown by Massman and Farrier (1992) to result in the movement of fresh air into the subsurface during a barometric pressure cycle. Velocities simulated at the high point of the pressure cycle and the low point were equal in magnitude and opposite in direction indicating that the fresh air that migrates into the vadose zone moves back out of the vadose zone as the barometric pressure decreases. From a contaminant transport perspective, gas that migrates upward from depth in homogeneous permeable media during a low barometric pressure event will be pushed back down as the barometric pressure increases (Nilson et al., 1991).

The presence of fractures, however, has been shown by Nilson et al. (1991) to produce conditions for net outflow of gas from the vadose zone due to barometric pressure fluctuations. The effects on gas transport due to barometric pressure fluctuations shown in numerical simulations by Massman and Farrier (1992), Nilson et al. (1991) and others are considered to be negligible in the field by Weisbrod et al. (2009) who argue that the advective events required to drive these pressure fluctuations are infrequent and depend on local weather variability. The low frequency of atmospheric events required to drive advective transport and the need for fractures to make it effective are reasons that air advection is not considered in performance assessment models.

However, other processes may contribute to significant net transport of gas. Gas migration to the atmosphere due to thermally driven convection has been demonstrated in the field by Weisbrod et al. (2009). The experiment was conducted in the Negev Desert, Israel on a fracture with an aperture that varied from 1 to 5 cm. Temperature gradients due to daily thermal cycles were shown to be sufficient to induce convective venting. The aperture of the fracture tested was large and thermal gradients in the Negev Desert are steep. The significance of the process at the Clive site for contaminant gas transport and drying of the cover would have to be determined. Air flow should be measured or simulated for apertures considered to be representative of expected cracks in the proposed cover at Clive under site specific atmospheric conditions to determine the relevance of this process to the Clive site.

64. INTERROGATORY CR R313-25-8(4)(A)-64/1: YUCCA MOUNTAIN STUDIES

Consider more recent Yucca Mountain information in preparing the Geochemical Modeling report.

EnergySolutions' Response: The most recent version of ANL-WIS-MD-000010 (Rev 6) is being referenced, as suggested. The Yucca Mountain Project reference (SNL, 2007), as well as the previous YMP reference (LANL, 1997) base the solubility distributions on “conservative” estimates for solubility. With the complexity of performance assessment models, it is difficult to identify what a “conservative” assumption means because of the non-linearity of the model and because of multiple endpoints. An assumption might be conservative for one endpoint, but that same assumption might not be conservative for a different endpoint. It is better to create wider distributions where there is uncertainty in the solubility than it is to be “conservative.”

SNL (2007) discusses solubility for almost all of the elements in the Clive PA model and models in detail the solubility of Am, Np, Pa, Pu, Th, and U. Some of the solubility values in SNL (2007) are presented in look up tables with pH and

partial pressure of CO₂ as variables. It is assumed that the Clive system has a pH of 7-8 (consistent with the Geochemical Modeling report) and a pCO₂ of 3.5 to 1.5. The pCO₂ ranges from atmospheric CO₂ to 100 times atmospheric CO₂, where 10 times atmospheric CO₂ is most likely. This range of carbonate values is higher than that assumed in the Geochemical Modeling report, but it is consistent with the high carbonate concentrations observed at Clive.

To provide a basis for comparison of the Clive DU PA model solubilities to the SNL (2007) solubilities, the ranges that were used as inputs to distribution development min, max and most likely values from the Clive DU PA model were compared to SNL (2007). This comparison is the first step in developing revised solubility distributions for the Clive DU PA model. Revisions of these distributions in the Clive DU PA model would involve a statistical analysis to develop these ranges into model input distributions. A side-by-side comparison of solubility ranges for these two references by element is given in the table below.

Overall, there is good agreement in the table between the Clive DU PA solubilities and the most recent YMP solubilities.

Table. 2-64/1. Solubility ranges for the Clive DU PA model and for the most recent Yucca Mountain Project solubility reference (SNL, 2007).

Element	Clive DU PA Model Solubility Ranges (Geochem White Paper) All units are in mol/L		YMP Solubility Ranges (SNL, 2007) All units are in mol/L		SNL (2007) notes
	min	max	min	max	
Actinium	1.00E-08	1.00E-05			not modeled in SNL (2007) because of its "short" half life from Table 6.9-2 (SNL, 2007)
Americium	1.00E-09	1.00E-06	6.6E-08	4.6E-06	
Cesium	1.00E-02	1.00E+01			no solubility given for Cs in SNL (2007) because of its high solubility
Iodine	1.00E-04	1.00E+00			no solubility given for I in SNL (2007) because of its high solubility
Neptunium	1.00E-05	1.00E-02	9.2E-07	1.4E-05	Table 6.6-9 (SNL, 2007)
Protactinium	1.00E-08	1.00E-05	9.4E-07	1.5E-05	Table 6.11-2 (SNL, 2007)
Lead	1.00E-08	1.00E-05			transport of Pb not modeled because of its short half life
Plutonium	1.00E-10	1.00E-05	9.4E-09	2.5E-06	Table 6.5-1 (SNL, 2007)
Radium	1.00E-09	1.00E-05	3.1E-07	3.8E-07	Section 6.12, p. 6-143

Radon	1.00E-03	1.00E-01			not modeled in SNL (2007)
Strontium	1.00E-06	1.00E-03			no solubility given for Sr in SNL (2007) because of its high solubility; also recognize that's conservative
Technetium	1.00E-04	1.00E-02			no solubility given for Tc in SNL (2007) because of its high solubility
Thorium	1.00E-08	1.00E-06	5.0E-08	1.7E-05	Table 6.8-1 (SNL, 2007)
Uranium	5.00E-06	2.00E-03	6.8E-06	3.3E-03	Table 6.7-3 (SNL, 2007)

65. INTERROGATORY CR R317-6-6.3(Q)-65/1: COLLOID TRANSPORT

Discuss the potential for other types of colloids and colloidal-forming constituents in the waste (e.g., ligands). Explain how these phenomena might affect K_d coefficients in GoldSims and justify how and why the K_d values used are representative of or conservatively low for the actual site conditions.

EnergySolutions' Response: A more detailed discussion of potential colloid transport is being added to the Geochemical Modeling report to:

- provide brief background information on colloids, including describing the different kinds of colloids that can affect radionuclide transport;
- provide brief background information on how colloids can affect K_{ds} ,
- clarify that references given in that paragraph, including Contardi et al. (2001) and Geckeis and Rabung (2008) refer to other types of colloids (besides actinide intrinsic colloids),
- provide clearer justification for why colloidal transport is not expected at the Clive site, including more justification on the effects of high ionic strength on colloid retention,
- include the reference for the statement, "Retention of colloids is favored at high ionic strength, low pH and in impermeable rock" (Geckeis and Rabung, 2008)

In doing so, text will be added to justify how and why the K_d values used are representative of site conditions. With the complexity of performance assessment models, it is difficult to identify what a "conservative" assumption means because of the non-linearity of the model and because of multiple endpoints. An assumption might be conservative for one endpoint, but that same assumption might not be conservative for a different endpoint. It is better to create wider

distributions where there is uncertainty in the solubility than it is to be “conservative.”

66. INTERROGATORY CR R313-25-8(4)(A)-66/1: COLLOID RETENTION

Provide references from technical, peer-reviewed publications to support the statement that retention of colloids is favored in solutions of high ionic strength.

EnergySolutions’ Response: Degueldre et al 2000 states,

“Factors decreasing the colloid stability include an increase in salt (Na^+ , K^+) concentration and in water total hardness (Ca^{2+} , Mg^{2+}).” (Degueldre et al 2000, p.1048 (p.6/9))

ANL 2000 states,

“High ionic strength solutions will destabilize and promote aggregation and flocculation of the colloids.” (ANL 2000, Section 6.2.1, p.20-21 of 57).

These references are being cited in the appropriate paragraph of the Geochemical Modeling report (Section 5.0, page 18) and inserted in the References section at the end of the report to support that retention of colloids is favored in high ionic strength solutions.

67. INTERROGATORY CR R313-25-8(4)(A)-67/1: SOLUBILITY AND SPECIATION OF RADIONUCLIDES

Consider the solubility and speciation work with radionuclides in high ionic strength brines performed to support the Waste Isolation Pilot Plant. If it is not relevant, explain how solubility and speciation in high ionic strength brines are addressed.

EnergySolutions’ Response: Currently, throughout the Geochemical Modeling report there is some discussion of higher ionic strength and how it affects particular geochemical parameters. The WIPP documents suggested are being reviewed and a discussion of the relevance of the geochemistry of WIPP is being incorporated into the Geochemical Modeling report.

68. INTERROGATORY CR R313-25-8(4)(A)-68/1: DISTRIBUTION OF HYDRAULIC GRADIENTS

Provide any factors considered when developing the magnitude and distribution of hydraulic gradients from off-normal conditions.

EnergySolutions' Response: The distribution for hydraulic gradient is specific to horizontal gradients in the shallow aquifer. Vertical gradients were not considered in the model.

Monthly averages of the site-wide hydraulic gradient from 1999 through 2010 were calculated by EnergySolutions from water level measurements. These data were used to establish a distribution for the mean site-wide gradient. The influence of any off-normal conditions occurring during the time period of the water level measurement data would be included in this data. Analysis of the data indicated that there is considerable time correlation in the data with the values changing less from month to month than they do over longer time periods. To account for this behavior several auto-regressive, moving-average (ARMA) models (Brockwell and Davis 1996) were fit to determine a model that adequately captured the time with an adequate fit for the time correlation. Amongst these models, a best model was chosen based on the Akaike information criterion (AIC), and a standard error for the mean was established based on this model's fit.

A performance assessment is based on estimates of the expected performance of the site. To achieve a realistic estimate of expected performance spatio-temporal scaling (upscaling) is needed for defining parameter distributions in probabilistic models. These upscaled distributions represent a large area/volume and time frame instead of only points in time and space. Spatio-temporal scaling is critical for model definition and understanding the impact on uncertainty for estimating 95th percentiles (for example) of model output distributions. Without proper scaling, models outputs are compromised.

The influence of off-normal conditions on shallow groundwater flow is discussed in Envirocare (2004) for two cases. In the first, flow was affected by localized recharge from a surface water retention pond in the southwest corner of the facility in the spring of 1999 and in the second, a ground water mound formed between March 1993 and spring 1997 below a borrow pit excavated near the 11e.(2) cells that occasionally filled with rain water. The mound decreased and was negligible by the time of the report in 2004. The latter of these conditions was captured by the hydraulic gradient data set used to develop the distribution for the model. The influence of these conditions on the hydraulic gradient appear to be transient and of small magnitude. The only type of climate change considered in the model was the potential impact of glacial epoch pluvial lake events on the CAS waste embankment.

The hydraulic gradient (i) is modeled as normal distribution with a mean of 6.9×10^{-4} and a standard deviation of 1.27×10^{-4} . The influence of the range of the gradient given by the distribution can be evaluated by calculating a range of groundwater velocity derived from the gradient using Darcy's law. The saturated hydraulic conductivity (Ks) is modeled as a normal distribution with a mean of

9.6×10^{-4} cm/s and a standard error of 9.67×10^{-5} cm/s. Porosity (ϕ) is modeled as a normal distribution with a mean of 0.29 and a standard deviation of 0.05. From Darcy's law the groundwater flux (J) is:

$$J = K_s i$$

and the groundwater velocity (v) is:

$$v = J/\phi$$

The range of groundwater velocity is estimated by choosing values from each distribution corresponding to the mean ± 3 standard deviations and calculating values of v from the equations above. Maximum and minimum values for groundwater derived from the hydraulic gradient distribution range from 4.2 times the mean to 1/5th of the mean.

The significance of uncertainty in the value of the hydraulic gradient was evaluated for the Clive DU PA model through a sensitivity analysis. The sensitivity analysis identifies which variable have distributions that exert the greatest influence on the response. The response evaluated in the sensitivity analysis for the PA model was dose. The results showed that hydraulic gradient was quantitatively determined to not be a sensitive parameter. The text of the Saturated Zone Modeling report is being modified to include this discussion.

69. INTERROGATORY CR R313-25-8(4)(A)-69/1: LONGITUDINAL DISPERSIVITY

Provide the longitudinal dispersivity value used in the model and references for any studies or calculations that demonstrate the GoldSim model grid spacings are sufficiently small. Provide the mass-balance information for both the flow and contaminant transport from the model simulations. Indicate the length and location of the horizontal domain used for groundwater flow and transport modeling in the GoldSim simulations.

EnergySolutions' Response: The text in Section 4.0 and subsections in the Saturated Zone Modeling report is being revised as follows:

[Section 4.0, first paragraph, p.4:]

“Calculations in the PA Model that are needed for estimating transport in the shallow saturated zone include the cross-sectional area normal to the flow direction (thickness times width), definitions of the material

SatZone_Medium (hydraulic conductivity, porosity, and bulk density of Unit 2), the Darcy velocity (a function of gradient and hydraulic conductivity) and radioelement-specific solid/water partition coefficients (Kds). The distributions for bulk density and porosity have been described previously in Section 3.2 and the hydraulic gradient in Section 3.3. Aquifer dimensions are described in Section 4.1. Since the flow through the saturated zone is modeled as a horizontal column of discrete GoldSim Cell pathway elements, dispersivity is not explicitly defined as it would be for an analytical solution such as a plume. This is discussed in Section 4.2. The distributions for Kds are described in the Geochemical Modeling white paper.”

[Section 4.1, p.4 et seq.:]

4.1 Saturated Zone Dimensions

“Both the unsaturated (vadose) and saturated zones are represented in the Clive DU PA Model as GoldSim Cell pathway elements. A Cell pathway is mathematically equivalent to a continuously-stirred tank reactor (CSTR), in which the contents are instantaneously and uniformly mixed throughout the volume. The representation of the saturated zone in the PA Model consists of a series of linked cells. The mass and rate of water flowing through the column of cells depends on the Darcy velocity and the cross-sectional area perpendicular to the flow direction. This area is simply the (stochastic) thickness of the aquifer times its width, which is dependent on the geometry of the embankment. The transport of contaminants in water through the vadose zone and into the saturated zone is modeled as advective mass flux links from the unsaturated zone vertical column into the various cells underlying the embankment. This contaminated recharge is distributed along the saturated zone flow pathway, with a fraction entering each saturated zone cell. The cell pathways and their interconnections are represented schematically in Figure 1.”

[Section 4.1, p.5, last paragraph:]

“An assumption of the mixing cell approach is that all contaminant mass that enters the cell is completely mixed and equilibrated among all media in the cell, consistent with the mathematical representation of a CSTR. To provide contaminant mass balance, GoldSim requires information specifying the volume of the cells. For the Clive DU PA model, the extent of the saturated zone below the Class A South cell and the distance from the toe of the waste in the disposal cell to the compliance point are represented as a horizontal network of linked cells (Figure 1). GoldSim requires the specification of the length of the cell in the direction of flow

and the cross-sectional area of the cell. The length of each cell is the transport distance divided by the number of cells. The choice of the number of cells used is based on standard modeling practice, with more discussion provided in Section 4.2. The cross sectional area is the product of the cell width and height. For the Clive DU PA model, the cell width is set to the width of the Class A South cell perpendicular to the direction of flow (“length overall” in Figure 3 of the Embankment Modeling white paper). The height of the cell corresponds to the aquifer thickness.”

[Section 4.2, p.11:]

4.2 Dispersion

“The process of spreading of a contaminant in groundwater that occurs in addition to movement by advective flow is represented in mathematical models by the dispersion coefficient. The dispersion coefficient represents both the mechanical (hydrodynamic) and chemical components of mixing and is written as:

[equation 2 and its where block remain as is]

Only longitudinal dispersion is considered for this discussion because of the geometry of the transport pathway. The width of the disposed waste is the dimension perpendicular to the groundwater flow direction. This distance is 1,429.6 ft (“length overall” in Figure 3 of the Embankment Modeling white paper). The distance from the edge of the waste to the compliance point is 90 ft as required by the groundwater discharge permit. The entire horizontal length of the saturated zone cells is this 90 ft plus the footprint of the embankment parallel to the direction of water flow (1775.0 ft, the “width overall” in Figure 3 of the Embankment Modeling white paper), making a total length of 1865 ft. With this geometry, the width of the source is more than 5 times the distance from the edge of the source to the point of compliance, making transverse dispersion insignificant.

In a numerical model such as the Clive DU PA Model, the discretization of the flow path into cells results in an effective (numerical) longitudinal dispersion (parallel to the flow direction) due to the full mixing of a CSTR even with no additional dispersivity defined. Because of this inherent numerical dispersion, no additional dispersion coefficient is included in the saturated zone transport calculations in the Clive DU PA Model.

Dispersion is discussed in the User’s Guide for the GoldSim Contaminant Transport Module (GoldSim 2010) in the context of the GoldSim Aquifer

pathway element. The Aquifer element is a collection of linked Cell elements, and the saturated zone in the Clive DU PA Model is also represented as a collection (column) of Cell elements, which is somewhat more flexible than the predefined GoldSim Aquifer element. Longitudinal dispersivity is commonly approximated as 0.1 times the length of the transport path (GoldSim 2010). For the Clive DU PA Model the point of compliance is a fixed location 232 ft from the edge of the DU waste, since the length travelled under the side slope of the embankment, which contains no DU waste (142 ft), is added to the standard 90 ft. The estimated value of the dispersivity would then be $232 \text{ ft} / 10 = 23 \text{ ft}$. In order to reduce unwanted numerical dispersion, GoldSim (2010) recommends that the number of Cell elements used in the column be greater than the transport path distance divided by twice the dispersivity. For the Clive DU PA Model geometry, the number of cells should therefore be greater than $232 \text{ ft} / (2 \times 23 \text{ ft}) = 5$. The horizontal column of Cell elements that represents the saturated zone to the well in the Clive DU PA Model contains 20 cells and there are 2 cells under the side slope. The number of cells making up the transport path exceeds the minimum recommended. The influence of the value chosen for dispersivity on model results could be evaluated with some model modification in future sensitivity analyses.

A diagram is being provided in the Saturated Zone Modeling report showing the location of the saturated zone modeling domain including the location of DU waste, the point of compliance monitoring well, the DU disposal cell's buffer zone, and outer boundaries of property owned and controlled by ES.

The mass balance of water flow is not in question, since it is up to the GoldSim programmer (the model author) to assure that all flows are properly accounted for. GoldSim performs no solutions whatsoever to the hydraulics of the model. In the case of the saturated zone, the water flow through the horizontal column is defined as a constant value all the way through the column. Since there are no numerical calculations in GoldSim with respect to water flow calculations, mass balance of water has no mass balance error.

The mass balance of contaminants (radionuclides) is determined internally by the GoldSim software as part of its proprietary solution algorithms. The internal solver accounts for advective flows, diffusion in air and water (where applicable), partitioning between air, water, and solid phases, as well as radioactive decay and ingrowth. The modeler and the user are not privy to the internal mass balance calculations, but a good indication of how well the model is doing can be had by experimenting with the settings for solution precision, which are accessible to the user. Using the GoldSim interface, go to Model | Options dialog, and select the Contaminant Transport tab. Under the first set of options, General Options, there

is a drop-down box where the user can set the solution precision, in qualitative terms: low, medium, and high. If choosing a higher solution precision does not result in substantially different results, then the user has an indication that the mass balance is acceptable, since refining the precision does not improve the calculation.

70. INTERROGATORY CR R313-25-7(2)-70/1: GULLY SCREENING MODEL

Explain and justify why a more sophisticated erosion model than the initial screening-type gully model is not needed and why gully formation is restricted to locations only on the cover system and does not include other locations.

EnergySolutions' Response: As committed in Section 1 of the “Condition 35 Compliance Report”, Revision 1, significant quantities of depleted uranium will be disposed below grade to enhance assurance of continued isolation under geologic-time events. The impact of gullies on the dose assessment is minimal for the below-grade disposal scenario. Therefore, the screening-type gully model is adequate for this evaluation.

The Clive DU PA Model v1.0 evaluated the effects of the occurrence of gullies in a screening approach, as stated in the Final Report. The mathematical model used to represent a fully-formed gully provided a suitable proxy for a fully-fledged landscape evolution model, which would be a much more significant undertaking. A small number of gullies were used simply in order to determine if gullies presented any contribution to dose or threat to waste containment. One purpose of this v1.0 of the model, then, is to identify those processes that are of concern for the site. As the sensitivity analysis has made clear, gully formation is indeed a process of concern for the site, and in that sense, v1.0 of the Model has done its job.

This interrogatory suggests a scenario where sheet and gully erosion could begin in a nearby excavation, away from the disposal cell, and by head-cutting processes eventually erode the side and top slope areas of the embankment cover. For example, surface soil is excavated at the Clive site to provide material for clay liners and barriers in the waste cover systems. These excavations have left shallow borrow pits of unconfirmed stability in the vicinity of radioactive waste disposal embankments.

While the detachment and movement of soil particles by water and wind is a natural process occurring at very slow rates since the soil was formed, the steeper slopes remaining from the borrow pit construction may act to increase the rate of erosion on the faces of the borrow pits and upslope from them. As accelerated erosion continues the heads of small channels formed at the borrow pit face by surface water flow migrate upslope away from the face. To investigate the likely

rates of this headward erosion process a suite of landscape evolution models using the SIBERIA code were developed for a representative face of a borrow pit to predict the response of the pit face to water erosion processes during runoff events.

The models provide a quantitative description of the evolution of slopes and channels over time. The objective of the models was to provide a realistic estimate of the rate of progression of hillslope erosion loss and channel development towards the existing embankments. Results at 1,000 years showed the greatest elevation change at the crest of the pit wall as expected with channels extending upslope only 100 m to 150 m depending on the rainfall intensity used. Sediment from upslope accumulated at the base of the pit wall effectively decreasing the slope with time. These results represent bare soil conditions. The presence of rock, vegetation, and plant litter are likely to reduce the rates of hillslope erosion and channel growth. Model parameters were based on soil texture measurements at the site and photographs of erosional features, but the model was not calibrated. SIBERIA model predictions of long-term erosion effects for the borrow pits should be considered as approximate assessments of their evolution. The lack of site specific runoff and sediment yield data and the assumption of steady-state landscape forming events make long-term predictions uncertain.

The results of the SIBERIA modeling for the borrow pit are being abstracted and adapted to the disposal mound in the model of the ET Cover. Because of the slope differences, this will over-estimate sediment transport offsite, and will over-estimate depth of gullies formed. This will be included in the next version of the model and the report. Further erosion modeling needs will be evaluated after that model and report are reviewed.

Note also, that under the scenario that the DU waste is disposed below grade, the erosion consequences are likely to be minimized. This is evident in the current model results by comparing the three pairs of scenarios.

See also Interrogatory #120.

71. INTERROGATORY CR R313-25-8(4)(A)-71/1: BIOTIC PROCESSES IN GULLY FORMATION

Provide additional rationale for excluding potentially important biological processes when considering gully formation.

EnergySolutions' Response: One part of this question pertains to the initiation and formation of gullies. Page 4 of the Erosion Modeling report states that animal burrowing is but one mechanism that could lead to gully formation on the cover system.

For the purposes of the model, several simplifying assumptions are made. One of these assumptions is that the gully functions independently of the main model processes. This component of the model looks at the effects of gully formation on the rest of the model. The mechanism of gully formation (e.g., burrowing animals, tree throw, OHV use, tornados) is not important in the function of the model, only that the gully exists.

The various mechanisms that might start a gully are to be considered in the determination of input distributions that would represent the number and timing of gully forming. In the Clive DU PA Model v1.0, no such sophisticated analysis was done—rather, a simple distribution was used as a screening tool in order to determine whether gully formation would be a significant process at the site.

Another part of this question addresses gully penetration into and possibly through the cover, and what effects that may have on dose assessment. It is true that plants that root in gullies or animals that burrow into the bottom or slopes of gullies that have already formed would be closer to the waste than plants and animals on the surface of the cover. The thinner cover at gullies could also result in enhanced infiltration and enhanced radon flux from the wastes below, especially if the radon barrier were compromised.

72. INTERROGATORY CR R313-25-8(4)(A)-72/1: DE MINIMIS DOSE VALUE

Provide the justification for proposing a de minimis (i.e., below regulatory concern) dose value.

EnergySolutions' Response: NRC was required under Section 10 of the Low-Level Waste Policy Amendments Act of 1985 to

“establish standards for determining when radionuclides in waste streams were in sufficiently low concentrations or quantities as to be below regulatory concern, thereby potentially exempting them from NRC Low-Level Waste regulation” (NRC, 2007; NUREG-1853, Section 3.5).

The de minimus risk level introduced in Section 3.3.3 of the Dose Assessment report is not related to establishing concentrations or quantities “below regulatory concern” in disposed waste. Rather, this level was introduced to support a methodology for evaluating collective (population) radiation dose in relation to the as-low-as-reasonably-achievable (ALARA) assessment endpoint of the Performance Assessment.

The rationale for establishing and applying a de minimus risk level in the assessment of collective dose is described in Section 3.3.3 of the Dose Assessment report as follows:

“In the context of the current assessment, and in lieu of guidance that defines what an ‘acceptable’ population dose might be; a means must be applied so that all populations (e.g., the entire United States) are not assessed, as this would be burdensome and meaningless. For instance, it is known that a large population will indeed be exposed to the site if current conditions continue; i.e., the population of drivers on Interstate-80. However, as previously mentioned, each of these drivers would be exposed for very short periods of time. In order to gauge the importance of quantifying dose for this population, and indeed any population that might be exposed for brief periods and/or to very low concentrations, the de minimus risk approach will be applied. As explained previously, according to the EPA a 0.05 mrem/year dose corresponds to approximately a 1-in-1-million excess cancer risk. Receptors other than Ranchers, Sport OHVers, or Hunters will be evaluated using this individual dose threshold to determine whether their doses should be considered when computing collective dose. Cumulative population dose will not include contributions from these receptors unless individual doses are above 0.05 mrem/year.”

Clarification along these lines is being added to the Report.

73. INTERROGATORY CR R313-25-19-73/1: ALARA CONCEPT

Ensure that the information provided on the ALARA concept is consistent with that in International Commission on Radiological Protection (ICRP) Publication 101b.

EnergySolutions’ Response: Sections 1 and 2 of the Decision Analysis Methodology report are being revised to incorporate ICRP Publication 101b. ICRP 101b (2006) describes updates to previous ICRP publications addressing ALARA, BATNEEC (best-available technology, not entailing excessive costs), and optimization. The ICRP document is not limited to radioactive waste issues, therefore not all of the recommendations are germane to radioactive waste disposal, particularly not in the US. However, in general, the ICRP recommendations align with the spirit of the decision analysis approach applied in the PA. For example, ICRP (2006, p. 71) states that “the principle of optimisation is defined by the Commission as the source-related process to keep the magnitude of individual doses, the number of people exposed, and the likelihood of potential exposure as low as reasonably achievable below the appropriate dose constraints, with economic and social factors being taken into account.”

Individual doses are addressed in the PA via comparisons with individual dose limits (consistent with NRC and UDEQ regulations), and ALARA is addressed via estimation of collective population dose over the performance period plus ‘conversion’ of this to economic terms, consistent with NRC guidance (see Section 6.4, pages 76–77, of the Neptune and Company, Inc., Final Report for the Clive DU PA Model version 1.0, June 1, 2011: Appendix A of EnergySolutions, Utah Low-Level Radioactive Waste Disposal License – Condition 53 (RML UT2300249) Compliance Report, June 1, 2011).

For example, the PA’s approach specifically addresses the following characteristics of the population (from Table 3.1, p. 83 of ICRP, 2006):

- Gender
- Age
- Habits
- Characteristics of the exposure
- Distribution of exposures in time and space
- Number of individuals
- Minimum individual dose
- Maximum individual dose
- Mean individual dose
- Statistical deviations
- Collective dose associated with ranges of individual doses

Thus, to the extent possible under the current applicable regulations, the DU PA’s ALARA approach is consistent with ICRP (2006). The ALARA analysis that was performed (and that needs to be updated and fixed) was based on population dose endpoints and on the “cost to society” of such population doses. The dose costs used originated in an expert elicitation sponsored by NRC, and resulted in an estimate of \$1,000 per person rem per year. This has been updated since, but the underlying principle was that this dose cost would be used to represent all associated costs and values. In effect the \$1,000 per person rem per year value judgment is meant to capture many aspects of cost and value judgments.

It could probably be argued (and we would argue) that there are better approaches than using default values provided by NRC and/or DOE. It would be better to develop costs and value judgments that are specific to the site. NRC recently endorsed site-specific Performance Assessments, and this should be a component of a site specific assessment. We would argue that more effort should be put into these aspects of the model so that waste disposal, closure and long term maintenance/monitoring can be optimized. ALARA opens the door for this type of analysis, but at the moment we have tried to move the process forwards a few steps by actually incorporating an ALARA analysis of this type.

Note also, there are other aspects described in the ICRP document, such as social considerations/value or environmental (e.g., ecological impacts) considerations, which are not directly addressed in PAs. It is arguable whether the original \$1,000 per person rem per year value includes these aspects. The basic decision analysis approach could certainly be expanded to incorporate any of the types of analysis discussed in ICRP (2006; e.g., Annex A) depending on the particular need. We agree with the ICRP that PAs should move toward a more holistic, decision-analysis basis; as this approach would allow broader set of considerations to be assessed in a rational decision-making framework. This would lead to much more effective disposal, closure and long term maintenance/monitoring decisions. The approach employed in the DU PA is a step in this direction.

74. INTERROGATORY CR R313-25-8(5)(A)-74/1: TAILORED DISCUSSION OF SENSITIVITY ANALYSIS

Expand on the Sensitivity Analysis report to discuss the sensitivity index and the partial dependence plots for specific parameters modeled in the Clive DU PA.

EnergySolutions' Response: The purpose of the white papers is to provide details about inputs to the process, and, in this case, the SA methods used for model evaluation and identification of sensitive parameters (variables). It is not intended to describe results. However, the results section in the main text is being expanded, or an appendix is being added that more fully describes the sensitivity analysis output, and provide more context when certain types of input (such as inventory) are not identified as sensitive.

75. INTERROGATORY CR R313-25-7(9)-75/1: BRANCHING FRACTIONS

Provide a reference list with complete information for Tuli, 2005.

EnergySolutions' Response: A References Section is being created and the following reference is being added to the Model Parameters report.

Tuli, J.K., 2005, Nuclear Wallet Cards, National Nuclear Data Center. Brookhaven National Laboratory. Seventh edition, April 2005.

76. INTERROGATORY CR R313-25-7(10)-76/1: QUALITY ASSURANCE PROJECT PLAN SIGNATURE PAGE

Provide a complete signature page for the Quality Assurance Project Plan and its appendices.

EnergySolutions' Response: The Quality Assurance Project Plan and appendices are being updated to include signatures of Neptune and Company officials. There were no Utah approvals required.

77. INTERROGATORY CR R313-25-7(10)-77/1: QUALITY ASSURANCE PROJECT PLAN PAGE NUMBERING

Provide page numbers in the Quality Assurance Project Plan.

EnergySolutions' Response: The Quality Assurance Project Plan is being revised to include page numbers.

78. INTERROGATORY CR R313-25-7(10)-78/1: GOLDSIM MODEL CALIBRATION

Describe the role of model calibration in substantiating that GoldSim adequately simulates the physical, chemical, and biological processes at the Clive site.

EnergySolutions' Response: Calibration of a model refers to demonstrating that the model is capable of producing values of the state of a system consistent with observed values. Calibration is accomplished by determining the combination of model structure, parameters, boundary conditions, and forcing functions that produce the values of the state of a system that give the best possible fit to the observed values. Model calibration is one approach used for model parameter estimation. Model calibration is usually considered to be a step in the model development process rather than part of model corroboration and verification. However, traditionally model calibration is used on models that are parameter rich and data poor, in which case the calibration (really estimation) must be constrained, so they cannot cover the entire parameter space. For this reason, Bayesian methods would be better, but this is not the current direction of traditional calibration.

The system states simulated by the Clive DU PA model are the concentrations of radionuclides in media (and eventually dose) over extremely long time periods. For calibration, these concentrations in media would be required as calibration targets. Radionuclide concentrations representing transport for long time periods have been identified at natural analog sites but are not available for most disposal sites. Because of the long time periods considered, a calibration exercise for the Clive DU PA model where parameter distributions are adjusted to match observed concentrations is not feasible.

An approach different from calibration was used to represent parameters for the Clive DU PA model. Due to natural heterogeneity and random variability a model parameter is often more accurately represented by a statistical distribution than by a single value (EPA, 2009). The data range and variance of the spatial and temporal effects being modeled for the Clive DU analysis are too broad for data that represent points in time and/or space to be used directly. The probabilistic simulations for the PA modeling involve randomly selecting values from all input distributions (outside of the exposure parameters), and then applying those values

to the entire spatio-temporal domain of the model. Spatio temporal scaling (upscaling) is the methodology used to transform point data into distributions representing expected values of a parameter and their uncertainty for model input. Upscaling in this context is a form of averaging to the time steps and spatial scale of a specific modeling application. The upscaled parameter input distributions also provide the basis for the uncertainty analysis for the model.

Approaches for the model evaluation process including verification and corroboration are described in the response to Interrogatory CR R313-25-7(10)-80/1: Testing of GoldSim Abstractions.

The Clive DU PA Model is a highly-integrated system model, with many interrelated processes. Given that these processes influence each other, and their combination can produce sometimes counter-intuitive results, there is no practical way to verify the calculations. The main approaches used for model evaluation for the DU PA model are reasonableness testing during model development, and global sensitivity analysis. Global sensitivity analysis is used for far more than simply identifying sensitive parameters. It is used throughout model testing to evaluate the model, determine if the model is performing in ways that are expected, and for evaluating if there are components of the model that need refinement. Because all the inputs are probabilistic, the global sensitivity analysis varies all inputs simultaneously. It is essentially a regression analysis, but piecewise non-linear regression. As such the output can be interpreted directly. If the results do not match expectations of the model, then the sensitivity analysis will very quickly indicate that there is something not quite right, and the model is investigated for the unexpected results. This is a very powerful tool for model evaluation. The approach is very different than the calibration approach described above, but provides justification for the model, and a basis for model updating as more data are collected. This cycle of model building and sensitivity analysis will continue throughout the PA Maintenance program.

Otherwise, the only process that is actively calibrated within the Clive DU PA Model v1.0 is that of the air-phase diffusion of radon gas. This is deemed necessary since the relatively short half-life of ^{222}Rn (under 4 days) adds a challenge to numerical analysis of diffusive transport of species that decay quickly relative to the rate of diffusion. (The interested user can research Dahmköhler numbers.) The calibration is to the analytical solutions provided in the Nuclear Regulatory Commission Regulatory Guide 3.64 (NRC 1989).

79. INTERROGATORY CR R313-25-7(10)-79/1: CRITICAL TASKS AND SCHEDULE

Update the schedule and completion dates for the critical tasks.

EnergySolutions' Response: The Quality Assurance Project Plan (QAPP) is being revised to include actual completion dates for scheduled tasks and those that were indicated as TBD at the outset of the project as appropriate.

80. INTERROGATORY CR R313-25-7(10)-80/1: TESTING OF GOLDSIM ABSTRACTIONS

Provide information on the verification and benchmarking exercises that were designed to test the GoldSim abstractions against results obtained from process-level analytical and/or numerical models.

EnergySolutions' Response: Neptune uses a process for the model validation/verification and benchmarking described in this Interrogatory to test the GoldSim abstractions against results obtained from process-level analytical and/or numerical models. For the DU PA Model v1.0, model verification primarily consisted of reasonableness checking and did not include formal model benchmarking processes.

81. INTERROGATORY CR R313-25-7(2) AND 7(6)-81/1: COMPARISON OF DISPOSAL CELL DESIGNS

Provide a detailed annotated comparison of (1) the design of the Class A South embankment design¹ described in FRV1 and upon which the DU PA dated June 1, 2011, was based, (2) the Division-approved Class A West embankment design discussed in the 2013 Compliance Report (Revision 1, 2013) and (3) the Federal Cell design now proposed for DU disposal. The comparison should include design features and design criteria that are common to the three cells, as well as those that are different among the three designs. The comparison should include such factors as physical dimensions, materials used, types of waste, infiltration rates, depth of waste burial, waste depth compared to native grade, design life of the cell, liner and cover system specifics and other assumptions used in groundwater modeling, such as soil layer porosity and permeability, soil/water partition coefficients (K_d values) and solubilities. Explain and justify why the Class A West Cell design is relevant and applicable to the new DU disposal cell to be constructed in the far southwest corner of Section 32.

¹ At a minimum, this would include both *Amendment Request Class A South/11e.(2) Embankment*, Revision 0, dated January 4, 2008 (EnergySolutions 2008), and *Class A South/11e.(2) Embankment Revised Application & Response to Completeness Review*, dated June 9, 2009 (EnergySolutions 2009).

Also explain and justify why current construction specifications and quality assurance/quality control requirements used at the Class A West Cell (or any other Clive disposal cell) have relevance to the DU PA, now that DU Waste disposal is to be examined for at least 10,000 years.

Provide a single, stand-alone engineering design report, including drawings and construction specifications, for the cell where DU waste will be disposed. Include detailed cross-sections to clearly identify the specific below-grade depth interval that the DU waste will occupy, as well as design elevations for all pertinent site and disposal embankment features. If EnergySolutions plans to implement any evapotranspirative cover design for the DU cell, provide specific, discrete, and detailed engineering plans and specifications for the cell where this disposal will take place. Explain the current status in obtaining approval from DRC of an evapotranspirative cover design for the Class A West Cell.

Describe the types, forms, and locations of intruder barriers that will be provided for the DU waste in the disposal cell selected. Elaborate on how these barriers can and will endure across deep time periods (i.e., at least 10,000 years).

EnergySolutions' Response: Drawing series 14004 is provided in Section 4.0 to this response to clarify Federal Cell design and placement of significant quantities of depleted uranium therein.

See also the response to interrogatories CR R313-25-7(6)-84/1 and CR R313-15-1009(2)(B)(I)-158/1.

82. INTERROGATORY CR R313-25-20-82/1: LIMITATION ON INADVERTENT INTRUDER SCENARIOS

Explain and justify why the language of R311-25-7(8) limits the types of intrusion scenarios to be considered.

EnergySolutions' Response: Limitation and selection of credible inadvertent intruder scenarios are addressed in the response provided to Interrogatory CR R313-25-8(4)(B)-07/1.

83. INTERROGATORY CR R313-25-20-83/1: INTRUDER-DRILLER AND NATURAL RESOURCE EXPLORATION SCENARIOS

Explain why a lack of subsurface mineral resources renders the intruder-driller scenario inapplicable. Evaluate inadvertent intrusion at locations within the facility's buffer zone and determine all exposure pathways and doses to a member of the public.

Explain the reason for excluding the intruder-driller scenario from this PA, taking into account the fact that the guidance in NUREG/CR-4370 refers to an intruder drilling for water, not mineral resources, and the fact that such a scenario was included in a prior site-specific PA.

EnergySolutions' Response: See the response to Interrogatory CR R313-25-8(4)(b)-07/1. Additional justifications and scenario descriptions are included in Report Appendices 1 “Clive DU PA FEP Analysis”, 2 “Clive DU PA CSM”, and 11 “Dose Assessment”.

84. INTERROGATORY CR R313-25-7(6)-84/1: BELOW-GRADE DISPOSAL OF DU

Explain how Figure 1-2 demonstrates that the entire inventory of DU can be disposed below grade. Provide calculations demonstrating that below-grade disposal will be achieved in the Federal Cell and that the burial depth is sufficient to protect the DU waste.

Indicate the drum/cylinder dimensions and orientation after placement on the respective waste lifts. Indicate the container packing arrangement (e.g., cubic, rhombic, octahedral) and the minimum, maximum, and average distance that will be left between DU containers. Explain how a degraded embankment would continue to adequately control radiation dose to a member of the public and describe the types, forms, and locations of intruder barriers and how they will endure for a period of 10,000 years or more.

EnergySolutions' Response: Figure 1.2 has been clarified to reflect EnergySolutions' commitment that only a volume of depleted uranium that can be disposed of below grade in the Federal Cell will be managed, regardless of placement geometry.

“Below grade” is defined as being below the original grade elevation of the Clive site with no minimum additional cover. The performance assessment demonstrates that it is highly unlikely that a pluvial lake will encroach on the embankment within the compliance period; therefore, significant quantities of depleted uranium will remain buried beneath the overlying above-grade portion of the Federal Cell and its cover system. No additional cover or barrier is required to demonstrate performance to the compliance criteria.

NRC has confirmed that depleted uranium, even in significant quantities, is Class A LLRW. Thus, there is no requirement for an intruder barrier, let alone a demonstration that it could persist for 10,000 years or more.

In order to address the current round of interrogatories, the model is being revised to replace the rip-rap cover with an ET cover. This will have a significant effect

on infiltration (lowering infiltration) so that disposal of DU below grade is not expected to adversely impact groundwater. In addition, an erosion model is being included that addresses both sheet and gully erosion based on the properties of the ET cover. Upon this evaluation, a more informed response can be provided concerning the potential effects of erosion on waste buried below grade.

Regarding the comment on pluvial lake recession, more recent research indicates that the return of a pluvial lake is extremely unlikely in this climate cycle (less likely than modeled) because of the combination of expectation of insolation in the current climate cycle and current CO₂ levels. However, aeolian deposition will continue unabated, at rates that are at least 0.1 mm/yr (and perhaps considerably more). Consequently, by the time a lake returns, the site will be partially buried by aeolian sedimentation, or if the next lake does not arrive until the next climate cycle, completely buried. An update to the model is warranted given this new information. Consequently, under some reasonably possible, or even likely, future scenarios the site will not be destroyed by the first lake, but will instead be further covered instead. The aeolian deposition rates should be considered as part of the relatively near-term erosion modeling and the deeper time modeling. In both cases the aeolian deposition seems likely so enhance site stability.

The response to Interrogatory #18 describes the available information on aeolian deposition, and further research is being performed prior to completing the next version of the model.

85. INTERROGATORY CR R313-25-8(4)(A)-85/1: UNCERTAINTY DISTRIBUTIONS ASSIGNED TO DOSE CONVERSION FACTORS

When discussing the uncertainty associated with the risk coefficients in Federal Guidance Report 13, the discussion should include the work performed by Pawel et al. (2007), which was an update of the uncertainty analysis in Federal Guidance Report 13 for the cases of inhalation and ingestion of radionuclides and expands the analysis to all radionuclides addressed in that report. In addition, reference should be made to the guidance provided in NCRP, 1996; NCRP, 1998; NCRP, 2007; NCRP, 2009; NCRP, 2012; and Puncher and Harrison, 2013.

EnergySolutions' Response: With regard to part (1) of the last paragraph of the Basis for Interrogatory, please see the final paragraph of Section 3.4.3 of the Dose Assessment report:

“Note that this method only addresses one component of uncertainty associated with DCFs, and thus must be viewed as a pilot effort.”

The text of Sections 3.4.3 and 3.4.4 of the Dose Assessment report is being revised to include a summary of the literature that discusses the other factors that

contribute to uncertainty in the DCFs and the rationale for developing distributions that addressed only a limited portion of DCF uncertainties, as requested in parts (2) and (3) of the last paragraph of the Basis for Interrogatory. Key points from the supplemental information related to DCF uncertainty provided below are being used for these revisions.

Additionally, the last sentence of the first paragraph of Section 4.4 is being modified as:

“Distribution development for one source of uncertainties inherent in DCFs (i.e., associated with REFs) was described previously.”

Supplemental Information

Issues Associated with Addressing DCF Uncertainties in Addition to the REFs

1. Some sources such as EPA (EPA 2007, or Pawel et al. 2007) evaluate uncertainty associated with risk, not dose. It is difficult to separate out sources of dose-related uncertainty from those associated with dose-response (i.e., risk) in EPA’s work. However, because EPA has already conducted the considerable research to develop uncertainties associated with radionuclide-specific risks, an efficient alternative would be to evaluate cancer risk as part of the PA modeling and as an endpoint in addition to radiation dose. There are substantial advantages to a risk-based approach. While dose is essentially a proxy for risk, risk is likely better understood by stakeholders and decision-makers than dose; and would allow other analyses such as PAs for mixed chemical-radionuclide waste to be conducted, comparisons to be made between radioactive waste disposal and other forms of hazardous waste disposal, and so on. However, all of the present radioactive waste regulations focus on dose. If NRC was willing, EPA’s or a similar risk assessment approach could be applied alongside the dose assessment for comparative purposes. The cancer risk results can be used to inform the PA model sensitivity analysis. Dose could still be used to assess regulatory compliance, and cancer risk can be used to inform sensitivity analysis and risk communication and optimized decision making.
2. There would be considerable benefit to quantifying the full range of uncertainties associated with DCFs and/or risk. At present the total uncertainty associated with DCFs (aside from REFs) and/or risk conversions (see above) is not quantified in the PA, and thus total uncertainty in the PA modeling results is underestimated. Underestimation of total uncertainty can lead to suboptimal decisions; as the final dose or risk distributions will be too ‘narrow’ (i.e., expressing overconfidence in results). DCF and risk uncertainty could be considerable contributors to total uncertainty, and indeed could

overwhelm other sources of uncertainty in the PA modeling that have been previously identified as major contributors in the sensitivity analysis only because the scope of DCF/risk uncertainty assessment has been limited. In other words, if DCF and/or risk uncertainty are included in the sensitivity analysis, they may be ranked quite high in terms of contribution to total uncertainty.

3. As the only source of uncertainty associated with DCFs that was evaluated was the REF, a review of the broader literature was not considered necessary. However, if further sources of uncertainty are to be evaluated, then this literature should be reviewed. A brief example of such a review follows.
4. A major implicit assumption in the use of DCFs and dose limits is that ionizing radiation exhibits a linear, no-threshold dose-response curve with regard to carcinogenicity (the linear no-threshold hypothesis, or LNT). This has been assumed for many years, but there is a large and growing literature that counters this assumption; i.e., that ionizing radiation exhibits thresholds of effect and/or triggers adaptive response (depending upon the type of radiation, target organ system, etc.). If cancer risk is evaluated, then this could potentially allow thresholds of effect to be evaluated. This would likely affect estimated risks dramatically, as at present the assumption that there is no threshold of effect (with 100% confidence) may identify low-dose risks where none exist.
5. Quantification of other-than-REF uncertainties associated with DCFs would require some effort that is beyond the scope of this project alone. In some cases, these may be available in the literature (e.g., the work of Puncher and Harrison 2013), but such work has been performed for only a few of the radionuclides of interest. An efficient process may be to start with the radionuclides that have been evaluated by other researchers in order to demonstrate the impact of incorporating other-than-REF uncertainties in the dose assessment.
6. Incorporation of other sources of DCF uncertainties, or cancer risk uncertainties, will require model and distribution development, and thus can only be addressed in a future PA model revision.

Brief Review of Relevant Literature.

A number of groups have investigated uncertainty in radiation dose that is delivered to internal target organs (i.e., effective dose, via use of DCFs). For example, the US National Committee on Radiation Protection and Measurements (NCRP) has published a general methodological guide for uncertainty analysis in dose and risk assessments (NCRP 1996), a guide for evaluating the reliability of

the biokinetic and dosimetric models used to assess individual doses (NCRP 1998), and assessments of uncertainties associated with internal (NCRP 2009) and external (NCRP 2007) dosimetry. Additionally, the United Kingdom's Health Protection Agency's (HPA's) Centre for Radiation has conducted uncertainty analyses of internal and external dosimetry (Puncher and Harrison 2012, 2013).

Major sources of uncertainty associated with effective dose estimation include the following (Puncher and Harrison 2012):

- Biokinetic models and their parameter values that are used to predict the dynamic distribution of radioactivity within the body
- The geometric relationship of source and target tissues, their dimensions and masses. These influence the amount of energy deposited in tissues
- The relative effectiveness of different radiation types in causing cancer and differences between tissues in their sensitivity to radiation induced cancer

Estimation of disease dose-response and risk (i.e., risk assessment) and associated uncertainties involves 'translating' effective dose into estimation of additional disease (typically cancer) probability. The Biological Effects of Ionizing Radiation (BEIR) VII report (National Research Council 2006) contains extensive information on the state of knowledge regarding radiation dose-response, including a limited uncertainty analysis. Both NCRP (2012) and the US Environmental Protection Agency (EPA 2007) have investigated some sources of uncertainty in risk assessment.

With regard to evaluating radiation risk, major sources of uncertainty include the following (NCRP 2012):

- Issues associated with epidemiological and animal study design and application, including low statistical power and precision
- Inadequate or simplistic modeling of radiation risk (especially at low doses), or assumption of one generic model (typically the the linear no-threshold hypothesis, or LNT, model)
- Extrapolation or generalization of risk estimates to different populations

As an example, EPA (2007) estimated uncertainties for radionuclides that have published risk coefficients in EPA's Federal Guidance Report (FGR) No. 13 (EPA 1999). They addressed the following sources of uncertainty:

- Biokinetic models describing the biological behavior of ingested or inhaled radionuclides
- Specific energies that relate emissions from source organs to energy deposition in target organs
- Risk model coefficients representing the risk of cancer per unit absorbed dose to sensitive tissues from radiation at high dose and high dose rates
- Tissue-specific dose and dose rate effectiveness factors (DDREF); and tissue-specific high-dose relative biological effectiveness (RBE)

Uncertainties associated with alternative dose-response statistical models (i.e., aside from the LNT model) were not addressed by EPA (2007). EPA (2007) employed a combination of modeling and expert opinion in the analysis, and concluded that “the assessed uncertainty in the radiation risk [as opposed to dose] model was found to be the main determinant of the uncertainty category for most risk coefficients, but conclusions concerning the relative contributions of risk and dose models to the total uncertainty in a risk coefficient may depend strongly on the method of assessing uncertainties in the risk model”.

All groups that have attempted to analyze uncertainties associated with radiation effective dose and risk have acknowledged that this is a difficult undertaking, and there is no generic “one-size-fits-all” solution. Each type of radiation and target organ dose-response has unique characteristics. Therefore, the most straightforward way to evaluate uncertainties in dose and risk may be to employ the FGR 13 central values and ‘uncertainty categories’ published by EPA (1999, 2007). These are represented as a ratio of the 95th to the 5th quartiles:

Table 2-85/1. EPA Uncertainty Categories.

Uncertainty category	Definition
A	$Q_{95} / Q_5 < 15$
B	$15 \leq Q_{95} / Q_5 < 35$
C	$35 \leq Q_{95} / Q_5 < 50$
D	$50 \leq Q_{95} / Q_5 < 150$
E	$Q_{95} / Q_5 \geq 150$

As an example, if an uncertainty factor is 100, then a risk coefficient could vary from the published FGR 13 value by a factor as great as 10 (the square root of 100). Most radionuclides fall within categories A or B.

Unlike any other sources reviewed, ratios are available for a large (>800) number of radionuclides. The exact ratio values (as opposed to the letter categories) are available for all radionuclides with risk coefficients in FGR 13 (EPA 1999). Assuming a distributional shape such as lognormal, distributions can then be developed.

If uncertainties associated with effective dose only are evaluated, the scope of existing and published work is much more limited. For example, Puncher and Harrison (2012, 2013) only evaluated uncertainties for 9 radionuclides via ingestion and inhalation.

Recommended Approach for Incorporating Uncertainty in Radiation Dose / Risk

A possible initial approach might be to evaluate:

- 1) Uncertainties in risk estimates using the uncertainty factors in EPA (2007) as applied to applicable risk coefficients in FGR 13 (EPA 1999).
- 2) Uncertainties in DCFs using the Puncher and Harrison (2012) estimated distributions presented in Section 3.4 in that report. As mentioned above, these distributions are only for a limited set of radionuclides, but this will provide a ‘proof of principle’ exercise and a point of comparison with the risk distributions estimated using EPA (1999, 2007).

Note that neither of these approaches estimate uncertainty associated with choice of dose-response model (e.g., alternatives to the LNT approach). However, they will provide a more complete assessment of uncertainty compared with the REF-only uncertainty evaluated in the first version of the PA model. Once incorporated into the PA model and sensitivity analyses are conducted, a decision can then be made as to next steps; i.e. if the risk and/or DCF uncertainties are ranked high in the sensitivity analysis, then further investigation may be warranted. Regardless, eventual incorporation of dose-response model uncertainty will likely be important in terms of assessing the full range of uncertainty associated with estimated risks.

86. INTERROGATORY CR R313-25-8(5)(A)-86/1: CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL

The deep time assessment needs to consider the relative rates of progeny in-growth and pluvial lake sedimentation. It should be determined if there are points in time when individual exposures can be greater than at the time of peak activity, due to the influence of sedimentation on reducing surface concentrations of contamination or of wave-cutting increasing access to waste and doses received by receptors.

EnergySolutions' Response: There are two issues with this interrogatory statement. First, individual doses are evaluated only in the first 10,000 years of the PA using multiple exposure scenarios. Exposure scenarios with dose assessments are not evaluated in the second stage of the PA – deep time assessments. Instead radioactive species concentrations in lake sediments are tracked for multiple glacial cycles extending from 10,000 years to 2.1 Ma (see the first paragraph of the top of page 41 of Appendix A of the PA document).

Second, as explained in the first full paragraph of page 29 of Appendix 13 Deep Time Assessment, the first lake in the glacial cycle is assumed to remove and mix the above grade embankment material including both the above grade and below grade DU and associated waste. All of the DU waste in the disposal system is dispersed by lake-driven transport processes with the arrival of the first lake. The timing of the first lake arrival is modeled as a Poisson process with a rate that increases linearly over the glacial cycle time of 100 ka. Subsequent lakes (intermediate and large lakes) remix the sediment-waste with coincident dissolution of wastes into the water column and burial under new cycles of lacustrine sediments. In-growth of uranium progeny continues throughout the deep time assessment but is secondary to complete removal and dispersal of all buried DU waste in the first lake cycle. Overall sediment concentrations decrease through sequential glacial cycles because lake sedimentation continues but the only changes to the total waste inventory in the sediment mixtures are from decay and ingrowth.

No changes in the text are required.

As is noted in response to Interrogatory #18, the current modeling does not account for aeolian deposition prior to the return of the first lake. Given the current climate cycle is now considered unlikely to produce a lake that inundates Clive, the time frame over which aeolian deposition might happen could result in partial or complete burial of the disposal mound prior to the return of a lake. Aeolian deposition affects both erosion in the 10ky Compliance Period and longer term stability in deep time. Please see the response to Interrogatory #18.

87. INTERROGATORY CR R315-101-5.3(6)-87/1: ORAL TOXICITY PARAMETERS

The approach used in the Dose Assessment report with regard to oral toxicity should be revised based on the established drinking water standard for uranium and a review of recent literature on hazards from uranium ingestion. The report should also explain how the oral toxicity factors used in the PA were derived, as they may understate risk.

EnergySolutions' Response: Since ingestion of groundwater is not a dose pathway, the Dose Assessment report is correct, as provided. See the response to Interrogatory CR R313-25-7(2)-91/1 for more detail.

The proof-of-principle approach used in the Dose Assessment report to represent the oral toxicity of uranium was based on EPA's toxicity assessment supporting the current drinking water standard (maximum contaminant level [MCL] of 30 µg/L), and is correct. The uranium oral reference dose (RfD) of 0.0006 mg/kg-day associated with the derivation of the final uranium MCL is defined on page 76713 of Federal Register, Volume 65, No. 236, December 7, 2000 (Section I.D.2d). The discrepancy with the calculation provided stems primarily from the fact that the uranium oral RfD of 0.0006 mg/kg-day derived by EPA is related to a best-estimate drinking water equivalent level of 20 µg/L, rather than the final uranium MCL of 30 µg/L.

The EPA oral RfD of 0.003 mg/kg-day that is used in the PA is not that for "Uranium, natural" but rather for "Uranium, soluble salts." The basis for this oral RfD, which is published in the Integrated Risk Information System (IRIS) supporting the Superfund Program, is an EPA toxicity assessment published in 1985.

The discrete distribution used in the PA for uranium non-radiological oral toxicity assigns equal weight to the two oral RfDs. These RfDs reflect current EPA science policy associated with EPA's Superfund Program and Office of Water. A 50/50 probability was assigned to these oral RfDs to determine in the Sensitivity Analysis whether selecting one or the other of these published values was a significant contributor to uncertainty in the uranium Hazard Index in any exposure scenario. As discussed in response to Interrogatory CR R315-101-5.3(6)-33-1, the difference between the two uranium RfD values contributed less than 10% to uncertainty in receptor hazard index results.

Note that the global sensitivity analysis effectively changes all parameters simultaneously to find the most important (sensitive) parameters for a given endpoint. The uncertainty expressed in the uranium RfD could perhaps be expressed in different and arguably better ways, but the difference between the two values used appears to be swamped in the model by other uncertainties. Hence, the uranium RfD does not show up as a sensitive parameter.

88. INTERROGATORY CR R313-25-19-88/1: COLLECTIVE DOSE AND ALARA

Confirm that the population (collective) doses over 10,000 years presented in FRV1 Table 11 are not in error, underestimating those doses by about a factor of 10. If the doses are correct, explain and justify why it should stand as written.

EnergySolutions' Response: It is acknowledged that an error was made in calculation of collective doses. This error is being addressed in the next version, and is being coupled with the revised ET Cover design that is being incorporated into the next revision (hence all values will change, and will be reported correctly).

89. INTERROGATORY CR R313-25-7(9)-89/1: CONTAMINATION LEVELS IN DUF6

Review the basis for setting contamination levels in the DU PA and consider the substantial amount of contamination information available from the GDPs in lieu of surrogate data based on DU from SRS. Direct particular attention to contamination remaining in the heels of the DUF₆ cylinders. Describe in the PA how EnergySolutions will ensure that the cylinders shipped to Clive do not contain contaminated heels resulting from introduction of recycled uranium into the GDP process streams.

Revise the PA report to do the following:

1. Incorporate the new technical literature information for nuclide activity in the GDP DU waste.
2. Explain and justify why the already buried nuclear inventory for Clive was not included in the DU PA model, as required by R313-25-8(5)(a).

EnergySolutions' Response: Responses to the two items that are the subject of this interrogatory follow:

1. Incorporate the new technical literature information for nuclide activity in the GDP DU waste.

While the reports in question are available, the analysis relies primarily on information provided by personnel at the U.S. Dept. of Energy and personnel associated with the DUF6 Project in Piketon (near Portsmouth), OH, and Paducah, KY, since they are most familiar with the particular population of GDP DU that is the subject of this PA exercise. After many conversations with various DUF6 Project personnel, Neptune was advised to rely on the Hanson (2006) report, as it had been produced with the benefit of the Hightower et al. (2000) report and other technical memoranda from Oak Ridge National Laboratory in 2000. As such, the DU literature and DU waste is being revised in the Clive DU PA Model, as appropriate.

It should be noted, however, that the sensitivity analysis of the Clive DU PA Model v1.0 does not indicate that the fraction of contaminated cylinders or their precise isotopic composition were good predictors of model endpoints—therefore, refining the definitions of these parameters is unlikely to result in

meaningful differences in these results, or in the decisions made based on those results.

Contaminated cylinders will not be cleaned during the deconversion process. They will be inspected, and those deemed to have sufficient integrity will be reused, contaminated heels or not, for storage, transport, and disposal of U3O8 (personal communication from Jack Zimmerman to John Tauxe). Those without such integrity will be disposed as waste, not subject to this PA.

Also see response to Interrogatory #51.

2. Explain and justify why the already buried nuclear inventory for Clive was not included in the DU PA model, as required by R313-25-8(5)(a).

The average concentration of DU historically disposed by EnergySolutions prior to January 2010 is 1,988 pCi/g (which is less than the 5-percent limit promulgated in UAC R313-25-8(2)(c) of 1.8E+4 pCi/g - as clarified by the Division on May 24, 2010).

90. INTERROGATORY CR R313-25-7(1-2)-90/1: CALIBRATION OF INFILTRATION RATES

Explain how the infiltration rates predicted with HELP/UNSAT-H and HYDRUS were calibrated against actual field data. Explain and justify which infiltration rate should apply to the DU disposal embankment (Federal Cell) at Clive, addressing radon barrier damage via frost heave, root penetration, animal burrowing, insect burrowing, and desiccation.

EnergySolutions' Response: In development of the new evapotranspirative (ET) cover design, EnergySolutions examined the performance of other similar cover systems in use in the arid west (Appendix D of EnergySolutions, 2013b). EnergySolutions also examined natural localized plateaus and land features in the Clive area similar in shape, surface soil type, and slope to that proposed for the Federal Cell (Appendix D of EnergySolutions, 2013b). Furthermore, EnergySolutions used as input to the models site-specific meteorological data obtain at their Clive meteorological station since 1993 (MSI, 2014).

Additionally, EnergySolutions has historically been required to consider bounding input and overly conservative assumptions in its various performance assessments. These in turn have always predicted infiltration at rates orders of magnitude higher than anything observed onsite via collection lysimeter and Cover Test Cell performance.

The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design. These analyses

demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two order of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

While the Clive DU PA Model v1.0 relied on HELP modeling by Whetstone for determining the infiltration rates, this is being revisited in the next version of the model. The new modeling evaluates the hydraulic behavior of an evapotranspirative cap, rather than the former design of a rip-rap armored cap. This change in cap design makes moot the hydraulic modeling performed for the Clive DU PA Model v1.0.

91. INTERROGATORY CR R313-25-7(2)-91/1: DESIGN CRITERIA FOR INFILTRATION

Include specific design criteria for infiltration into the Class A South Cell (subsequently called the Federal Cell) and explain how the Utah groundwater protection levels will be met for 10,000 years. Explain and justify which infiltration rate will apply to the DU disposal cell and how a 500-year PA analysis for the groundwater pathway is compliant with R313-25-8(5)(a) in terms of both model prediction time and determination of peak dose.

EnergySolutions' Response: Revisions underway to the depleted uranium Performance Assessment GoldSim model demonstrate that infiltration into the Federal Cell's evapotranspirative cover complies with limitations of EnergySolutions' GWQDP.

The interrogatory, however, erroneously conflates R313 radiological dose standards with R317 non-degradation standards. The former, at R313-25-8(5), clearly does require a compliance period of 10,000 years for the "...performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules..." The performance standards of 10 CFR Part 61 and corresponding Utah rules are based on radiological dose to human receptors. There is not a requirement in 10 CFR Part 61 or rules adopted under Utah's Agreement State program implementing 10 CFR Part 61 to eliminate potential environmental impacts that do not cause radiological doses to be exceeded. Rather, 10 CFR 61.41 states: "*Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably*

achievable.” The corresponding Utah rule is found at R313-25-19: “*Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.*” Releases to the general environment should be minimized, subject to the principle of ALARA.

Utah ground water protection rules for Class IV aquifers at R317-6-4.7 set a standard subject to interpretation: “*Protection levels for Class IV ground water will be established to protect human health and the environment.*” No timeframe is provided; nor does this general statement in and of itself require a non-degradation standard. Rather, the Director is provided with discretion to set reasonable criteria for Class IV groundwater. This has been implemented (Part I.D.1 of Permit UGW450005) as requiring radioactive waste disposal facilities to demonstrate non-degradation of the groundwater for 200 years for non-radiological contaminants and 500 years for radiological contaminants. It should be noted that non-radiological contaminants consisting of heavy metals have an infinite environmental half-life; while radiological contaminants such as Tc-99 decrease with time, albeit over very long timeframes for nuclides with long half-lives. It should further be noted that the Division sets a considerably higher standard for radioactive waste disposal facilities than for any other groundwater discharge permittee in the state.

As a groundwater quality standard, non-degradation has been demonstrated using groundwater protection levels based on a potential dose of 4 mrem/year. In establishing this standard, certain simplifying assumptions were made regarding human consumption. That is, an assumption is made that the untreated water could be consumed and thus represents a dose pathway. For highly saline sources of groundwater, the consideration of untreated consumption in evaluating health protection determinations can be particularly critical and is consistent with the discretion described in NUREG-1573. For groundwater at the Clive facility, untreated consumption would of course lead to death within a matter of days for the consuming individual due to the high salt content. Consequently, for performance assessment purposes, considering site-specific data regarding groundwater quality, uses, and reasonable receptor pathways is an appropriate approach and is consistent with prior and current performance assessment approvals for the facility.

The non-degradation standard applies for a “*minimum*” of 500 years in accordance with Part I.D.1 of the Ground Water Quality Discharge Permit. As is summarized below, every approved PA for LLRW disposal at Clive has clearly documented a potential for Tc-99 and other mobile isotopes to exceed 4 mrem at some point after 500 years.

Table 2-91/1. Part I.D.1 of the Ground Water Quality Discharge Permit

Embankment	Nuclide	Year	Source
		Exceeding	
Class A West	Side Slope (0.168 cm/yr)		11/28/2011 Modeling Report
	Bk-247	500	
	Ca-41	500	
	Cl-36	500	
	I-129	500	
	Re-187	500	
	Tc-99	500	
	Si-32	530	
Class A West	Top Slope (0.090 cm/yr)		11/28/2011 Modeling Report
	Bk-247	500	
	Ca-41	500	
	Cl-36	500	
	I-129	705	
	Tc-99	715	
	Re-187	855	
	Si-32	1080	
Mixed Waste	Top Slope (0.183 cm/yr)		11/22/2000 Modeling Report (Cf-249 subsequently changed)
	Bk-247	500	
	Cf-249	500	
	Cl-36	500	
	Ca-41	640	
	I-129	1500	
	Tc-99	1500	
	Re-187	1500	
Mixed Waste	Side Slope (0.096 cm/yr)		11/22/2000 Modeling Report (Cf-249 subsequently changed)
	Bk-247	780	
	Cl-36	775	
	Cf-249	845	
	Ca-41	1080	
Class A Combined (Class A North)	Top Slope (0.244 cm/yr)		4/2006 Modeling Report
	Re-187	625	
	Tc-99	810	

Embankment	Nuclide	Year	
		Exceeding	Source
	I-129	855	
	K-40	1010	
Class A Combined (Class A North)	Side Slope (0.507 cm/yr)		4/2006 Modeling Report
	Re-187	500	
	Tc-99	500	
	I-129	500	
	K-40	565	
	Si-32	1500	
Class A Combined (Class A North)	Side Slope (0.451 cm/yr)		4/2006 Modeling Report
	Ca-41	500	
	Re-187	500	
	Tc-99	555	
	I-129	585	
	K-40	705	
Western LARW (Class A)	Top Slope (0.265 cm/yr)		7/19/2000 Modeling Report
	Re-187	745	
	Tc-99	785	
	I-129	830	
	K-40	990	
Western LARW (Class A)	Top Slope (0.310 cm/yr)		7/19/2000 Modeling Report
	Re-187	640	
	Tc-99	670	
	I-129	710	
	K-40	845	
Western LARW (Class A)	Frost-Protected Side Slope (0.364 cm/yr)		7/19/2000 Modeling Report
	Re-187	500	
	Ca-41	510	
	Tc-99	525	
	I-129	555	
	K-40	670	
LARW	Side Slope (Base Case, 1.50 cm/yr)		2/12/1998 Modeling Report
	Cl-36	110*	
	Tc-99	210*	

Embankment	Nuclide	Year	
		Exceeding	Source
	I-129	215*	
	K-40	275*	
LARW	Top Slope (Sensitivity Analysis, 0.279 cm/yr)		2/12/1998 Modeling Report
	Cl-36	460*	
	I-129	705	
	K-40	860	
11e.(2)	Top Slope (2.30 cm/yr)		7/26/2001 Modeling Report
	None	NA	
11e.(2)	Side Slope (1.69 cm/yr)		7/26/2001 Modeling Report
	None	NA	

* Note that isotopes projected to exceed GWPLs in less than 500 years were limited by the Radioactive Material License to concentrations for which the model demonstrated compliance up to year 500.

In review and approval of prior PA work, DRC has established a reasonable regulatory interpretation that the ground water protection standards are a non-degradation rather than dose issue; and that the non-degradation standard has a reasonable timeframe of 500 years.

Groundwater at the Clive site is not a potential dose pathway. As demonstrated in Table 3-2 of the 2013 Compliance Report, untreated consumption would lead to death for 100 percent of the receptors within a matter of days. Revised calculations in response to interrogatory 181 do not change this basic conclusion. It is not reasonable to assume that groundwater in the shallow unconfined aquifer would be treated for TDS then consumed. While technically possible, the shallow unconfined aquifer is of low yield; better groundwater production and quality is available at other locations in the west desert.

R313-25-19 requires an ALARA analysis to be applied to efforts to minimize potential environmental impacts. When these impacts have zero dose implications, they fail to pass the ALARA analysis. Even the analysis and modeling of potential groundwater impacts fails to pass an ALARA analysis, since zero person-rem are avoided. Nonetheless, it is reasonable under R317-6-4.7 to consider a non-degradation standard for 500 years consistent with current and prior PA approvals.

The radionuclides of concern in groundwater with this DU PA review are identical to those demonstrated to exceed after 500 years in prior approved PA work. This work was accepted under both R313-25-19 and R317-6-4.7. Thus,

there is no reason to abandon the existing regulatory distinction between non-degradation standards applying for 500 years and accepting the reality that groundwater is not a potential dose pathway either before or after that time.

92. INTERROGATORY CR R313-25-20-92/1: INADVERTENT INTRUDER DOSE STANDARD AND SCENARIOS

1. Justify why 25 mrem/yr should not be used as the dose limit for inadvertent intruders and instead why a 500 mrem/yr limit should be applied for inadvertent intruder analysis in unrestricted areas.
2. Include analysis in the PA for additional inadvertent intruder scenarios.

EnergySolutions' Response: Limitation and selection of credible inadvertent intruder scenarios is addressed in the response provided to Interrogatory CR R313-25-8(4)(B)-07/1.

In guidance to staff published by U.S. NRC stated,

“Given the significant uncertainties inherent in these long timeframes, and to ensure a reasonable analysis, this performance assessment should reflect changes in features, events, and processes of the natural environment such as climatology, geology, and geomorphology only if scientific information compelling such changes from the compliance period is available. In general, this analysis should strive to minimize radiation dose with the goal of keeping doses below a 500 mrem/yr analytical threshold.” (SRM-SECY-2013-075, February 2014).

In its “Basis of Interrogatory,” DRC acknowledges that NRC regulations establish a dose limit for members of the public of 500 mrem/yr. However, DRC concludes that a 25 mrem/yr dose limit should apply for disposal of DU because, among other things:

1. “[T]he NRC did not consider shallow land disposal of large quantities of concentrated DU waste in the original 10 CFR Part 61 rulemaking.”
2. “Since its original promulgation of 10 CFR Part 61, the NRC has amended its rules in 10 CFR Part 20 to reduce the dose limit in unrestricted areas to 25 mrem/yr TEDE (see current 10 CFR 20.1402). This same limit is reflected in the Utah rule at R313-15-402.”
3. Although DRC agrees that “the NRC license termination rules allow for a 500 mrem/yr dose to public in unrestricted areas, should certain conditions be met,” R313-15-403 limits the applicability of that dose standard “only to ancillary surface facilities that support radioactive waste disposal activities.”

4. The amendments to Part 61, which contemplate a 500 mrem/yr inadvertent intruder dose limit, have yet to be finalized.

As explained in more detail below, there is ample basis in existing and pending NRC rules for a 500 mrem/yr dose limit and a more stringent state limit violates state statutes.

NRC Rules.

Dose Limit v. Disposal Requirements. The dose limit is intended to protect an individual who is exposed to radiation from a site containing radioactive material. The requirements for disposal and long-term site management to assure compliance with such a limit may vary depending on the nature of the material, but the dose limit itself is based on protection of the exposed individual and not on the particular type of material at the site. SECY-13-0075, dealing with the pending proposal to amend Part 61 to address unique waste streams (including DU) explicitly acknowledges that the purpose of the dose limit is to protect the exposed individual – not to reflect the nature of the material at the site:

“A further protective assurance analysis should be performed for the period from the end of the compliance period through 10,000 years. Given the significant uncertainties inherent in these long timeframes, and to ensure a reasonable analysis, this performance assessment should reflect changes in features, events, and processes of the natural environment such as climatology, geology, and geomorphology only if scientific information compelling such changes from the compliance period is available. In general, this analysis should strive to minimize radiation dose with the goal of keeping doses below a 500 mrem/yr analytical threshold. The radiation doses should be reduced to a level that is reasonable achievable based on technological and economic considerations.”²

Thus, in considering disposal and post-closure management of large volumes of DU (and other unique wastes), NRC appropriately focuses on the mechanisms to assure that the dose limit is below the 500 mrem/yr threshold, not on whether a different dose limit should be imposed depending on the particular waste at the site.

Unrestricted Use/Inadvertent Intruder. The NRC rules provide that a

² Memorandum from Annette L. Vietti-Cook, Secretary, to Mark a Sartorius, Executive Director for Operations, *Staff Requirements – SECY-13-0075 – Proposed Rule: Low-Level Radioactive Waste Disposal (10 CFR Part 61) (RIN 3150-A192)* at 2 (Feb. 12, 2014) (<http://www.nrc.gov/reading-rm/doc-collections/commission/cvr/2013/2013-0075vtr.pdf>) (“SECY-13-0075”).

“site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a TEDE to an average member of the critical group that does not exceed 25 mrem (0.25 mSv) per year, including that from groundwater sources of drinking water, and that the residual radioactivity has been reduced to levels that are as low as reasonable achievable (ALARA).”

10 CFR 20.1402. The 25 mrem/yr dose in 10 CFR 20.1402 is a criterion, which if met, means the site is “acceptable for unrestricted use.” The NRC rules also provide for license termination under restricted conditions, and under certain circumstances provide for a 500 mrem/yr dose limit for an individual (including an inadvertent intruder) exposed at the site. 20 CFR 20.1403.

An “inadvertent intruder” is “a person who might occupy the disposal site after closure and engage in normal activities . . . in which the person might be unknowingly exposed to radiation from the waste.” 10 CFR 61.2. An inadvertent intruder could enter a site that meets the criterion for unrestricted use and thus the dose limit would be 25 mrem/yr; or the inadvertent intruder might enter a site that meets the criteria in 10 CFR 1403 for a dose limit of 500 mrem/yr.

Pending Amendments to Part 61. When Part 61 in its current form was promulgated in 1982, NRC had not considered the disposal of large quantities of DU. The current NRC “Disposal of Unique Waste Streams” rulemaking is intended in large part to take into account the issues pertaining to disposal of significant amounts of DU.³

As noted above, NRC is close to publishing the proposed amendments to Part 61, and based on SECY-13-0075, will propose a 500 mrem/yr dose limit:

“The proposed rule should clearly indicate that the intruder assessment should be based on intrusion scenarios that are realistic and consistent with expected activities in and around the disposal site at the time of site closure. . . . A further protective analysis . . . should strive to minimize radiation dose with the goal of keeping doses below a 500 mrem/yr analytical threshold.”⁴

It is true that there is not yet a final rule; however, the indications are very clear that NRC will propose a 500 mrem/yr dose limit for inadvertent intrusion, and for that limit to be reduced to 25 mrem/yr in the final rule will require a major change

³ See, e.g., Technical Basis For Proposed Rule To Amend 10 CFR Part 61 To Specify Requirements For The Disposal Of Unique Waste Streams, Including Large Quantities Of Depleted Uranium (FSME-10-XXXX), <http://pbadupws.nrc.gov/docs/ML11110/ML111040419.pdf>.

⁴ SECY-13-0075 at 1.

in direction after the proposed rule is published. If DRC requires a 25 mrem/yr dose limit for inadvertent intruders in the PA, it will most likely be inconsistent with the NRC rule without any basis to demonstrate why the NRC rule would be inadequate to protect the inadvertent intruder.

State Law.

No More Stringent Rule. Utah law prohibits the Radiation Control Board from adopting rules “for the purpose of assuming responsibilities from the United States Nuclear Regulatory Commission with respect to regulation of sources of ionizing radiation, that are more stringent than the corresponding federal regulations which address the same circumstances” unless the board “makes a written finding after public comment and hearing and based on evidence in the record that corresponding federal regulations are not adequate to protect public health and the environment of the state,” and such findings are “accompanied by an opinion referring to and evaluating the public health and environmental information and studies contained in the record which form the basis for the board’s conclusion.” Utah Code Ann. § 19-3-104(8) and (9).

As DRC acknowledges, the current NRC rules allow for a 500 mrem/yr dose limit, but points to UAC R313-15-401(1), which applies that limit only to “ancillary surface facilities.” Given that R313-15-401(1) is more restrictive than its federal counterpart, it should not have been promulgated without going through the steps required by Utah Code Ann. § 19-3-104(8) and (9).

Requiring a 25 mrem/yr dose limit for inadvertent intruders in the DU PA would also violate state statutes if, as seems likely, NRC adopts a 500 mrem/yr dose limit for inadvertent intruders in its pending rulemaking. Once that rule is finalized, and assuming that the rule will contain a 500 mrem/yr dose limit for inadvertent intruders, a requirement for a 25 mrem/yr dose limit imposed by the State will run afoul of state statute unless the process set forth in statute for setting a more stringent rule by the state is followed.

Conclusion.

Neither NRC rules nor state law requires a 25 mrem/yr requirement for DU. There is no need to petition the Radiation Control Board for an exemption or rule change, as existing law supports a 500 mrem/yr dose limit.

93. INTERROGATORY CR R313-25-22-93/1: STABILITY OF DISPOSAL SITE AFTER CLOSURE

1. Include long-term PA analysis for a scenario where wave-cut action from a pluvial lake breaches the Federal Cell cover system and DU waste. Alternatively, redesign the Federal Cell to locate the DU waste and its overlying radon barrier at an elevation that is below the native ground surface.
2. Revise the consideration of the span of time used in the PA modeling to go beyond the time period for which the disposal embankment maintains its designed condition and function, and explain and justify why the span of time used in the PA modeling for engineering design requirements was adequate to comply with the requirements of R313-25-8(4) and (5).

EnergySolutions' Response: Appendix 13 Deep Time Assessment includes a scenario and PA assessment of the return of a pluvial lake and erosion of the DU waste embankment. The details of the scenario used to assess a future lake cycle are described in section 4.0 Conceptual Overview of Modeling Future Lake Cycles; the model results for this scenario as concentrations of radionuclides in lake waters and lake sediments is presented in section 6.5 of the Clive DU PA Model version 1.0 Final Report. See also the responses to the following interrogatories:

1. Interrogatory 86 discuss the consequences of sedimentation after lake erosion of the embankment,
2. Interrogatory 129 discusses the processes of lake erosion and the justification for the conservative assumption of complete erosion of the embankment during the first lake return to the Clive site, and
3. Interrogatory 131 discusses process of wave erosion at lake shorelines and the possible consideration of the use of analogue studies of erosional features of preserved shorelines in the Lake Bonneville basin to revise erosion scenarios of the waste embankment.

In summary, the lake erosion scenario assumes complete erosion of the DU embankment during the return of the first pluvial lake to the Clive elevation. All waste, including both the above grade and below grade DU and associated waste, are mixed into the lake sediments. Subsequent lakes (intermediate and large lakes)

remix the sediment-waste with coincident dissolution of wastes into the water column and burial under new cycles of lacustrine sediments.

Overall sediment concentrations decrease through sequential glacial cycles because lake sedimentation continues but the only changes to the total waste inventory in the sediment mixtures after the first episode of lake erosion are from decay and ingrowth. Collectively, the lake erosion scenario uses conservative assumptions. In reality, the details of lake erosion depend on the timing of the return of the first pluvial lake, the degree of erosional burial of the embankment by aeolian sediments prior to the first lake arrival, the variability in depth of erosion during lake advances and retreat, and the interplay between lake erosion and lake sedimentation for sequential pluvial lake cycles. Multiple factors in the dynamics of these processes could significantly reduce lake sediment concentrations below the conservative estimates used in the current deep-time assessments.

The PA model uses four time periods for assessment (Section 5.1.2 Time Periods of Concern in the Clive Du PA Model version 1.0 Final Report) of the DU waste including:

1. Quantitative dose endpoints for 10,000 years including peak mean dose for comparison with performance objectives and the ALARA analysis.
2. An institutional control period of 100 years when doses are not calculated because there is no public access to the site.
3. Groundwater concentrations are compared with performance objectives for the first 500 years of the PA model consistent with the Utah requirements.
4. The deep-time model is run for 2.1 million years tracking peak radionuclide concentrations in lake water and sediment.

These composite time spans comply with the requirements of R313-25-8(4) and (5).

94. INTERROGATORY CR R313-25-3(8)-94/1: ULTIMATE SITE OWNER

Provide written evidence that the site owner shall be legally responsible for the Federal Cell, including all environmental liability that may develop for that disposal unit.

EnergySolutions' Response: Satisfaction of UAC R313-25-3(8), ultimate site owner is discussed in detail in Section 1 of the RML Condition 35 Compliance Report, Revision 1. As stated therein,

“EnergySolutions recognizes the following policy issues that must be resolved before disposing of concentrated depleted uranium in the Federal Cell . . .(2) Completion of a Memorandum of Agreement with DOE assuming long-term stewardship of the Federal Cell.” (EnergySolutions, 2013a, pg 1-1).

Therefore, it is recognized that any ultimate approval to dispose of depleted uranium must only come after DOE agreement that they will become the ultimate site owner and will be legally responsible for the Federal Cell, including all environmental liability that may develop for that disposal unit. However, while a prerequisite to the physical disposal of large quantities of depleted uranium, this acknowledgement does not prevent the Division’s review and acceptance of this depleted uranium Performance Assessment (in compliance with Condition 35 of License UT2300249).

95. INTERROGATORY CR R313-25-8(4)(A)-95/1: ESTIMATION OF I-129 CONCENTRATIONS

Consider an alternative approach to estimating I-129 concentrations in the waste and revise the PA accordingly. Alternatively, explain and justify why a proxy nuclide already in the PA model report could be used to account for the I-129 activity/dose in the environment near the Clive facility.

EnergySolutions’ Response: The wording is being changed to reflect that very small quantities of I-129 might be expected given the presence of Tc-99, given that they are both fission products.

Using the ratio of Tc-99 to I-129 provides a better path to a more reasonable estimate of I-129 concentrations. However, the EPRI reference provided does not contain sufficient information and acknowledges that there are very few actual I-129 measurements included in the data.

Neptune has consulted EPRI on this issue (personal communication from Billy Cox, EPRI, to Paul Black, Neptune and Company, Inc.). There is process knowledge that may be brought to bear: The equilibrium burnup ratio for Tc-99 to I-129 is about 200:1. That is, in spent fuel, the activity of Tc-99 is about 200 times the activity of I-129. The first step of fuel reprocessing is to dissolve the fuel in nitric acid, in order to facilitate the wet chemistry extraction of U, Pu, or other desirable constituents. In this process of dissolution in nitric acid, about 99% of the iodine is volatilized, and none of the technetium is volatilized. This alters the ratio of Tc-99 to I-129 by another factor of about 100. Once the acid has been neutralized in preparation for other processes, including whatever processes were used to bring the contaminated reactor return uranium to its current form as UO₃ powder, this ratio of 100×200:1, or about 20,000:1, is maintained. As such, it

the activity concentration of I-129 can be estimated as 0.00005 times the activity concentration of Tc-99.

There are a number of reports written by DOE and contractors regarding the fate of reactor return uranium (see the bibliography developed in response to interrogatory #51). Although it is unlikely that many of these focus on the contaminants in the process, they are being examined for more information that could shed light on this issue.

The use of ratios to develop a distribution for I-129 is also being evaluated. The Waste Inventory white paper is being revised to address this issue of scaling and the distributions utilized in the model.

96. INTERROGATORY CR R313-25-8(4)(A)-96/1: CURRENT AND FUTURE POTABILITY OF WATER

Demonstrate that there will only be non-potable water at the Clive site for 10,000 years, considering the potential for desalination, reverse osmosis, and other water treatment activities and the potential for higher groundwater quality in deep aquifers. Provide reliable evidence that (1) groundwater near Clive will not improve in quality in the future, (2) currently available treatment technology cannot render Clive groundwater useable for municipal or industrial purposes, (3) no potable or treatable groundwater exists at Clive in deeper aquifers, and (4) there is no current or future treatment technology that could render saline waters suitable for culinary or industrial use.

EnergySolutions' Response: EnergySolutions acknowledges the technical feasibility of treating saline waters at effectively any initial salinity. However, technical feasibility does not equate to probability of implementation. Within the west desert, there are numerous sources of surface and ground water for treatment that are of higher initial quality. In addition, regardless of the future ability to treat groundwater, there is not viable way to produce significant quantities of water from the upper, unconfined aquifer beneath Clive.

Furthermore, treatment of groundwater is a scenario that crosses from inadvertent to deliberate intrusion. Utah drinking water quality standards, as well as all state and federal standards, include criteria for radionuclides. If the need and technology for groundwater treatment is present, one must presume that a technical context recognizing the potential presence and hazards of radioactive constituents is also present. In accordance with NRC guidance, the inadvertent intruder must be protected but a deliberate intruder cannot be subject to the same dose protection criteria; since a deliberate intruder by definition knows of the radiological hazard and proceeds to disturb the disposal site regardless (Section 4.2.1 of NRC, 1981).

Please refer to the response provided to Interrogatory CR R313-25-8(4)(B)-07/1 regarding unreasonable speculation and projection of current known scenarios.

97. INTERROGATORY CR R313-25-8(4)(A)-97/1: NEED FOR POTABLE AND/OR INDUSTRIAL WATER

Add a discussion of various existing and historical examples of the waste industry in the Clive area and explain how they address the potential need for potable and/or industrial water in the area. Provide reliable evidence to substantiate claims that no moderate- or high-yield aquifers exist at depth near Clive and evaluate economic considerations for current and future beneficial uses of deep groundwater.

EnergySolutions' Response: Historic consideration of the nature and uses of Clive's native groundwaters is well documented (EnergySolutions, 2014b). Industrial facilities in the west desert use groundwater from recharge zones adjacent to the Cedar Mountains and the Grayback Hills. Drinking water is trucked to these sites from Grantsville. See also the response to Interrogatory CR R313-25-8(4)(a)-96/1.

Please refer to the response provided to Interrogatory CR R313-25-8(4)(B)-07/1 regarding unreasonable speculation and projection of current known scenarios.

98. INTERROGATORY CR R313-25-7(1)-98/1: MONTHLY TEMPERATURES

Describe the nature of the “*monthly temperatures*” referenced in the Conceptual Site Model report.

EnergySolutions' Response: Section 3.2.1 of the Report is being revised to clarify that the range in monthly temperatures cited are the ranges in mean monthly temperatures from 1992 through 2009.

The text in question is also in the DU PA in Section 4.1.2.3.1 which cites Whetstone (2006). Whetstone (2006) cites MSI (2004) as the data source of the 12-year average temperatures at the EnergySolutions site.

This reference will be replaced with MSI (2009), which describes the collection of hourly air temperature data in 2009 and how it compares to the 17-year record (1993-2009) in Tables 4-3 and 4-4. The hourly air temperature data for 2009 is included in Appendix C where it is apparent that mean monthly air temperature is calculated as the monthly average of hourly data. Since these datasets compare well, it is reasonable to assume that the 17-year record is calculated in the same manner.

The Interrogatory questions how the temperature range is calculated. The DU PA text states

“Data from the Clive Facility from 1992 through 2009 indicate that monthly temperatures range from about -2°C (29°F) in December to 26°C (78°F) in July (Whetstone, 2006).”

The Report text in question is being changed to the following:

“Data from the Clive Facility from 1992 to 2009 indicate that monthly temperatures range from about -2.4°C (27.7°F) in December to 26.4°C (79.5°F) in July (MSI, 2009) where monthly average temperatures are assumed to be calculated as the monthly average of hourly air temperatures for that month based on comparison with hourly data collected for 2009 and reported in MSI (2009).”

99. INTERROGATORY CR R313-25-7(1)-99/1: EVAPORATION

Clarify the meaning of the term “*evaporation*” as used in the Conceptual Site model report and provide documentation that evaporation exceeds precipitation.

EnergySolutions’ Response: Evapotranspiration is defined in Section 2.1.10 of EnergySolutions, (2013d). Furthermore, responses to Interrogatories 7.1 through 7.4 and 8.1 through 8.7 of Appendix B; and responses to Interrogatories 7.2 through 7.4 and 8.1 through 8.7 of Appendix F from this same reference demonstrate that evapotranspiration exceeds precipitation for the evapotranspiration cover design. See also MSI, 2014, for documentation that pan evaporation measured at the site meteorological station greatly exceeds precipitation.

The italicized text above is being revised to the following:

“The Clive facility is characterized as being an arid to semi-arid environment where annual pan evaporation greatly exceeds annual precipitation (MSI 2009). Average annual pan evaporation is 52 inches (MSI 2009, p. 4-7) while average annual precipitation is 8.5 inches (MSI 2009, p. 4-8). As a general rule of thumb, reference evaporation can be calculated from pan evaporation by multiplying pan evaporation by about 0.6 to 0.7 (e.g. <http://ag.arizona.edu/azmet/et1.htm>). Therefore, annual average reference evapotranspiration exceeds precipitation by about a factor of four.”

100. INTERROGATORY CR R313-25-7(1)-100/1: GROUNDWATER RECHARGE FROM PRECIPITATION

Address considerations that would affect the amount of groundwater recharge due to precipitation and snow melt, such as concentration of water in topographic depressions, increase in cover-system hydraulic conductivity, and inhibition of evaporation because of large-grain materials.

EnergySolutions' Response: Revision 1 of the GoldSim model evaluates performance of an ET cover design against the traditional rock armor mulch on the Federal Cell.

Section 3.2.3 on page 8 of the Conceptual Site Model report is being revised. The statement “*Because of the high evaporation rate, the amount of groundwater recharge due to precipitation is likely very small, except during high intensity precipitation events (Adrian Brown, 1997a).*” has been removed and the discussion on recharge in Section 3.4.2.1 Groundwater Flow Regime will be expanded.

“Recharge to the aquifer in the vicinity of Clive is thought to be composed of three components; a small amount due to vertical infiltration from the surface; some small amount of lateral flow from recharge areas to the east of the site; and the majority of recharge believed to be from upward vertical leakage from the deeper confined aquifer (Bingham Environmental (1994). Average annual groundwater recharge from the surface in the southern Great Salt Lake Desert in the precipitation zone typical of Clive was estimated by Gates and Krauer (1981). An estimated 300 acre feet per year were recharged to lacustrine deposits and other unconsolidated sediments over an area of 47,100 acres. This is a recharge rate of approximately 0.08 inches/year. Groundwater recharge from lateral flow occurs due to infiltration at bedrock and alluvial fan deposits away from the Site which moves laterally through the unconfined and confined aquifers (Bingham Environmental, 1994). This is evidenced by the increasing salinity of the groundwater due to dissolution of evaporate minerals as water moves from the recharge area to the aquifers below the Facility (Bingham Environmental, 1994). The majority of recharge to the shallow aquifer is believed by Bingham Environmental (1994) to be due to vertical leakage upward from the deep confined aquifer due to the presence of upward hydraulic gradients.”

“Deeper saturated zones in Unit 1 below approximately 45 ft bgs are reported to show higher potentiometric levels than the shallow unconfined aquifer. Differences in potentiometric levels are attributed to the presence of the Unit 2 clays (Bingham Environmental, 1994). Vertical gradients between shallow and deeper screened intervals in the monitor well

clusters were calculated by Bingham Environmental (1994). An upward vertical gradient was observed ranging in magnitude from 0.02 to 0.04 based on the distance between the screen centers. For a vertical hydraulic conductivity of 1×10^{-6} cm/s (Bingham Environmental 1994) this corresponds to a recharge range from 0.25 in/yr to 0.5 in/yr.”

“Estimates of vertical recharge from the surface take into account natural processes such as snow accumulation and melting, concentration of water in topographic depressions, drainages, fractures, holes, or burrows and increased surface permeability due to frost heave or plant roots. When features such as topographic depressions, drainages, or fractures result in enhanced infiltration, the vertical infiltration below the localized recharge points flows laterally at the water table toward the lower elevations of the water table (Freeze and Cherry, 1979). The effect of animal burrowing on subsurface moisture content was investigated in a field experiment at the Hanford Site by Landeen (1994). Over the course of five testing periods, three during the summer and 2 during the winter soil moisture measurements showed no influence of burrowing activities on long-term water storage.”

“Degradation models for changes in cover properties over time were discussed in the Benson et al (2011) report published by the NRC. While this is a useful report, the topic of cover performance is a complex topic with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. The cover design components and assigned physical properties in models of cover performance must be carefully chosen for applicability to the climate and hydrogeological setting of the Clive disposal facility. To provide a comprehensive sensitivity analysis for the influence cover degradation on modeled surface recharge, refined modeling of closure cover performance could be performed using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into a probabilistic performance assessment model.”

Given the change in design, items related to rip rap performance in this interrogatory are no longer applicable.

101. INTERROGATORY CR R313-25-7(1)-101/1: NATURE OF UNITS 1 AND 2

Indicate how the thickness of Unit 1 is accounted for in the numerical GoldSim model, and describe the nature of the confining unit. Provide information about local downward components of hydraulic gradient at the site that result in groundwater mounding.

EnergySolutions' Response: The description of Unit 1 in Section 3.3.1, page 9, of the Conceptual Site Model report is being revised:

“Unit 1 underlies Unit 2 and is saturated beneath the facility, containing a locally confined aquifer. Unit 1 extends from approximately 45 ft bgs and contains the deep aquifer. The deeper aquifer is reported to be made up of lacustrine deposits consisting of deposits of silty sand with some silty clay layers. One or possibly more silty clay layers overlie the aquifer (Bingham Environmental 1994).”

The aquifer system in the vicinity of the Clive Facility is described by Bingham Environmental (1991, 1994) and Envirocare (2000, 2004) as consisting of unconsolidated basin-fill and alluvial fan aquifers. Characterization of the aquifer system is based on subsurface stratigraphy observations from borehole logs and from potentiometric measurements. The aquifer system is described as being composed of two aquifers; a shallow, unconfined aquifer and a deep confined aquifer. The shallow unconfined aquifer extends from the water table to a depth of approximately 40 ft to 45 ft bgs. The water table in the shallow aquifer is reported to be located in Unit 3 on the west side of the site and in Unit 2 on the east side.

The deep confined aquifer is encountered at approximately 45 ft bgs and extends through the valley fill (Bingham 1994). The boring log from a water supply well drilled in adjoining Section 29 indicated continuous sediments to a depth of 620 ft bgs (DWR 2014, water right number 16-816 and associated well log 11,293). The deepest portion of the basin in the Clive area is believed to be north of Clive in Ripple Valley where the basin fill was estimated to be 3,000 ft thick (Baer and Benson (as cited in Black et al., 1999)).

Deeper saturated zones in Unit 1 below approximately 45 ft bgs are reported to show higher potentiometric levels than the shallow unconfined aquifer. Differences in potentiometric levels are attributed to the presence of the Unit 2 clays. These observations are interpreted as indicating that the shallow unconfined aquifer below the site does not extend into Unit 1 but is contained within Units 2 and 3 (Bingham Environmental, 1994)

Vertical gradients between shallow and deeper screened intervals in the monitor well clusters were calculated by Bingham Environmental (1994). An upward

vertical gradient was observed ranging in magnitude from 0.02 to 0.04 based on the distance between the screen centers.

Hydraulic conductivities measured from bailing tests are reported to average 7.45 ft/day ($2.6E^{-03}$ cm/s) by Envirocare (2004). Bailing tests in boreholes provide a saturated hydraulic conductivity more representative of the horizontal hydraulic conductivity than the vertical. Based on 3 measurements of vertical hydraulic conductivity on silty clay cores made by Bingham Environmental (1991), Envirocare (2004) and Bingham Environmental (1994) use a value of 1×10^{-6} cm/s for the vertical hydraulic conductivity. This corresponds to an anisotropy ratio K_v/K_h of 1:2600. Average linear vertical groundwater velocity ranged from 0.05 ft/yr to 0.10 ft/yr based on these vertical gradients, a porosity of 0.4 and a vertical hydraulic conductivity of 1×10^{-6} cm/s (Bingham, 1994).

Horizontal groundwater velocities were calculated by Bingham Environmental (1994) for 17 monitoring wells having measurements of hydraulic conductivity and estimated gradients. Hydraulic conductivities ranged from 2.9×10^{-5} cm/sec to 9.5×10^{-4} cm/sec and horizontal hydraulic gradients ranged from 2×10^{-4} to 1×10^{-3} . Average linear horizontal groundwater velocity ranged from less than 0.02 ft/yr to 2.1 ft/yr based on a porosity of 0.3. The ratio of linear horizontal velocities to linear vertical velocities ranged from 0.4 to 21.

The influence of downward hydraulic gradients on shallow groundwater flow is discussed in Envirocare (2004) for two cases. In the first, flow was affected by localized recharge from a surface water retention pond in the southwest corner of the facility in the spring of 1999 and in the second, a ground water mound formed between March 1993 and spring 1997 below a borrow pit excavated near the 11e.(2) cells that occasionally filled with rain water. The mound decreased and was negligible by the time of the report in 2004.

Unit 1 in the GoldSim Model:

Unit 1 is not included in the numerical GoldSim model. The confining unit at the top of Unit 1 forms the bottom boundary of the model. The shallow aquifer is represented in the model as being completely contained within Unit 2. The point of assessment for the groundwater pathway is a monitoring well located 90 ft horizontally from the toe of the waste. The monitoring well extends through the shallow aquifer in Unit 2 ending at the top of unit 1. A Figure will be added to Section 7.1.1 Groundwater Flow and Transport in the Conceptual Site Model report depicting the engineered features of the landfill, the hydrostratigraphic units below the waste in the unsaturated and saturated zones, the location of the water table of the shallow aquifer, and the lower boundaries of the GoldSim model.

102. INTERROGATORY CR R313-25-7-102/1: SEISMIC ACTIVITY

Address the fact that active faults tens of miles away from the site can potentially cause local ground accelerations, even if the site itself does not have any known active faults in its vicinity, or explain and justify why the issue is not important to the long-term stability of Clive embankments.

EnergySolutions' Response: The lack of Quaternary and/or capable faults in the vicinity of the Clive site is not sufficient evidence to dismiss seismic activity as a potential issue of concern. While the absence of surface faults in the site is consistent with a low probability of surface-fault rupture, ground shaking associated with background earthquakes require assessments (i.e. moderate-size earthquakes (M 5.5 – 6.5) that do not cause surface rupture, see Wong et al., 2013).

Seismic hazard assessments have been evaluated previously for the Clive site including assessments of active or potentially active faults in the region and background earthquakes. The peak ground accelerations for both seismic sources is 0.24 g. The peak ground accelerations for the Clive site are within the range of estimated ground accelerations for two DOE regulated and approved low-level waste disposal sites (Area G, Los Alamos, New Mexico (LANL, 2008), and Area 5, Nevada National Security Site, Shott et al. 2008). Performance assessments for these sites conclude that the impacts of ground shaking on waste disposal systems are minor (and are overshadowed by the longer-term effects of subsidence).

The negligible effects of the peak ground accelerations on the long-term stability of Clive's embankments has previously been demonstrated and found acceptable by the Division. No new information on seismic hazards has been identified that would change or require revisions of the previous work. The text in Appendix 2, Conceptual Site Model and in Section 6.0 of Appendix 1, Clive DU PA FEP

Analysis is being revised and will reference the existing seismic hazard assessments.

The following sections summarize the results of seismic hazard assessments for the Clive site:

“The seismic hazard assessment is based on an assessment of the peak ground acceleration (PGA) associated with the Maximum Credible Earthquake (MCE) for known active or potentially active faults in the site region, and the PGA obtained from a probabilistic seismic hazard analysis (PSHA) to assess the seismic hazard for earthquakes that may occur on unknown faults in the area surrounding the project site (i.e., background seismicity). For fault sources, the PGA is calculated at the 84th percentile level and is based on the maximum rupture length and rupture area for each fault. The return period for ground motions resulting from a background earthquake is identified as 5000 years (equal to a one percent probability of exceedance in 50 years). The approach to select a MCE PGA from the larger of the values associated with the deterministic MCE for faults or the PSHA result for background earthquakes at a 5000 year return period is consistent with the discussions among AMEC, ES, Utah DEQ and their peer reviewer, URS Corporation, and is consistent with the recommendations of the Utah Seismic Safety Commission (2003) and as required by the Utah Division of Water Rights (Dam Safety Section) for assessment of dams.

The deterministic assessment follows the approach described in our October 25, 2011 letter, and is updated in the following paragraphs. Potential fault sources are shown on Figure B-1.1 and are listed in Table B-1.1 of Appendix B, including an assessment of the fault parameters, source to site distance, and PGA. Specific fault parameters and other information in Table B-1.1 include fault name, slip type, maximum magnitude, location of site on hanging wall or footwall, fault dip, rake, maximum rupture length (fault length), downdip rupture width, distance measures required for ground motion attenuation relationships, and PGA for median and 84th percentile levels. We use a suite of four Next Generation Attenuation (NGA) relationships . . . all of which are applicable for the site conditions and types of sources in Utah and the Intermountain Region. Additional parameters for attenuation relationships include site shear wave velocity, VS30, taken as 305 m/s as described in the October 25 Letter, and depth to top of bedrock (Z1.0 and Z2.5), taken as default values calculated from the site VS30 as recommended by the authors of the NGA relationships (also as described in the October 25 Letter).

The maximum magnitude for each fault is based on rupture of the full length of the fault, and where available is taken as the maximum value published by the Utah Working Group on Earthquake Probabilities (WGUEP, 2011), except for the Stansbury fault as noted below. For faults not assessed in the previous studies, including the Skull Valley fault, the maximum magnitude was assessed using the same methodology as the WGUEP study, based on maximum rupture length, rupture width, and the empirical relationships of Wells and Coppersmith (1994). For short faults where the calculated maximum magnitude is less than MW 6.5, a maximum magnitude of 6.5 is adopted because this is judged to be a reasonable minimum value of magnitude for earthquakes that rupture to the ground surface.

For the Stansbury fault, the maximum magnitude is assessed as MW 7.3 based on consideration of the maximum rupture length, fault width, and maximum fault displacement identified in previous investigations. . . The value of MW 7.5 listed in the October 25 Letter and by the WGUEP is judged to be too conservative because it is higher than the maximum value obtained from empirical relationships, considering all combinations of rupture length, rupture width, and maximum fault displacement cited in those previous investigations. We note that it may be reasonable to consider an extreme value with a very low weighting (e.g., less than 10 percent) in a probabilistic analysis, but that it is not reasonable practice to adopt an extreme value for the MCE for a deterministic analysis.

The maximum of the 84th percentile PGA values calculated for the Mmax events on the fault sources is equal to 0.24 g, as obtained for the Stansbury and the Skull Valley faults (Table B-1.1). For the PSHA, we used the current version (Ver. 7.62) of commercial program EZ-FRISK to calculate the PGA for the background earthquake. The program developer, Risk Engineering, has prepared input fault and background seismicity files for Utah for use in calculating seismic hazard; these files are based on the same fault source parameters and independent seismicity catalog used by the U.S. Geological Survey (USGS) to prepare the 2008 National Seismic Hazard Maps.

The seismicity catalog is an independent (de-clustered) catalog based on moment magnitude (MW) that covers the Western United States; the seismicity in the vicinity of the project site is shown on Figure B-1.1. The recurrence rates for the background seismicity are based on the same recurrence models and maximum magnitudes used by USGS, which is a spatially smoothed gridded approach, with a maximum magnitude of 7.0 for Utah (Peterson et al., 2008). As for the deterministic analysis, we use the same suite of four NGA relationships and the site VS30 of 305 m/s. The

PGA is taken as the weighted average of the mean values for the four NGA relationships at a return period of 5000 years (equal to 0.24 g, Table B-1.1).

The largest PGA from the deterministic assessment of fault-specific sources and the probabilistic assessment of the background earthquake is 0.24 g. The maximum magnitude varies from 7.0 to 7.3 for the sources that result in the maximum PGA; we identify the largest value, MW 7.3, as appropriate for use in the seismic stability analyses for this project.”(EnergySolutions, 2012, pg. 2-3).

In review of this information and its implications on the Class A West Embankment design, the Division concluded, “Based on the information summarized above, the Division concludes that the Licensee’s proposed design basis conditions and justification for the design criteria for waste placement and backfill for the CAW Embankment are acceptable.” (DRC, 2012, pg. 33).

103. INTERROGATORY CR R313-25-7-103/1: HISTORICAL FLOODING

Discuss historical non-chronic flooding that has occurred on site and how this can potentially impact infiltration, especially once the cover system is compromised by erosion, burrowing, and other events. Discuss flooding that has occurred on the site prior to the human historical record but within the historical geologic record (based on evidence from the field).

EnergySolutions’ Response: The ability of Clive’s exterior berm system and embankments to withstand the impacts of a Probable Maximum Flood has previously been demonstrated (Appendices E and G of EnergySolutions, 2013b). No changes in present methodology or meteorology have been observed that warrant revising this recent analysis.

104. INTERROGATORY CR R313-25-7(2)-104/1: INFILTRATION IN THE PRESENCE OF RIP RAP OR NATURAL ROCK

1. Realistically quantify the impacts on infiltration or water penetration when the presence of rip rap or natural rock on the embankment cover decreases both evaporation and transpiration. Include technical evidence to support the conclusions made regarding evapotranspiration effects on water infiltration.
2. Specify the total length of the soil zone path used in unsaturated flow modeling and describe the characteristics of the soil involved.
3. Explain and justify how much time will be needed to complete the cover system siltation and establishment of a permanent and viable plant community after closure of the DU cell, including how much of the cover system vertical profile will be in-filled with silts and other Aeolian deposits.

4. Explain and justify why the proposal to use human intervention to help mitigate the effects of future events that could jeopardize the stability of the engineered facility at Clive is congruent with the rule requirement to eliminate active maintenance of the disposal site.

EnergySolutions' Response:

EnergySolutions currently plans to use an evapotranspiration (ET) cover design rather than the design requiring rip rap specified in the Clive DU PA model. Given the change in design, items 1 and 3 (and the example reference to rip rap in 4) in this interrogatory are no longer applicable. In response to item 2, the CSM report is being revised to contain a detailed description of the entire vadose zone path modeled.

In response to item 4, the referenced CSM report text is referring to human intervention in the context of applying different types of engineering controls, not with respect to active maintenance. This is elucidated in the sentence beginning, *“For example, the disposal cell could be protected...”* Active maintenance of the disposal site has not been assumed in the PA. The cell is designed and projected to perform in accordance with R313-25-7(2), which requires “elimination **to the extent practicable** of long-term disposal site maintenance” [emphasis added].

The third sentence of the first paragraph of Section 7.2.1.6 of the CSM report is being revised to state:

“If in the future another ice age were to occur similar to those that have occurred during the Pleistocene, disposal cell design could help mitigate the effects of future events that could jeopardize the stability of the engineered facility at Clive.”

105. INTERROGATORY CR R313-25-8(4)(A)-105/1: HUMAN USE OF GROUNDWATER

Identify the human uses for which the groundwater at the Clive site is suitable, and consider the potential human uses of the groundwater after treatment.

EnergySolutions' Response: Uses and modeling of Clive's groundwater in this Depleted Uranium Performance Assessment are consistent with EnergySolutions' other various Performance Assessments.

EnergySolutions acknowledges the technical feasibility of treating saline waters at effectively any initial salinity. However, technical feasibility does not equate to probability of implementation. Within the west desert, there are numerous sources of surface and ground water for treatment that are of higher initial quality and production.

Furthermore, treatment of groundwater is a scenario that crosses from inadvertent to deliberate intrusion. Utah drinking water quality standards, as well as all state and federal standards, include criteria for radionuclides. If the need and technology for groundwater treatment is present, one must presume that a technical context recognizing the potential presence and hazards of radioactive constituents is also present. In accordance with NRC guidance, the inadvertent intruder must be protected but a deliberate intruder cannot be subject to the same dose protection criteria; since a deliberate intruder by definition knows of the radiological hazard and proceeds to disturb the disposal site regardless.

Please refer to the response provided to Interrogatory CR R313-25-8(4)(B)-07/1 regarding unreasonable speculation and projection of current known scenarios.

Additionally, it should be noted that desalination occurring in the Persian Gulf and Israel is to fulfill a pressing human need for a dense population. Neither of these exists at Clive.

106. INTERROGATORY CR R313-25-8(4)(A)-106/1: DESALINATION POTENTIAL

Modify the text to reflect the fact that TDS concentrations at Clive are not a barrier to desalination to potable water levels.

EnergySolutions' Response: Section 3.4.2.2 of the Conceptual Site Model is being revised to acknowledge the technical feasibility and practical improbability of groundwater desalination at Clive.

While it is true that desalination occurs in the Persian Gulf and Israel, it is done to fulfill a pressing human need for a dense population. Neither of these currently exists at Clive, nor is it likely to.

The text of the CSM document is being changed as follows:

[Conceptual Site Model white paper, section 3.4.22:]

“The underlying groundwater in the vicinity of the Clive site is of naturally poor quality with high salinity and high TDS, as a consequence, is not suitable for most human uses (NRC, 1993). Brodeur (2006) reports that groundwater beneath the Clive site had a total dissolved solid (TDS) content of 40,500 mg/L (40.5 ‰). The majority of the cations and anions are sodium and chloride, respectively. This is not potable for humans or livestock, nor is it suitable for irrigation. Groundwater is used for dust control, however, this water is pulled from the deeper aquifer, not the low-

yielding, shallow-unconfined aquifer found beneath Clive. For comparison purposes, sea water typically has a salinity content three to five times that of the groundwater at the site, thus the salinity content at the site is higher than average sea water.”

107. INTERROGATORY CR R313-25-7(1)-107/1: PREDOMINANT VEGETATION AT THE CLIVE SITE

Reconcile apparent discrepancies with respect to which type of vegetation predominates at the Clive site and revise the Conceptual Site Model report to be consistent with the research conducted previously by EnergySolutions contractors at Clive.

EnergySolutions’ Response: Assessment by SWCA in 2013 of predominant vegetation species surrounding the Clive site has been provided to the Division (Section 2.3 of Appendix C from EnergySolutions, 2013d). As reported therein,

*“The vegetation communities that occur on and near Clive, and the shrub, forb, and grass species that comprise them were documented during 2010 and 2012 field studies (SWCA 2010, 2012). Inter-Mountain Basins Mixed Salt Desert Scrub (Lowry 2007) is the dominant vegetation cover type on analogs to the Clive site. The target vegetation community on the ET cover consists of approximately 15% cover of small stature native shrub species (*Atriplex confertifolia*, *Atriplex canescens*, *Bassia americana*, *Picrothamnus desertorum*, and *Suaeda torreyana*), with additional cover provided by sparse native forbs and grasses.”* (pg. 31, Appendix C, EnergySolutions, 2013d).

Section 3.5.1 of the Conceptual Site Model is being revised accordingly.

The Conceptual Site Model does say on page 11 that the predominant vegetation is shadscale. It then goes on to say,

“Shrubs are widely spaced, totaling between 1.5% and 20% ground cover, depending upon vegetation association. The shadscale-gray molly community covers most of the South Clive site, with black greasewood becoming prominent only on the eastern quarter of the site. SWCA (2011) found very little transition between the shadscale-gray molly and black greasewood vegetation associations, and that shadscale and gray molly totaled less than 0.5% cover in the greasewood association, suggesting that the shadscale-gray molly-black greasewood community identified by Envirocare (2000) is perhaps better classified as a pure greasewood community. Envirocare reported that the black greasewood-gardner saltbush community only occurs in the far northeast corner of the Clive site.”

This indicates that there are three main vegetation types at the site, and these are investigated further by SWCA (2011). Of the three main vegetation types, shadscale saltbush makes up 60% of the site based on percent cover (Envirocare 2000, p.3 section 2.2), making the claim that it is the predominant vegetation at the site accurate.

It is inappropriate to discuss the results of the SWCA 1 ha plot surveys (SWCA 2011) with regards to total plant cover at the site. The three 1 ha plots were chosen to each be in the primary vegetation associations at the site, so by definition they are different vegetation types. These plots do not indicate overall coverage at the site as they are not a representative sampling of percent cover, but rather provide good data on the proportion of vegetation types within each of the three habitat types. As stated on page 1 of that report (SWCA 2011), the purpose of this survey was to identify plant species present and estimate the percent cover and stem densities of grasses, forbs, shrubs, and trees in each vegetative association. This survey was not designed to determine coverage of each vegetative association at the site, but the percent cover of species within each vegetative association.

The text in the CSM that states that shadscale is the predominant vegetation over most of the site is not contraindicated by the vegetation assemblages in the 2011 SWCA plots. The 2011 plots were selected precisely because they do represent different vegetation assemblages in the vicinity of Clive. The PA model evaluated both the predominant assemblage at the site (shadscale-gray molly) and less common assemblages (black greasewood, halogeton-disturbed, mixed grassland, juniper-sagebrush) with the recognition that any of those assemblages could colonize the cover depending on future changes in temperature, precipitation, and/or soil salinity.

With regard to the comment “For Plot 3, “Shadscale makes up only 1/10th of 1% of ground cover, so it can hardly be called predominant here,” as mentioned above this sampling design was not intended to provide any data on overall coverage at the site. Previous surveys had shown that shadscale was the predominant vegetation. This sampling design was simply describing the plant composition within each vegetation type.

With regard to the comment

“In Plot 5, located to the west of most current operations, shadscale saltbush does dominate among shrubs and forbs, at 12.5%, but the coverage is relatively small compared to biological soil crust coverage at 70.7%,”

biological soil crust is not a plant (but rather a community of organisms including cyanobacteria, green algae, microfungi, mosses, liverworts, and lichens). When discussing dominant vegetation, the plant species with the most cover is used, even if much of the area is biological soil crust or bare ground.

108. INTERROGATORY CR R313-25-8(4)(A)-108/1: BIOINTRUSION

Include additional information about biointrusion from SWCA (2012).

EnergySolutions' Response: Assessment by SWCA in 2013 of predominant burrowing animal species surrounding the Clive site has been provided to the Division (Section 2.2 of Appendix C from *EnergySolutions*, 2013). Section 3.5.2 of the Conceptual Site Model is being revised to incorporate and reference this work, performed during the 2.5 years between when the DU Performance Assessment was submitted and reviewed.

Discussion of mammal bioturbation in the CSM was based on information and data collected by SWCA as part of the initial performance assessment, including small mammal trapping, mammal burrow surveys, and ant nest surveys within the Clive plots (SWCA, 2011). The CSM is being updated based on work performed by SWCA subsequent to the PA. Excavation of cover materials by badgers was included in the PA based on data collected by SWCA, 2011. Because badgers occurred at very low frequency at the site compared to small burrowing mammals (primarily deer mice and kangaroo rats), all burrowing mammals were lumped together to derive distributions of burrow density and burrow volume. Mammal burrowing was modeled to a maximum depth of 2 m based on the likely average vertical extent of multiple badger excavations (Kennedy et. al, 1985).

The text is being updated with the more recent information collected by SWCA, and the new data is being evaluated to determine if changes are needed to the model.

Also see response to Interrogatory R313-25-8(4)(A)-28/1.

109. INTERROGATORY CR R313-25-7(2)-109/1: GEOCHEMICAL DEGRADATION OF RIP RAP

Address the issue of the geochemical degradation of the rip rap over time and indicate why potential rip rap degradation will not require perpetual care.

EnergySolutions' Response: Selection of an ET cover design eliminates the need to address this issue for the DU PA.

EnergySolutions currently plans to use an evapotranspiration (ET) cover design rather than the design requiring rip rap specified in the Clive DU PA model.

Given the change in design, this interrogatory is no longer applicable. The CSM report is being revised to contain a detailed description of the revised design.

110. INTERROGATORY CR R313-25-8(4)(A)-110/1: RADON TRANSFER FROM WATER

Provide a basis for stating that radon has a preference for remaining in water.

EnergySolutions' Response: The statement that radon has an affinity for water is made in the sense that relative to other radioactive noble gases, radon has a higher affinity for water. The Henry's Law constant, expressed as a dimensionless air/water concentration ratio, is about 4.6 for radon. It is over 16 for krypton, and nearly 30 for argon. So, by comparison, radon has a higher water/air concentration ratio than these other gases. It is all relative. Nonetheless, the text can be changed, as follows, since the only thing that matters is the actual value.

[Conceptual Site Model white paper, section 7.1.3.1, last paragraph:]

“Radon that does enter the environment partitions between air and water. Soil moisture therefore retards the migration of radon as it migrates through the soil, making it less available to diffusion in air under wetter soil conditions.”

[Conceptual Site Model white paper, section 9.4.1, fifth paragraph, first sentences:]

“Radon partitions between air and water, per its Henry's Law constant (KH). For this reason, wet soils are much better at attenuating radon migration than dry soils.”

111. INTERROGATORY CR R313-25-7-111/1: LIKELIHOOD OF LAVA DAM FORMATION

Describe why the future likelihood of lava dam formation is considered small, given that lava dams formed during the Pleistocene and affected Lake Bonneville.

EnergySolutions' Response: The intention of the sections cited in the interrogatory statement (Conceptual Site Model, Deep Time Assessment) is not to imply that future volcanic activity in and near Lake Bonneville is unlikely to form lava dams or affect glacial lake cycles. Lava dams in the northern parts of Lake Thatcher and Lake Bonneville affected the rise and drainage history of the lakes during the Pleistocene (Link et al., 1998) and volcanic activity likely affected drainage into Lake Bonneville during and following the last glacial maximum. Basaltic volcanic eruptions associated with the Black Rock Desert volcanic field

(Nash, 1989) pre-date, were contemporaneous with, and post-date the multiple stages of Lake Bonneville (Nash, Oviatt and Nash, 1989, 2014).

Volcanic eruptions near the Clive site are low probability events during the 10,000 year first stage of the DU performance assessment. However, Quaternary basaltic and rhyolitic eruptions occurred along the length of the eastern margin of the Great Basin (north-south zone through central Utah) and will occur again within the Bonneville lake region during the 2.1 Ma interval of the deep time assessment. These future events will affect anticipated glacial lake cycles. However, the magnitude of these effects on lake levels is small compared to the fluctuations in lake levels associated with the modeled 100 ka glacial cycles.

Future volcanic events are typically screened from consideration in a performance assessment on the basis of a low probability of occurrence and/or limited consequences. The scenarios of a major asteroid impact and a future volcanic eruption at Yellowstone volcanic center (caldera cycle eruption) were similarly not screened. Instead, the impacts of these events are so catastrophic on a global scale that consideration of their impact on a low-level radioactive waste disposal site at Clive is literally inconsequential.

The text of the cited sections is being revised accordingly to clarify the importance of lava dams and volcanic activity.

112. INTERROGATORY CR R313-25-8(4)(A)-112/1: HYDRAULIC CONDUCTIVITY

Revise the hydraulic conductivity values to be consistent with the values in NUREG/CR-7028. Increase the model's radon barrier permeability by at least two orders of magnitude and re-run the simulations, or provide evidence, explanation, and justification as to why the DRC Director should accept the current assumptions as presented.

EnergySolutions' Response: The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two order of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

See also the response to Interrogatory CR R313-25-8(5)(A)-176/1.

113. INTERROGATORY CR R313-25-8(5)(A)-113/1: PLACEMENT OF BULK LOW-LEVEL WASTE AMONG DU CANISTERS

Describe modeling and consequent assessment related to the placement of bulk low-level waste between, above, or below the DU canisters.

EnergySolutions' Response: Bulk Class A LLRW will be placed above the DU. It will not be placed below or between the concentrated DU, in order to conserve cell space below grade for only significant quantities of depleted uranium. Performance assessment for these nuclides is addressed via the ET cover performance assessment currently undergoing DRC review (EnergySolutions, 2013d). Consistent with the historic Division-accepted practice, this assessment took no additional credit for migration restriction attributable to waste container or waste form. As such, the condition of the disposal of other Class A low-level radioactive bulk wastes within the Federal Cell is a modeled condition. Therefore, it is unnecessary to repeat this analysis in this Depleted Uranium Performance Assessment.

The goal of the Clive DU PA Model v1.0 has been simply to evaluate the potential future human risk from the SRS and GDP sources of DU proposed for disposal.

114. INTERROGATORY CR R313-25-19-114/1: ELEVATED CONCENTRATIONS OF TC-99

Discuss the transport of technetium in groundwater at the site, including Tc-99 soil/water partitioning coefficients used in the GoldSim model and results of model predictions for transport of technetium in groundwater at the site for periods of at least 10,000 years. Describe steps that can be taken to limit the presence of technetium in groundwater to concentrations less than or equal to the Utah groundwater protection level of 3,790 pCi/L.

EnergySolutions' Response: Revision 2 of the GoldSim model is being prepared to evaluate an ET cover design. It is expected that the reduced infiltration afforded by this design will reduce predicted Tc-99 levels in groundwater. See also response to Interrogatory 163 regarding the period of performance for groundwater.

It should be noted that the GWPLs for the Clive site, as documented in the Ground Water Quality Discharge Permit No. UGW450005, apply for only the first 500 years following closure of the site. There is, therefore, no regulatory

need to evaluate groundwater concentrations of radionuclides after that period of compliance. See the response to Interrogatory CR R313-25-7(2)-91/1.

As for soil/water partition coefficients for Tc addressed in (1), the most extensive discussion available is that in the *Geochemical Modeling* white paper, Part (2) is addressed above.

Nevertheless, there are two approaches that could be implemented that would reduce concentrations of ⁹⁹Tc in groundwater in general. One approach, as discussed in the Final Report, is to situate the DU that is contaminated with ⁹⁹Tc higher in the waste layering. In modeling various waste placement strategies, it is clear that this results in lower groundwater concentrations of ⁹⁹Tc. However, the modeled cover design is being changed from the riprap layer to an ET cover, which will affect infiltration and hence mobility of ⁹⁹Tc in the system.

A second strategy, would be to not dispose of contaminated DU in the first place, especially considering the below grade capacity is considerably exceeded by the DU that needs a disposal option. This approach would still allow for disposal of roughly 95% of the GDP DU, which has no such contamination, and is the first to undergo deconversion at any rate. The deconversion plants in Piketon and Paducah intend to work through their contaminated DUF₆ inventories as the last of their deconversion efforts (personal communication from Jack Zimmerman, Uranium Disposition Services, LLC, to John Tauxe, Neptune and Company, Inc.), and so are unlikely to produce any contaminated DU₃O₈ for at least 20 years.

In the meantime, other disposal protocols may be developed, for example, iron could be added to the grout or other components of the system to change the geochemical conditions and enhance iron facilitated co-precipitation. This would reduce the mobility of the Tc-99 in the system. Note that there is iron in the disposal system containers, and no credit has been taken for that in the model to date.

115. INTERROGATORY CR R315-101-5.3(6)-115/1: URANIUM TOXICITY REFERENCE DOSES

Expand the discussion of uranium toxicity to include the Superfund and drinking water RfDs, indicate whether they are for soluble or insoluble uranium salts or both, describe why there is a five-fold difference between the two RfDs, and indicate the basis for assigning a 50/50 probability to each RfD.

EnergySolutions' Response: Additional text is being added to Section 3.4.5 of the Dose Assessment report:

“A discrete distribution is used to represent the uranium oral RfD based on current EPA science policy associated with EPA’s Superfund Program

and Office of Water. A uranium oral RfD of 0.0006 mg/kg-day is associated with the derivation of the final uranium drinking water maximum contaminant level (MCL) is defined on page 76713 of Federal Register, Volume 65, No. 236, December 7, 2000 (Section I.D.2d). A uranium oral RfD of 0.003 mg/kg-day for soluble salts of uranium is published in the Integrated Risk Information System (IRIS) supporting the Superfund Program. A 50/50 probability is assigned to these oral RfDs to determine in the Sensitivity Analysis whether selecting one or the other of these published values is a significant contributor to uncertainty in the uranium Hazard Index in any exposure scenario.”

116. INTERROGATORY CR R313-25-8(4)(A)-116/1: CS-137 DECAY

Change Figure 1 and the Excel file to show the correct amount of Cs-137 decaying to Ba-137.

EnergySolutions’ Response: Although Tuli (2005) does not recognize this decay mode, it is noted in Kocher (1981), as follows:

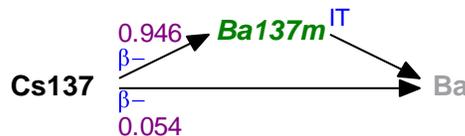


Figure 2-116/1, Cs-137 Decay Modes

This decay mode is being included in the Clive DU PA Model, and the figure is being updated. There is no effect on the model, since dose conversion factors from the decay of 137Cs implicitly include that of 137mBa as well.

Since the decay product 137mBa is short-lived and is not modeled for contaminant transport, it does not appear in the Species list, nor in the “Clive PA Model Parameters.xls” Excel file. Therefore, no modification of the Excel file is indicated.

117. INTERROGATORY CR R313-25-8(5)(A)-117/1: GROUNDWATER PROTECTION LIMIT FOR TC-99

Provide documentation (e.g., a Result Mode GoldSim file) that supports the contention that the Tc-99 GWPL will be met for 10,000 years. In addition, explain why EnergySolutions is proposing to include a Tc-99 waste source term concentration limit of 1,720 pCi/g under the side slope, given statements in various places in the PA report that no DU is to be included under the side slopes.

EnergySolutions’ Response: Revisions underway to the depleted uranium Performance Assessment GoldSim model demonstrate that infiltration into the

Federal Cell's evapotranspirative cover will subsequently comply with limitations of EnergySolutions' GWQDP.

The interrogatory, however, erroneously conflates R313 radiological dose standards with R317 non-degradation standards. See the response to Interrogatory CR R313-25-7(2)-91/1.

118. INTERROGATORY CR R313-25-7(10)-118/1: GOLDSIM RESULTS

Provide the GoldSim model files (i.e., .gsm files) that support the results (i.e., groundwater concentrations, receptor doses, receptor uranium HQs, ALARA, and deep time results) that are reported in FRV1.

EnergySolutions' Response: The current model is being revised to include the ET Cover design. Once that model is completed, then a complete set of GoldSim model runs will be provided for comparison.

119. INTERROGATORY CR R313-25-8(4)(A)-119/1: RESUSPENSION AND AIRBORNE PATHWAYS

Revise the model inputs and re-run the simulations as noted, or provide documentation and justification that the analysis of exposures due to the air pathways in the PA is conservative, in particular with regard to the resuspension flux entered into GoldSim and the model's calculation of the resuspension rate and airborne radionuclide concentrations, particularly when gullies that extend into the buried DU are present.

EnergySolutions' Response: EnergySolutions has committed to dispose of significant quantities of depleted uranium only below grade in the Federal Cell. Therefore, gullies will not extend into buried DU and the model does not need to be revised as suggested.

- 1) Three values of friction velocity were used to calculate high, mid, and low estimates of average-annual PM10 emission rates. A distribution is being fit to these results that will improve on the distribution described in the Atmospheric Transport Modeling report and on the distribution used in the DU PA model.
- 2) An incorrect link was used in the model for calculating the soil resuspension rate. The link is being corrected providing a consistent approach for the calculations.
- 3) Radionuclide exposure concentrations in airborne dust in the container Exposure_Dose.Media_Concs.Transport_Media is being revised to account

for the contribution of dust resuspension from gullies. Correction of this error will require additional modeling.

120. INTERROGATORY CR R313-25-8(4)(A)-120/1: GULLIES AND RADON

Provide justification as to why the presence of gullies in the embankment has no impact on the radon flux at the surface of the embankment, and thus no impact on the general population doses. Alternatively, modify the GoldSim model to have the embankment surface radon flux account for the presence of gullies within the embankment, include the “short-circuiting” of radon migrating upwards through the degraded cap and the release of radon directly to the atmosphere from any gullies that extend downwards into the disposed DU.

EnergySolutions’ Response: The Clive DU PA Model v1.0 evaluates the effects of the occurrence of gullies in a screening approach, as stated in the Final Report. The mathematical model used to represent a fully-formed gully provided a suitable proxy for a fully-fledged landscape evolution model, which would be a much more significant undertaking. A small number of gullies were used simply in order to determine if gullies presented any contribution to dose or threat to waste containment. The effects of the gullies on biotic activities, enhanced infiltration, or enhanced radon flux were not examined. The potential for exposure of the waste was noted, confirming the significance of gully formation as a process to be considered more fully in subsequent model iterations.

One purpose of this v1.0 of the model, then, is to identify those processes that are of concern for the site. The Interrogatory identifies the ground surface flux of radon as one such process. As the sensitivity analysis has made clear, gully formation is indeed a process of concern for the site, and in that sense, v1.0 of the Model has done its job.

The next version of the model changes from the riprap cap to an ET cap. SIBERIA modeling has been performed on the Borrow Pit, the results of which are being abstracted and adapted to the disposal mound in the upcoming model of the ET Cover. Because of the slope differences, this over-estimates sediment transport offsite, and over-estimates depth of gullies formed. This is being included in the next version of the model and the report. Further erosion modeling needs is being evaluated after that model and report are reviewed.

Note also, that under the scenario that the DU waste is disposed below grade, the erosion consequences are likely to be minimized. This is evident in the current model results by comparing the three pairs of scenarios.

See also Interrogatories #070 and 071.

121. INTERROGATORY CR R313-25-19-121/1: GULLIES AND RECEPTOR LOCATION

When gullies are assumed to be present in the embankment, provide justification for using the radionuclide soil concentration and radon flux averaged over the entire embankment surface (including areas without and with gullies) when calculating exposures to hunters, ranchers, and off-highway vehicle (OHV) enthusiasts. Alternatively, provide the estimated exposures to these receptors when they are assumed to spend all (or most) of their time in the gullies.

EnergySolutions' Response: Discussion is being added to the text of the Erosion Modeling report per below:

“In the GoldSim implementation of gully erosion, a gully is assumed to form (via rainfall, etc.) after the initiating event of an OHV disturbing the rip-rap outer cover material; i.e., the OHVs are only initiating the gullies. The gullies that are modeled are deeply-incised to the extent that they reach the waste layers with side walls at the angle of repose and a wedge shape with a narrow top and broader base where the gully meets the level grade surrounding the disposal cell. The steep-walled profile of the eventual deeply-incised and narrow gullies would likely preclude extensive OHV activity in the gullies themselves; i.e., once a gully forms, OHV users (if any) would likely ride elsewhere on the cap. Thus, the use of area-average embankment air and soil concentrations in the Dose Container for OHV user exposure across the entire disposal unit, including gullies, is appropriate and likely to be protective.”

Given this conceptual explanation, even 5% of time spent in gullies seems conservative, if the area of gullies is 5% of the total area. The deeply incised portions of the gullies are too narrow for OHVing.

Note that this provides a conceptual explanation. However, the model is being updated to address removing the riprap cap and replacing it with an ET cover. An erosion model is being abstracted and adapted to these conditions from previous work performed on the Borrow Pit. Questions about erosion and gullies are being re-addressed.

122. INTERROGATORY CR R313-25-8(4)(D)-122/1: SIZE OF PLUVIAL LAKES

Provide complete references to support assumptions with respect to the size of recurring pluvial lakes. Revise the Deep Time Assessment report to rely on more recent paleolake evidence focused on the Bonneville Basin.

EnergySolutions’ Response: It is acknowledged that there is uncertainty associated with “*number, timing, and recurrence interval*” of lakes, as well as the existence of smaller-scale cycles. The heuristic model for the glacial lake cycles in the deep time assessment is not designed to be an exact representation of the depositional record of the Clive site. Instead the model is designed to represent the long-term variability in climate and glacial-lake cycles for the next 2.1 million years.

The occurrence of large and smaller lakes is discussed in the sections following Section 3.1 of the Deep Time Assessment white paper. Following is text replacing the quoted text above in the white paper (following the existing paragraph):

“Slightly different external forcing and internal feedback mechanisms can lead to a wide range of responses in terms of the causes of glacial-interglacial cycles. The collection of longer ice core records, such as the European Project for Ice Coring in Antarctica (EPICA) Dome C core located in Antarctica, has highlighted the clear distinctions between different interglacial-glacial cycles (Jouzel et al., 2007). Variation in climatic conditions appears to be sufficient that large differences have occurred in each of the past 100 ky cycles. At the present time, the EPICA Dome C core is the longest (in duration) Antarctic ice core record available, covering the last 800 ky (Jouzel et al., 2007).”

“Note that there is considerable uncertainty associated with the number, timing, and recurrence interval of lakes in the Bonneville Basin. The 100 ky glacial cycle is roughly correlated with the occurrence of large lakes (Balch et al. 2005, Davis 1998), and there appear to be smaller, millennial scale (“Dansgaard-Oeschger”) cycles within this larger cycle that are not necessarily uniform (Madsen 2000). For example, the Little Valley lake cycle peaked in elevation at about 135 ky, the Cutler Dam lake cycle peaked about 65 ky, and the Bonneville lake cycle peaked about 18 ky BP (Machette et al. 1992). The following sections discuss these cycles in more detail.”

123. INTERROGATORY CR R313-25-8(4)(D)-123/1: TIMING OF LAKE CYCLES

Incorporate other existing literature on lake cycles in the Bonneville basin for a complete perspective on lake cycles in the Bonneville basin. Describe why the Burmester core data are applicable to the Clive site, including location and distance from Clive, ground elevation, and geologic setting.

EnergySolutions’ Response: There is uncertainty associated with the timing of lake cycles (see also comment #122). The heuristic model for the glacial lake cycles in the deep time assessment is not designed to be an exact representation of

the depositional record of the Clive site. Instead the model is designed to represent the long-term variability in climate and glacial-lake cycles for the next 2.1 million years. Additional justification for employing the Burmester core data, as well as text changes for clarification, are provided below:

“Various studies have investigated previous lake cycles in the Bonneville Basin. These include studies of Lake Bonneville shoreline geomorphology (Currey et al. 1984), palynological (i.e., pollen) studies of deep boreholes (Davis 1998), and studies of the geochemistry of deep-water lacustrine depositional sequences (Eardley et al, 1973; Oviatt et al, 1999, Balch et al. 2005). Analysis of these sediment cores is used to help understand previous lake levels and characteristics as well as establish the approximate age of previous lake cycles (e.g., Oviatt et al., 1999). “

“Oviatt et al. (1999) analyzed hydrolysate amino acid enantiomers for aspartic acid, which is abundant in ostracode protein. Ostracodes are small crustaceans that are useful indicators of paleo-environments because of their widespread occurrence and because they are easily preserved. Ostracodes are highly sensitive to water salinity and other limnologic changes. Therefore, portions of sediment cores that contain ostracodes indicate fresher, and hence probably deeper, lake conditions than the modern Great Salt Lake (Oviatt et al., 1999). To establish the approximate timing of previous lake cycles, Oviatt et al. (1999) examined sediments from the Burmester sediment core originally collected in the early 1970s near Burmester UT (Eardley et al. 1973). Burmester is approximately 65 km east of Clive on the southern edge of the Great Salt Lake, at an elevation of 1286 m. This is the closest deep core site that is relevant to the Clive area (elevation 1307 m). Oviatt has also collected sediment data from Knolls (to the west of Clive) and at Clive itself (described further in Section 3.3). These data are largely consistent with the more recent layers from Burmester, indicating similar sedimentation processes at work at least during these time periods.”

“Data from the 307 m Burmester core suggest that a total of four deep-lake cycles occurred during the past 780 ky (Table 2). Oviatt et al. (1999) found that the four lake cycles correlated with marine $\delta^{18}O$ stages 2 (Bonneville lake cycle: ~24-12 ky), 6 (Little Valley lake cycle: ~186-128 ky), 12 (Pokes Point lake cycle: ~478-423 ky), and 16 (Lava Creek lake cycle: ~659-620 ky).”

[NOTE: the following is inserted from interrogatory #124, as the white paper text was changed in response to that comment.]

“Oxygen isotope stages are alternating warm and cool periods in the Earth’s paleoclimate which are deduced from oxygen isotope data (Figure 2). These correlations suggest that large pluvial lake formation in the Bonneville Basin occurred in the past only during the most extensive Northern Hemisphere glaciations. There are many interacting mechanisms that could control or ‘force’ glaciation and deglaciation. For example, Oviatt (1997) and Asmerom et al (2010) suggested that these extensive glaciations were controlled by the mean position of storm tracks throughout the Pleistocene, which were in turn controlled by the size and shape of the ice sheets. Other glaciation forcing mechanisms have been suggested. The review by Ruddiman (2006) suggests that insolation changes due to orbital tilt and precession, greenhouse gas concentrations, changes in Pacific Ocean circulation, and possibly other interacting mechanisms could contribute to glaciation and deglaciation cycles in North America, and thus pluvial lake existence and size. Lyle et al. (2010) suggests that lake levels in the Pleistocene western US were influenced by stronger spring/summer precipitation fed by tropical Pacific air masses, rather than higher numbers of westerly winter storms. Regardless, the high-level, conceptual modeling of lake cycles that was conducted here did not assume any particular mechanism of glaciation/deglaciation. For example, the modeling simply assumed a 100 ky cycle, regardless of the mechanism.”

[NOTE: Continued response to the present comment below]

“Balch et al (2005) conducted a more recent detailed study on ostracode fossils in Great Salt Lake sediment (i.e., under the lake). Other fossil invertebrates were also used as paleoecological indicators in this study. Both brine shrimp and brine fly fossils are indicators of hypersaline environments because they have a much higher salinity tolerance than most other invertebrates. This study’s findings were consistent with Oviatt et al.’s (1999) later cycles, but as the core was not as deep the findings are not as useful for the present purpose as the Burmester data. The Burmester core data are most germane to the present modeling effort because they represent a relatively long time period in which to establish the occurrence of pluvial lakes in the region. However, note that there is considerable uncertainty associated with the number, timing, and recurrence interval of lakes in the Bonneville Basin. The 100 ky glacial cycle is roughly correlated with the occurrence of large lakes (Balch et al. 2005, Davis 1998), and there appear to be smaller, millennial scale cycles within this larger cycle that are not necessarily uniform (Machette et al. 1992, Madsen 2000). It is likely that shallow lakes have also occurred in each glacial period, but the shorelines have been destroyed by later lakes. Sediment mixing that occurs during lake formation can also mask the

existence of previous shallow lakes. Thus, it is impossible to have complete confidence in historical lake formation characteristics and formation.”

“But, it can be said that large lakes have occurred in the past, as have intermediate lakes and shallower lakes. The model addresses these concepts by allowing large lakes to return in some glacial cycles, and by allowing intermediate lakes to occur as part of the transgressive and regressive phases of lake development.”

124. INTERROGATORY CR R313-25-8(4)(D)-124/1: MECHANISMS FOR PLUVIAL LAKE FORMATION

The discussion of mechanisms for pluvial lake formation is incomplete. Describe other possible forcing mechanisms that have been proposed for the formation of Great Basin pluvial lakes and present the basis for the selected approach.

EnergySolutions’ Response: Following are text changes for clarification:

“Oxygen isotope stages are alternating warm and cool periods in the Earth’s paleoclimate which are deduced from oxygen isotope data (Figure 2). These correlations suggest that large pluvial lake formation in the Bonneville Basin occurred in the past only during the most extensive Northern Hemisphere glaciations. There are many interacting mechanisms that could control or ‘force’ glaciation and deglaciation. For example, Oviatt (1997) and Asmerom et al (2010) suggested that these extensive glaciations were controlled by the mean position of storm tracks throughout the Pleistocene, which were in turn controlled by the size and shape of the ice sheets. Other glaciation forcing mechanisms have been suggested. The review by Ruddiman (2006) suggests that insolation changes due to orbital tilt and precession, greenhouse gas concentrations, changes in Pacific Ocean circulation, and possibly other interacting mechanisms could contribute to glaciation and deglaciation cycles in North America, and thus pluvial lake existence and size. Lyle et al. (2010) suggested that lake levels in the Pleistocene western US were influenced by stronger spring/summer precipitation fed by tropical Pacific air masses, rather than higher numbers of westerly winter storms. Regardless, the high-level, conceptual modeling of lake cycles that was conducted here did not assume any particular mechanism of glaciation/deglaciation. For example, the modeling simply assumed a 100 ky cycle, regardless of the mechanism.”

Note the heuristic nature of the model, which is consistent with the regulatory requirement to perform “*qualitative modeling with simulations*”. This heuristic model does not attempt to predict the exact timing and size of lakes in the long-

distant future, but instead acknowledges that large lakes have occurred in the past, as have intermediate lakes and shallower lakes, and that the model addresses these concepts by allowing large lakes to return in some glacial (100-ky) cycles, and by allowing intermediate lakes to occur as part of the transgressive and regressive phases of lake development. Large lakes are associated with an elevation in the model, so the rate of intermediate lakes depends on the elevation of the large lakes. This captures the essence of the 100-ky cycles lake effects and the associated build up of sediment over time.

Also, see responses to Interrogatories from #s 122-126.

125. INTERROGATORY CR R313-25-8(4)(D)-125/1: DEEP LAKE CYCLES

Correct the age ranges for the Lake Bonneville flood events to reflect more recent information.

EnergySolutions' Response: The text below (Section 3.2, page 8, of the Deep Time Assessment white paper) is being changed for clarification:

“Most studies indicate that the high-stand (i.e., the highest level reached) of the lake at the Zenda threshold (1,552 m), located north of Red Rock Pass, occurred approximately 18.3–17.4 ky BP. The high-stand of the lake was followed by an abrupt drop in lake level due to the catastrophic failure of a natural dam composed of unconsolidated material at approximately 17.4 ky BP. As a result of this flood, the lake dropped to a level of 1,445 m, called the Provo level. The Provo level is the maximum level that any future deep lake is likely to reach (Currey et al. 1984, Oviatt et al. 1999). A more recent study (Miller et al. 2013), using radiocarbon dating for Provo shoreline gastropod deposits, estimates that the dam collapse and Bonneville flood event occurred between 18.0 and 18.5 ky BP, and therefore the high-stand may have occurred earlier. However, Miller et al. (2013) indicate that “uncertainties in [gastropod] shell ages may be as large as thousands of years, and the major shorelines of Lake Bonneville and the Bonneville flood require more work to establish a reliable chronology.” The lake regressed rapidly during the last deglaciation, then increased again to form the Gilbert shoreline between 11.2-12.9 ky BP which coincided with the Younger Dryas global cooling event (Oviatt et al., 2005).”

126. INTERROGATORY CR R313-25-8(4)(D)-126/1: SHALLOW LAKE CYCLES

Examine the presumed shallow lake cycles within the context of other references regarding lake cycles from other areas of the Great Basin.

EnergySolutions' Response: There were typographical errors in the quoted paragraph cited (Section 3.3, page 9 of the Deep Time Assessment white paper) that are corrected below. Intermediate lakes are defined in the white paper as lakes that at least reach the elevation/location of Clive, so the text as indicated reads “*intermediate*” instead of “*shallow*”. Additionally, references to “*shallow*” lakes in Table 3 of the white paper are being changed to “*intermediate*”. The paragraph describing these distinctions is being moved to a position before the quoted paragraph. The name of Section 3.3 (Shallow Lake Cycles) will also be changed as indicated:

3.3 Shallow and Intermediate Lake Cycles

“For modeling purposes, a distinction is made between shallow, intermediate and large lakes. Large lakes are assumed to be similar to Lake Bonneville, occurring no more than once per 100 ky glacial cycle. Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur. The Gilbert shoreline of Lake Bonneville is an example (Currey et al 1984). Shallow lakes are assumed to exist at all other times. The current Great Salt Lake is an example. For the purpose of modeling, the depths of these lakes are not as important as the areal extent in terms of modeling the occurrence. Under current climate conditions, it is assumed that intermediate lakes will not occur. Under future climate conditions, some glacial cycles will produce a large lake in the Bonneville Basin, and intermediate lakes will occur during the transgressive and regressive phases of a large lake, or during glacial cycles that do not exhibit a large lake.”

“Intermediate lake events have occurred in the Clive area. These are documented in Table 3 (C.G. Oviatt, Professor of Geology, Kansas State University, personal communication December 2010, January 2011, and email communication herein referred to as 'C.G. Oviatt, personal communication'). These events are evident when analyzing a pit wall interpretation at the Clive site (Appendix A; C.G. Oviatt, unpublished data) as well as at the ostracode and snail record present in the Knolls (12 km west of Clive near the Bonneville Salt Flats) sediment core (Appendix B; C.G. Oviatt, unpublished data). The pit wall study conducted by Oviatt occurred during early development of the Clive disposal facility. From the Clive pit wall interpretation, it is presumed that at least three intermediate lake cycles occurred prior to the Bonneville cycle, although there is uncertainty

associated with that estimate. For example, these intermediate cycles could in fact be part of the transgressive phase (i.e., rising lake level) of the Lake Bonneville cycle (C.G. Oviatt, personal communication). By analyzing the Knolls core interpretation, the Little Valley cycle is present at approximately 16.8 m from the top of the core. Given the pit wall at Clive was 6.1 m deep and does not capture the Little Valley cycle, it is possible that other smaller lake cycles occurred in the Clive region in addition to the three intermediate lake events noted in Table 3 (labeled as Pre-Bonneville Lacustrine Cycles). There are few data to support the specific number of lakes that may reach Clive and the rate of sedimentation. There is also uncertainty associated with the particular times that these cycles occur, as age dating (e.g., via radiocarbon dating) has not been performed in the Great Salt Lake area. Most studies simply examine the degree of lake salinity using fossil records, and are associated with cores that are in or near the Great Salt Lake. For example, Balch et al. (2005; Fig. 6) estimated that there were six “saline/hypersaline” (i.e., shallow to intermediate) lake cycles that occurred between the Lake Bonneville and Little Valley cycles, and approximately that same number between the Little Valley cycle and the maximum age evaluated (300 ky). However, this work does not inform the question of whether these lakes may have reached the elevation of Clive, nor does similar work such as Davis (1998). Assumptions used in modeling are documented in Section 6.2.”

127. INTERROGATORY CR R313-25-8(4)(D)-127/1: CARBONATE SEDIMENTATION

Provide additional rationale for the assumption that carbonate sedimentation will not occur in intermediate lakes, based on the limnology literature.

EnergySolutions’ Response: The intent of the cited sections is not to exclude carbonate deposition in intermediate lakes (see for example the second paragraph of section 6.2 that references carbonate oolitic deposition in intermediate lakes). The primary emphasis of the descriptions in section 3.3 is on the sediment depositional rates of intermediate versus large lakes not on the presence or absence of carbonate deposition. A key assumption for the deep time assessment is the observation, based on core sediment studies, that the net depositional rate of deep lakes is lower than the sediment depositional rate for intermediate lakes. The conceptual basis for this assumption is sedimentation rates are dependent on basin location, presence or absence of fluvial deposition, wave dynamics, availability of local sediment sources, slope, water chemistry and biological activity. Carbonate deposition is likely to occur under a wide range of lake conditions but the ratio of carbonate deposition to clastic sedimentation will increase as the lake deepens because of the reduction in sedimentary influx with increased distance from shoreline processes and decreased wave activity.

There are recognized trends in carbonate mineralogy that can be correlated with lake volume and indirectly lake depth (for example, Oviatt, 2002; Oviatt et al., 1994; Benson et al., 2011). The transitions from low-magnesium calcite to high-magnesium calcite to aragonite generally reflect increasing lake salinity and increasing magnesium concentration which occur with decreasing lake volume. Similarly, for a hydrologically closed pluvial lake system, the relative concentration of total inorganic carbon should decrease as lake size increases. The $\delta^{18}\text{O}$ of deposited carbonate can be correlated with rising lake levels because of the interplay between the $\delta^{18}\text{O}$ value of river discharge entering a lake and the $\delta^{18}\text{O}$ value of water vapor exiting the system via evaporation (Benson et al. 2011). The mineralogy and isotopic composition of carbonate composition can be obtained from sediment cores. However, interpretations of the data are complicated by multiple processes including local groundwater discharge, introduction of glacial rock flour, and reworking of lake sediments during transgressive and regressive lake cycles.

The model parameters used in the deep time assessment are sensitive to lake duration and sedimentation rates but are not dependent on the dynamics of carbonate deposition. Radionuclides in sediment will partition between the lake water and solid phase dependent on element-specific solubility and assigned sorption properties. Radionuclides remaining in the pore water can diffuse into the lake water. Some radionuclide species may bind with carbonate ions in the lake water and precipitate as carbonate. However, the deep time assessment assumes all waste is precipitated into local sediments during lake recession. Additional detail on lake dynamics/circulation and processes of radionuclide partitioning in lake carbonate and evaporite deposits during lake recession is being added.

128. INTERROGATORY CR R313-25-8(4)(D)-128/1: LAKE SEDIMENTATION

Use the information in existing journal literature on sedimentation rates to update statements in the Deep Time Assessment report. Emphasize how the core data and sedimentation rates for those locations are relevant to the Clive site given the paleodepositional facies involved.

EnergySolutions' Response: The heuristic model for the glacial lake cycles in the deep time assessment is not designed to match the depositional record of the Clive site. Instead the model represents the long-term variability in climate and glacial-lake cycles for the next 2.1 million years. Probability distribution functions are sampled in the model simulations for sedimentation rates for large and intermediate glacial lakes (Table 1, Appendix 13 Deep Time Assessment). The selected distributions represent potential variability in lake sedimentation for a wide range of conditions spanning multiple glacial cycles. Section 3.4 describes sediment accumulation rates determined from studies of sediment cores and pit exposures at a range of sites in the Lake Bonneville basin and including

unpublished data from the Clive site. The model design does not necessarily require matching the sedimentation rates to the specific depositional facies at the Clive site.

While inclusion of rate data from published literature from as many sites as possible is always a consideration, the added data would only be important if it modifies the distribution parameters used to represent lake sedimentation during future glacial cycles. Moreover, the sedimentation rates are not key parameters affecting the deep time model results (lake and sediment concentrations). The model results are strongly dependent on assumptions of embankment erosion and incorporation of DU waste in lake sediments, radionuclide recycling between sediment and lake water, and remixing of waste/sediment mixtures during successive glacial lake cycles. Additionally, the model results are more dependent on the parameter distribution used to represent site dispersal area of waste during lake erosion intervals (see the model parameter list in Table 1, Appendix 13 Deep Time Assessment) than the parameters for lake sedimentation rates.

No changes are needed in the text.

Note that the model is heuristic, capturing the concepts of large and intermediate lake formation, and sedimentation through each glacial cycle (which includes aerial deposition, lake/wave scouring and lake deposition).

129. INTERROGATORY CR R313-25-8(4)(D)-129/1: LAKE EROSION

Provide a reference to support the assumption that a lake is large enough to obliterate a relatively soft pile. Explain why such obliteration will not be cause for ongoing active maintenance.

EnergySolutions' Response: The assumption of complete erosion of the embankment during the first lake return to the Clive site is considered a simplifying assumption. Figure 13 in the Clive DU PA model and the accompanying text show that the U-238 concentration in sediments is driven by the first lake event, with decreasing sediment concentrations in successive lakes. If the embankment is not completely eroded, there will be less waste mixed in the sediments, and lower sediment concentrations of U-238 in the first and all successive lake sediments. Consequently, this simple assumption is probably conservative for the endpoints of U-238 concentrations in sediment and lake water.

The concept is that subsequent to obliteration by a lake, there will no longer be a disposal site that needs to be maintained. Assuming the waste is dispersed through wave action and lake dynamics, and that the waste is no longer containerized in this environment, any exposed waste will be dispersed with other

material in the mound and with other material being moved with the returning lake. There will be nothing left to maintain if the whole site is obliterated.

Aerial deposition is being addressed as part of evaluating erosion of the ET cover. Aerial deposition rates suggest that greater stability will be provided for the site over time, so that only the upper portions of the site might be dispersed. The DU, disposed below grade, could stay buried. This is being evaluated further in the next model revision.

The degree of erosion will be strongly dependent on local lake conditions as well as the dynamics and duration of wave action and shoreline processes. If documentation is required for the conservative assumption of complete erosion of the waste embankment, a preferred approach would be examination of natural analogues of erosion processes and erosion effects in the Lake Bonneville basin. See the response to Interrogatory #131 for a discussion of possible natural analogue studies that could potentially be applied to model revisions and/or supporting studies of the lake erosion part of the deep time model.

Also, note that there is no expectation or requirement of active maintenance of a low-level waste disposal system for time periods of 10,000 years or longer.

Refer to R313-25-22: *The disposal facility shall be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.*

130. INTERROGATORY CR R313-25-8(4)(D)-130/1: LAKE GEOCHEMISTRY

Provide references to support statements concerning the geochemistry of uranium in the carbonate system and adsorption behavior on clays, iron oxides, and ferrihydrites and revise the statements as needed to reflect the literature.

EnergySolutions' Response: Section 4.0, page 13, of the Deep Time Assessment report states the following:

“While the lake is present, some waste in the water column will bind with carbonate ions and precipitate out into oolitic sediments, while the remaining waste will fall out with the sediment as the lake eventually recedes.”

This section (Section 4.0, page 13) of the Deep Time Assessment documentation is referring to precipitation of radionuclides with soluble carbonate ions to form carbonate minerals. It is not discussing adsorption onto clays or carbonates. This

statement is elaborated on in Section 6.5.2. Text is being added to Section 4.0, page 13 after the quote above to reference Section 6.5.2 for more details.

The K_{ds} for U and the other elements are the same in the Deep Time model as in the original model. The only change to U geochemistry in the Deep Time model is the solubility, which decreases for the reasons described in Section 6.5.2.

Interrogatory #147 asks to justify high U K_{ds} that are associated with ferrihydrites and clay. See the response to Interrogatory #147 for more discussion on U adsorption.

131. INTERROGATORY CR R313-25-8(4)(D)-131/1: POTENTIAL WAVE ENERGY

Provide support and references for the assumption that shallow lakes have low wave energy.

EnergySolutions' Response: Waves in small lakes could be destructive and potentially erode the waste embankment. As noted in the response to Interrogatory 129, the deep time model makes the conservative assumption that the embankment is completely eroded during the return of the first lake cycle to the elevation of the Clive site. Note also that the model revision includes an ET cover and will also address aerial deposition prior to when the first lake arrives. Aerial deposition rates in the area are at least 0.1 mm/yr, which covers and increases stabilization of the disposal system, and complete cover of the disposal system is also possible if the first lake does not arrive in the current climate cycle.

Examination of the literature on erosion of engineered features of coastal shorelines is a possible approach to evaluating lake erosion. However, the approach would be difficult to apply to the dynamics of transgressive and regressive stages of glacial lakes. A potentially more useful approach would be analogue studies examining erosional features of preserved shorelines in the Lake Bonneville basin. Two approaches could be considered. The first is examination of erosional features of the regressive-phase Provo shorelines (Sack, 1999) in the Clive vicinity. Field measurement could be made on the erosion depth/height of preserved shorelines and used to develop a distribution of erosion depths for use in parameters developed for a more physically realistic erosion model (an alternative to complete erosion of the embankment and release of disposed DU). Additionally, the surficial expression of shorelines could be used to refine the SiteDispersalArea parameter in the deep time GoldSim model (Table 1, Appendix 13, Deep Time Assessment). Both parameters would be significant in model evaluations of radionuclide concentrations in lake sediments.

A second approach would be systematic examination of erosional features of volcanic landforms modified by post-Provo shoreline erosion in the Black Rock

Desert volcanic field (Nash, 1990). The advantages of this approach are two-fold. First, volcanic landforms have distinctive shapes (scoria cones, tuff cones, tuff rings) allowing reconstruction of erosional modification of their original shape/geometry (see attached Figures below). Second, volcanic landforms exhibit a range of resistance to lake erosion varying from poorly consolidated scoria cones (easily eroded), indurated tuff cones and tuff rings from palagonization (the process of alteration of hydrated basaltic glass to form palagonite), and highly resistant lava flows with distinctive flow structure (pahoehoe and aa lava flows). The physical properties of this range of volcanic landforms would be analogous to the physical properties of closure cover designs.

These analogue studies would only be considered if model revisions are required to reduce the conservatism of the assumption of complete erosion of the waste embankment in the first return of a glacial lake.



Figure 2-131/1, Google Earth Depiction of Volcanic Landforms

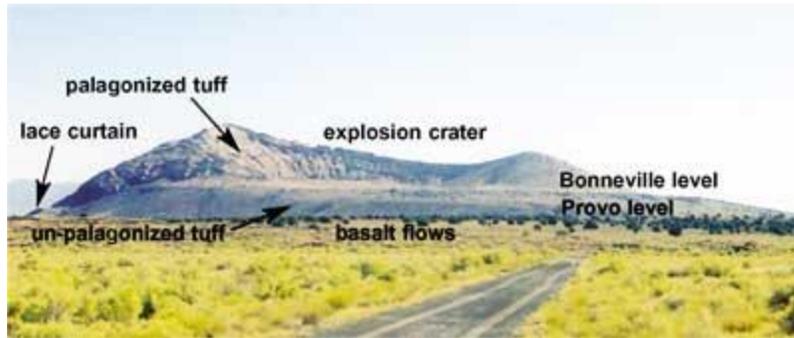


Figure 2-131/2, Bonneville Volcanic Landforms

Google Earth photograph of the Pahvant Butte in the Black Rock Desert, a 16,000 BP tuff cone (crater diameter is 3 km for scale); oblique view of the crater from photograph on the WWW with identification of the Bonneville and Provo shoreline benches.

132. INTERROGATORY CR R313-25-8(4)(D)-132/1: SEDIMENTATION MODEL

Provide more detail on the sedimentation model as it relates to the text.

EnergySolutions' Response: The data in Figure 9 represent a time history, in which case a time series technique is appropriate. The data in Figure 9 show a range in elevation of about 5 m for the roughly 150 year period. The model incorporates the time history curve, so that it preserves the elevation range over time. A serial correlation is also assumed, which is evident from Figure 9 (if not, all data points would look random across the plot, instead of showing upward and downward trends for shorter period of time). An autoregressive model achieves variability across time, but in a correlated fashion that allows the elevation of the lake to increase for short periods and then decrease for short periods.

It was further assumed that, in the transgressive phase of the development of a lake, the lake elevation would increase. So, the model for the transgressive phase has an increasing function so that the elevation of the lake is increasing with time, but subject to shorter term variability modeled with a time series function that allows lakes to expand for a while and then shrink for a while (as evidenced by the data presented in Figure 9).

The underlying conceptual model is that as the climate cycle continues beyond the inter-glacial period, the elevation of the lake will rise in general, but include “stops and starts” along the way. The 150 year data record was used to model the “stops and starts” with the autoregressive time series model, whereas the general

trend (upwards during the transgressive phase) was modeled as a transgressive and then regressive curve. The text description is being expanded to include more information on the modeling, in particular the transgressive and then regressive curve that underlies the process.

However, it is important to note that the intent of the deep time model is to allow large lakes to return periodically, and to allow intermediate lakes to appear during the transgressive and regressive phases. The number of lakes that return is not nearly as important as the process that allows at least some lakes to return.

More information can be provided about the processes affecting lake sedimentation. Sedimentation happens through three basic mechanisms. The first is aerial deposition of wind-blown deposits that happens predominantly during the inter-glacial period. The second is sediment that is physically moved by lake action (and related water action – for example, once the lake returns there will be more above lake and below lake “rivers” that will move sediment – lake action will scour sediment, hence the benches that are seen around the Bonneville basin). The third is lake precipitation or oolitic sedimentation.

The historical record consists of data that represent seven or eight 100 ky cycles. Our analysis of the different cores (Burmester, Knolls, and the borrow pit wall at the Clive site), suggest roughly 15-20 m of sediment per cycle, whether or not a large lake returns. Note that these sediments are often mixed so that the differentiation between aerial deposition, alluvial sediment, and lake sediment (oolitics) is difficult. But, it appears that all processes contribute to the overall lake sedimentation cycles, with more aerial deposition in some cycles, and more lake sediment in other cycles, etc. The mixing of sediment occurs when a lake returns and churns the aerial deposition, and then lake sediments; both overly and mix with other sediments (depending on the duration of the lake cycle and the maximum lake depth, both of which affect lake sedimentation rates).

These interacting processes are being described in greater detail in the revised report. In addition, supplemental research is being performed using analogue features in the Lake Bonneville basin to better constrain processes of sedimentation and embankment erosion, as well as how the disposal mound might be partially covered by the time a lake returns.

133. INTERROGATORY CR R313-25-8(4)(D)-133/1: CALCULATIONS OF RADIOACTIVITY IN WATER AND SEDIMENT

Provide context for the equations and variables presented for calculating radioactivity in water and sediment.

EnergySolutions’ Response: A scenario considering occurrence of an intermediate lake, the resulting destruction of the EnergySolutions waste

embankment, and dispersal of the waste is modeled. The activity per unit volume of sediment following the dispersal of the waste is estimated using equation 13 on page 31 of the Deep Time Assessment report:

$$C_{\text{sediment}} = \frac{R_{\text{above grade}}}{V_{\text{material above grade}} + V_{\text{sediment}}}$$

In this equation C_{sediment} is the activity per unit volume of the sediment, $R_{\text{above grade}}$ is the activity of the waste in the above grade portion of the embankment, $V_{\text{material above grade}}$ is the volume of material in the above grade portion of the embankment, and V_{sediment} is the additional sediment transported to the dispersal location due to lake formation. V_{sediment} is estimated as the depth of sediment due to lake processes times the area over which the waste is dispersed.

The calculation of the activity diffusing from the sediments into the water during a time period is described on pages 31 and 32 of the Deep Time Assessment report.

As radionuclides associated with the sediments dissolve into the pore water, they diffuse into the lake water using a constant flux model based on Fick's first law, with the following assumptions:

- There is an interface boundary layer of 0.1 m above the sediment, above which the water has a radionuclide concentration of 0. In fact, there will be some buildup of concentration as a radionuclide migrates into the water, but it will diffuse into the lake. It is conservative to assume a zero concentration, which results in the highest possible flux.
- The concentration in sediment remains constant over the deep time period. The sediment concentration should in fact diminish over time if enough mass is migrated into the water, but for simplicity, the sediment concentrations are kept constant across time steps.

Fick's law for this case estimates the activity diffusing from a given area of sediment into the lake with time. The activity per area per time is the flux. Fick's law states that this flux is given by the change in activity with distance multiplied by a free-water diffusion coefficient. The calculation assumes that there is a stagnant interface boundary layer of water between the sediment and the open water that is 0.1 m thick. The assumption is also made that the activity concentration is zero in the open water. The difference in concentration across the stagnant layer is then the concentration in the sediment C_v minus the concentration in the open water or $C_v - 0$. Fick's law would be written as:

$$\text{Activity Flux} = \frac{R}{\Delta t A} = D_m \frac{C_v - 0}{0.1}$$

Where:

R is the activity,

Δt is the length of the time period,

A is the area of the sediment that contains the waste, and

D_m is the diffusion coefficient for the radionuclide in water.

Multiplying both sides of the equation by $\Delta t A$ gives equation 14 in the Deep Time Assessment report.

The activity concentration in the lake water is then calculated by dividing the total activity, A, by the volume of lake water. The volume of lake water is the product of the lake depth and the dispersal area. The above equations are implemented in the GoldSim model to provide qualitative assessments of deep time concentrations in lake water and lake sediment following the return of a lake in the Bonneville Basin large enough to demolish the CAS embankment. The text in the Deep Time Assessment report is being revised to provide context for the equations and variables presented.

134. INTERROGATORY CR R313-25-8(4)(D)-134/1: FUTURE LAKE LEVEL ELEVATIONS

Provide further discussion on the potential rise of the lake level with respect to the proposed facility and more specific definitions of the depth of “intermediate” and “deep” lakes.

EnergySolutions’ Response: Please also see the response to Interrogatory CR R313-25-8(4)(d)-126/1 with regard to distinctions between “shallow”, “intermediate”, and “deep” lake definitions as germane to modeling. Text has been added following the paragraph below:

“For modeling purposes, a distinction is made between shallow, intermediate and large lakes. Large lakes are assumed to be similar to Lake Bonneville, occurring no more than once per 100 ky glacial cycle. Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur. The Gilbert shoreline of Lake Bonneville is an example of a lake that attained the elevation of Clive (Currey et al 1984). Shallow lakes are assumed to exist at all other times. The current Great Salt Lake is an example. For the purpose of modeling, the depths of these lakes are not as important as the altitude attained. Under current climate conditions, it is assumed that intermediate lakes will not occur. Under future climate conditions, some glacial cycles will produce a large lake in

the Bonneville Basin, and intermediate lakes will occur during the transgressive and regressive phases of a large lake, or during glacial cycles that do not exhibit a large lake.”

“It is also possible that intermediate lakes could occur and thus reach the elevation of Clive under unusual conditions. The areal extent of lakes is not only determined by elevation, but by local topography, precipitation, temperature, characteristics of inflow and outflow sources, and other factors. For instance, the Great Salt Lake ‘spilled’ over a 1285 m (4217 ft) topographic barrier to the west of the present lake into the area of the present Great Salt Desert as recently as the 1700s (Currey et al., 1984). This expanded lake was about 15 m lower than the Clive site. Precise dating of shorelines for the Great Salt Lake and variants is unfortunately lacking. Radiocarbon dating for the Pyramid Lake area in Nevada indicates that this lake’s levels have lowered approximately 35 m from the late Holocene (3.5 to 2.0 ky) to today (Briggs et al. 2005). Radiocarbon and tree-ring dating to determine lake levels in the Carson Sink area in Nevada indicates that lake elevations have risen approximately 20 m twice in the last 2000 years (Adams 2003). It is not possible at this time to interpolate from these studies to the Great Salt Lake area. However, given that there is lack of empirical evidence that under present climate conditions that an intermediate lake would reach the Clive site, this condition is not addressed. Future intermediate lake assumptions are described in Section 4.1.1.1.”

135. INTERROGATORY CR R313-25-19-135/1: EXPOSURE TO GROUNDWATER

Provide a calculation of the doses to an individual who pumps, processes, and uses the groundwater from a well located near the Clive facility to ensure that exposures are below the levels specified in R313-25-19. Examine how byproducts of future desalination processes that might rely on radio-contaminated groundwater at Clive will need to be managed to protect public health and the environment, incorporating additional dose to a member of the public if needed.

EnergySolutions’ Response: Please see the response to Interrogatory CR R313-25-7(2)-91/1.

136. INTERROGATORY CR R313-25-7(1)-136/1: IRON (HYDRO)OXIDE FORMATION

Clarify whether the formation of iron (hydro)oxides derived from the waste containers was considered in predicting sorption.

EnergySolutions' Response: In the Clive DU PA model, the K_{ds} of the waste are assumed as those for Sand. No credit is taken for degradation of the steel to form iron (hydr)oxide or the subsequent sorption by radionuclides to these solids. Taking credit for the iron present in the waste is appropriate and is more realistic for the transport of radionuclides, slowing down the movement of radionuclides out of the waste.

Text is being added to Section 2.0 of the Geochemical Modeling report to clarify that no credit was taken for adsorption onto the steel drums in the development of K_{ds} for the waste materials.

137. INTERROGATORY CR R313-25-7(1)-137/1: TOTAL DISSOLVED CARBONATE CONCENTRATIONS AND OTHER GEOCHEMICAL DATA

1. Reassess the total dissolved carbonate concentrations to determine whether they were underestimated, leading to the underestimation of uranium sorption in subsurface earth materials.
2. Explain and justify why the geochemical data from the seven wells listed in Tables 5 and 6 of the Geochemical Modeling report are representative of the shallow aquifer at Clive, especially in light of the presence of 78 compliance monitoring wells now found in Section 32.
3. Describe what hydrostratigraphic units the water table occupies below the Class A South cell, including in terms of groundwater mounding that exists near GW-19A.
4. Explain and justify the range of TDS quoted for the shallow aquifer at Clive.

EnergySolutions' Response:

1. The underestimation of soluble carbonates leads to an overestimation of U sorption. As stated in reply to other interrogatories (#140, #142, #148), the carbonate assumptions are being clarified, including the applicability of the references used for K_d distribution development to the Clive site, especially with respect to the high carbonates expected at Clive.
2. The monitoring well data is being revisited and clarified in Table 5, further demonstrating the representativeness of these 7 wells for the shallow aquifer of the Federal Cell. If applicable, data from compliance monitoring wells is being included in the Geochemical Modeling report in Table 5 or an

additional table to encompass the range of geochemical parameters expected at Clive.

3. The Geochemistry Modeling report is being revised and describes what units the water table occupies below the Federal Cell, including groundwater mounding at the southwestern margin of the Federal Cell (e.g., near GW-19A).
4. The TDS values in Table 5 range from about 20 parts per thousand to 70 parts per thousand. Data from EnergySolutions (2013) were not available when the original Geochemical Modeling report was written. With a minimum of 10.4 parts per thousand, these data appear to be fairly consistent with Table 5 TDS values. The EnergySolutions (2013) data is being incorporated into the Geochemical Modeling report.

138. INTERROGATORY CR R313-25-26(1)-138/1: MONITORING WELL COMPLETION ZONES

Clarify from which completion zones the wells are sampled.

EnergySolutions' Response: Completion zones and screen depths (and associated groundwater concentrations) are reported annually to the Division for EnergySolutions' point of compliance monitoring wells (EnergySolutions, 2014b). However, the text in question only discusses the shallow aquifer data, as evidenced by the statement that

“All wells are completed within the upper unconfined aquifer...”

The text is being changed to the following:

“The Clive Facility has a large number of monitoring wells with completion zones in the shallow aquifer and monitoring data are currently collected from these wells on at least an annual basis.”

139. INTERROGATORY CR R313-25-7(1)-139/1: ION CHARGE BALANCE

Clarify the ion charge balance.

EnergySolutions' Response: The table below is being added to Section 2.2 of the Geochemical Modeling report, as a revised Table 6, along with the modified text below.

“Sodium and chloride are clearly the dominant ions with slightly alkaline pH. Excellent charge balance is obtained using these data, indicating all major ions are being accounted for. Note that the dominance of Na and Cl in the charge balance (86% and 92%) obscures many of the other ion contributions.”

Table 2-139/1 (6): Ion Concentrations from GW Wells Surrounding the Waste Cell. Negative and positive percent charge balance contributions are given on a molar basis.

GW Well	Br ⁻ (mg/L)	F ⁻ (mg/L)	Cl ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	K ⁺ (mg/L)	Na ⁺ (mg/L)
GW-16R	22	3.8	22,914	1.4	1,769	354	486	476	14,263
GW-25	23	8.8	25,783	1.1	4,420	527	853	565	16,465
GW-19A	0	0	37,800	0	0	1,028	1,580	616	23,800
GW-57	18	8.5	23,110	1.9	4,652	707	844	530	14,398
GW-100	26	1.8	20,254	1.1	2,911	496	683	457	12,993
GW-110	17	1.5	17,989	2.1	2,226	322	469	432	11,400
GW-125	16	0.9	20,813		2,494	427	637	488	12,813
Average (mg/L)	20	4.2	24,094	1.5	3,079	552	793	509	15,162
Average (mol/L)	2.2E-04	1.9E-04	6.8E-01	1.8E-05	2.7E-02	1.4E-02	3.3E-02	1.3E-02	6.6E-01
percent of charge balance	0.03%	0.03%	92 %	0.002%	7.5 %	3.6 %	8.5 %	1.7 %	86 %

140. INTERROGATORY CR R313-25-7(1)-140/1: DETERMINATION OF K_d VALUES

1. Provide a more detailed description of the determination of K_d values used in the recent PA modeling.
2. For those elements/nuclides that are redox sensitive, describe the redox condition assumed in selecting appropriate K_d values and compare this assumption with all aquifer redox data collected from the shallow Clive aquifer to date.
3. Add a summary table to Section 4.1 of the Geochemical Modeling report that provides more detail on inputs to the model.
4. Compare the site-specific K_d values determined by Adrian Brown Consultants (1997) with the PA model’s K_d descriptive statistics and explain and justify any similarities or differences in light of the local geologic conditions and geochemistry and the depositional environment that created the pluvial lake deposits occupied by the Clive vadose zone and shallow aquifer.

EnergySolutions’ Response:

1. Clarification is being added to the text to describe how K_d values were selected from references (EPA, 1999) and used for the Clive DU PA model, especially for Cs and Pa with respect to the effects of TDS on sorption and the applicability of the references.
2. The redox assumptions are being clarified for the elements that are redox sensitive and the role redox plays in selection of K_d ranges. The assumptions of redox conditions for Clive and comparison to the aquifer redox data is being discussed.
3. A summary table is being added to the Geochemical Modeling report to include:
 - Element simulated in the GoldSim model
 - K_d distribution type used in the model (normal or log-uniform)
 - Defining values of the distribution (mean and variance, or min and max, respectively for normal or log-uniform)
 - Range of K_d inputs used to develop distributions (as in the Response to Interrogatory #146)
 - The corresponding laboratory-determined K_d , using Clive soils and Clive groundwater, reported by Adrian Brown Consultants (1997)
4. A discussion of the K_d values from Adrian Brown Consultants (1997) and their applicability to the Clive DU PA model and how they were used in K_d distribution development is being included in the Geochemical Modeling report.

141. INTERROGATORY CR R313-25-7(1)-141/1: PH AND K_D VALUES AND SERNE (2007)

Consider pH values when estimating K_d values and provide more detail on the “*non-groundwater scenario*” used in Serne (2007).

EnergySolutions’ Response: The intention of citing the Serne (2007) report is to use it primarily as a secondary reference for comparison purposes for K_{ds} . The sites are somewhat similar, although there are differences.

For example, the Clive soils have a pH range of 7 to 8. The pH of the soils in Serne (2007) are 6.2 to 7.8. Since pH is an important contributor to K_d , it should be noted that K_{ds} from Serne may have a wider distribution than would be expected at Clive. As part of the analysis of the Serne (2007) K_d ranges, it should be noted that the Clive K_{ds} are slightly broader ranges that to include slightly higher pH values of the Clive soils.

Text is being added to say,

“Of note is that the Hanford soils are slightly acidic (pH 6.2 to 7.8),”

The total organic carbon content referenced in Serne (2007) of 0.5% to 1.5% is the total organic carbon content in the sediments along the river banks. So this is the carbon content of the solid phase rather than the groundwater. According to the NRCS Web Soil Survey (<http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>), Clive soils are slightly lower in organic matter, with ranges at Clive from approximately 0.3% to 1%. These slight differences will not make much difference in the K_d estimations.

Text is being added to say

“...with organic content of 0.5 to 1.5% organic carbon, slightly different from the Clive location with organic carbon contents of approximately 0.3% to 1%.”

Text is being added to clarify the non-groundwater scenarios as

“scenarios that do not involve direct ingestion of contaminated well water by humans or animals,” as in Serne (2007).

142. INTERROGATORY CR R313-25-7(1)-142/1: REFERENCES FOR K_D DISCUSSION

Provide additional references to support the discussion of K_d values. Alternatively, either (1) select conservatively low K_d values or (2) collect Clive soil and groundwater samples and perform independent laboratory testing to determine a site-specific empirical value(s).

EnergySolutions’ Response: The expected chemical species of each ion is presented based primarily on EPA (1999) and EPA (2004). Detailed chemical modeling is not needed, in general, for the initial Clive DU PA model, except, perhaps, for certain elements of interest, such as uranium. If necessary, the probabilistic model will demonstrate, through sensitivity analysis, whether or not more detailed modeling is needed to reduce uncertainty in sensitive parameters. The text is being modified to clarify the references that provide a basis for the speciation of each chemical element.

The discussion of chemical speciation is relevant only in that it provides justification for selecting K_d values from some references versus other references. The applicability of each reference depends in part on the chemical speciation. The text is being modified to clarify the chemical speciation of the element in the reference, along with a discussion of the applicability of the reference for K_d distribution development at the Clive site.

The solid phase composition of sites is being compared if possible and if applicable. The emphasis for the level of detail needed for justification of the applicability of a reference should be on demonstrating that the most appropriate data were used. Carbonate concentrations and pH may be more important factors than solid phase composition, although clay and iron oxide contents are also important.

Clarification is being added to the Geochemical Modeling report to justify the K_d distributions from the literature so that site-specific data are not needed. Conservatively low K_d values are not easily interpretable and will not be used, in general. With the complexity of performance assessment models, it is difficult to identify what a “conservative” assumption means because of the non-linearity of the model and because of multiple endpoints. An assumption might be conservative for one endpoint, but that same assumption might not be conservative for a different endpoint. It is better to create wider distributions where there is uncertainty in the solubility than it is to be “conservative.”

143. INTERROGATORY CR R313-25-7(1)-143/1: NEPTUNIUM SPECIATION

Correct a reference to Np(VI) and provide citations. Alternatively, either (1) select conservatively low K_d values or (2) collect Clive soil and groundwater samples and perform independent laboratory testing to determine a site-specific empirical value(s).

EnergySolutions’ Response: The graphs presented from the Geochemist’s Workbench provide some insight into aqueous speciation of Np. However, these diagrams show only the dominant species at each point in the diagram. In solution multiple different solution species can be present, even though only one is dominant. That is why it is also helpful to look at different types of diagrams, such as activity vs. pH diagrams.

For example, see Figure 5.8 below, taken from EPA (2004). This figure shows that for Np(V), carbonate complexes begin to form at pH 7, where dissolved carbonate concentrations are 57 mg/L. So, while Np carbonate complexes do not dominate Np speciation, there could be 10-20% (or more, depending on redox and carbonate concentrations) of soluble Np complexed with carbonates for the Clive range of pH values.

That said, there is very little research on Np carbonate complex sorption and a limited number of K_d studies for Np. So, the effects of carbonate solution complexation on K_d are not evaluated for Np.

The text is being corrected to add the EPA (2004) reference to Figure 5.8, illustrating the formation of carbonate complexes above pH 7. The text will also

change to refer to “Np(V)” carbonate complexes instead of “Np(VI)” carbonate complexes, since Np(V) is the most likely redox state of Np for the conditions at the Clive site.

This interrogatory is being addressed as a text change. There is no need to either select conservatively low K_d values or derive site-specific empirical K_d value(s).

Figure 5.8. Calculated aqueous speciation for Np(V) as a function of pH. [Neptunium(V) aqueous speciation was calculated based on a total concentration of dissolved neptunium of 1×10^{-8} mol/l, the water composition in Table 5.1, and thermodynamic constants from Lemire *et al.* (1984).]

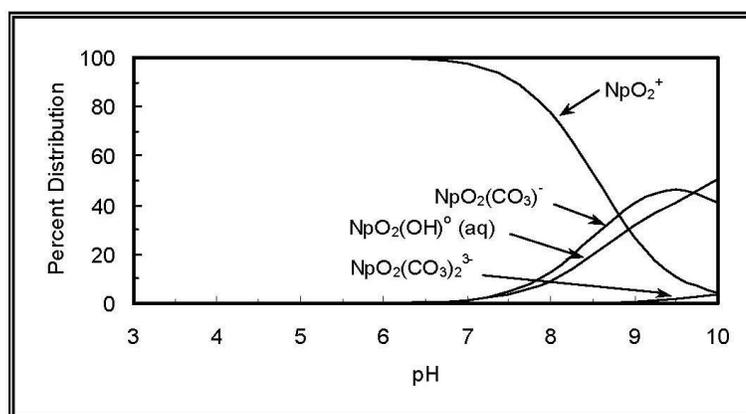


Figure 2-143/1, Aqueous Speciation for Np(V)

144. INTERROGATORY CR R313-25-7(1)-144/1: PLUTONIUM SPECIATION

Provide additional information to support the assumptions with respect to plutonium speciation.

EnergySolutions’ Response: It is assumed that discussion of neptunium in the Interrogatory text is a typo and should have been plutonium. As such, it is recognized that Pu(IV) could also be present in the Clive system because of slightly reducing conditions in the saturated zone and in localized areas of the disposal system. The groundwater chemistry data in Table 5 of the Geochemical Modeling report may be biased towards slightly reducing conditions. In the unsaturated zone, oxidizing conditions are generally expected. However, Pu(IV) may be an important form of Pu to consider for Clive geochemistry.

EPA (1999) indicates that soil redox conditions are not as important as ligand presence and concentration, as well as carbonate ion concentrations (Section

5.6.6.1). There is some discrepancy between EPA (1999) Figure 5.3, which indicates $\text{Pu}(\text{OH})_2(\text{CO}_3)_2$ would be the dominant Pu solution species, and the figures above, generated using Geochemist Workbench.

The range of the K_d distributions for Pu at Clive encompasses the contributions of Pu(IV) on K_d values. Bechtel SAIC (2004) (e.g., pp. A-39 to A-42) demonstrate that Pu(IV) species tend to have higher K_d values associated with them than Pu(V) and Pu(VI) species, where Pu(IV) K_d s are predicted to be on the order of 103 ml/g, which is the upper range of the Clive DU PA model K_d values. Including Pu(IV) in the K_d distribution development should not change the Pu K_d distributions recommended for the Clive DU PA.

Text in Section 4.1.6 is being changed to acknowledge the likely presence of Pu(IV).

145. INTERROGATORY CR R313-25-7(1)-145/1: SORPTION REVERSIBILITY AND GLOVER ET AL. (1976) DATASET

Provide further explanation for the potential impact of reversibility of sorption on the PA and the relevance of the Glover et al. (1976) dataset.

EnergySolutions' Response: A fundamental assumption of the adsorption modeled in the Clive DU PA is that the adsorption is reversible. The sentence

“Some studies indicate the sorption is non-reversible”

does not refer to critical knowledge about sorption of Pu in the Clive system. That sentence is being removed from the Geochemical Modeling report.

The references to Glover et al. (1976) in the Geochemical Modeling report (Section 4.1.7) are intended to highlight the use of the Glover et al. (1976) data in the EPA report to develop the Look-up Table (Table 5.11, EPA 1999) for Pu sorption coefficients. Glover et al. (1976) measured many different soil parameters along with sorption of Pu and Am. Regression equations were developed from Glover et al. (1976) to get the Look-up Table that separate levels of carbonate concentrations and clay content, making this data applicable to the Clive DU PA. However, the Look-up Table has lower maximum K_d s than the other references for Pu K_d s investigated in the Geochemical Modeling report. To incorporate the uncertainty that these other references might include potential K_d values, a slightly higher range was chosen than that which is given in the Glover-derived Look-up Tables.

The text of Section 4.1.7 is being modified to clarify the role Glover et al. (1976) played in the K_d range development for Pu for the Clive DU PA model. Text is

also being added to clarify that the higher range that was chosen as consistent with other references for Pu solubility.

146. INTERROGATORY CR R313-25-7(1)-146/1: DETERMINATION OF K_d VALUES

Provide further explanation on how the K_d values for each radionuclide were selected. Elaborate on how the soil textures listed in Table 1 of the Geochemical Modeling report, or any other factors, were used to determine the Clive K_d ranges for the respective nuclides. Provide a summary table of actual K_d values used for each element/nuclide.

EnergySolutions' Response: The Geochemical Modeling report is being revised to include a table of the ranges of K_d values for the three soil textures (sand, silt, clay) for each element in the model, and relate them to the literature references as described in the subsections of the report. Providing these ranges will make the distribution development more transparent. It will clarify the values chosen from the literature and how they were used to develop probability distributions as described in Section 3.0. These changes are being made concurrently with changes made per the Response to Interrogatory #140 CR R313-25-7(1)-140/1.

147. INTERROGATORY CR R313-25-7(1)-147/1: DETERMINATION OF K_d VALUE FOR URANIUM

Provide support for assumptions regarding the derivation of the partition coefficient for uranium with regard to the results of an increase in ionic strength and the potential bias of high K_d values for ferrihydrite and kaolinite.

EnergySolutions' Response: The sentence,

“As the ionic strength increases, other cations will displace the uranyl (UO_2^{2+} ion)”

is from EPA (1999). The text is being changed to

“As the ionic strength increases, other cations, such as Ca^{2+} , will displace the uranyl (UO_2^{2+}) ion (EPA, 1999).”

The sentence

“These very high K_d values are considered potentially biased by one order of magnitude”

reflects conclusions from EPA (1999) that some of these high K_d values correspond to experiments where precipitation of U occurred in addition to adsorption.

The Geochemical Modeling report is being modified to clarify assumptions and derivations of geochemical parameters, as discussed in other interrogatories, such as Interrogatory CR R313-25-7(1)-140/1.

148. INTERROGATORY CR R313-25-7(1)-148/1: INFLUENCE OF CARBONATE ON URANIUM SPECIATION

Resolve contradictory statements regarding uranium sorption and focus the discussion on the influence of carbonate on uranium speciation.

EnergySolutions' Response: The intention of the text and of the K_d distribution development for U in this section is to discuss general geochemistry knowledge about U sorption, site specific considerations for U sorption and then other references and how their results apply to Clive DU PA modeling. The text in Section 4.1.13 will be revised to focus on the effects of carbonate and pH on U sorption. The carbonate assumptions for the Clive site will be clarified as to the applicability of the references used for K_d distribution development to the Clive site, especially with respect to the high carbonates expected at Clive.

As stated in the Response to Interrogatory CR R313-25-7(1)-140/1, more detailed documentation of how these distributions were developed is being provided in a revised Geochemical Modeling report.

149. INTERROGATORY CR R313-25-7(1)-149/1: AMERICIUM SORPTION

Provide additional justification for the assumptions made regarding americium sorption and for the preferred range of values in light of the elevated TDS content of shallow Clive groundwater and the competing ion effect.

EnergySolutions' Response: Section 5.1.2 of the Geochemical Modeling Report refers to americium solubility, not sorption. Elevated TDS and the competing ion effect apply more to sorption than solubility.

As per the request in Interrogatory CR R313-25-8(4)(a)-64/1, a more recent Yucca Mountain study (SNL, 2007) was used to review the solubility distributions for all elements in the Clive DU PA model. The range of americium solubility values from SNL (2007) were examined for pH values of 7 to 8 and pCO_2 values of 3.5 to 1.5. The pCO_2 range was chosen based on the assumption that atmospheric CO_2 partial pressures (pCO_2 of 3.5) to slightly elevated CO_2 partial pressures (pCO_2 of 2.5) will be most likely, as described in Section 2.0, page 3 of the Geochemical Modeling Report. A maximum pCO_2 value of 1.5 is

likely slightly high but was chosen to encompass the range of possible CO₂ partial pressures and equivalent dissolved carbonates at the Clive site.

Given these assumptions, the range of Am solubilities in SNL (2007), Table 6.9-2 are from 6.6×10^{-8} mol/L to 4.6×10^{-6} mol/L. With these values, the maximum of 10^{-6} M in the original reference does not seem unrealistic. This range is close to the range in the original Clive DU PA and so no changes are recommended for the Am solubility range at this time.

With probabilistic modeling, whether or not a parameter distribution is “unnecessarily broad” is being decided in part in a sensitivity analysis. If the parameter is a sensitive parameter, the uncertainty in that parameter’s input distribution may be unacceptably large in the context that it leads to too much uncertainty in the result. If that is the case then further investigation may be desired to refine the input distribution so that the range is not “unnecessarily broad.” However, if the parameter is not sensitive, then there is less need to refine the distribution.

150. INTERROGATORY CR R313-25-7(2)-150/1: PLANT GROWTH AND COVER PERFORMANCE

Clarify the nature and degree to which plant growth might impact future system performance. Justify the use of the selected root penetration value and discuss the potential for deep plant rooting.

EnergySolutions’ Response: Detailed analysis conducted by SCWA demonstrating negligible degradation of the Evapotranspirative Cover’s radon barrier from animal borrow has previously been conducted (EnergySolutions, 2013d). As a result of their analysis, SWCA concluded,

“The proposed biointrusion barrier and capillary breaks in the [Evapotranspirative] cover have been demonstrated to effectively deter or limit penetration by deep rooting plants [native to Clive] into protective [clay] layers” (pg 45).

Plant growth is being accounted for in the GoldSim model of ET cover performance.

Root Depth

At this site, the water table is about 9 m below ground surface, and the cover mound is 13.7 m in height, so the water table is almost 23 m below the surface of the cover. Greasewood is known to occur down to water tables as deep as 19 m. However, the vegetative survey of the Clive site found that the majority of greasewood plants are less than one meter tall, and studies have found that greasewood of that size tend not to produce taproots (Robertson, 1983).

Additionally, the root excavation of greasewood at the Clive site found that the deepest roots of these smaller plants ranged from 40-70 cm (SWCA 2011).

However, given the known ability of phreatophytes to form deep tap roots and the fact that larger plants do occupy parts of the Clive site, especially where precipitation runoff is concentrated, and these plants may extend taproots to exploit deeper water, the model should take into account the possibility of tap roots somewhere on the site. For the purposes of the model the greasewood root depth was limited to the more modest amount of 5.7 m (as opposed to 19 m) because 1) the aboveground plant biomass at the site do not support the idea of tap roots deeper than this and 2) it is thought that the roots would not penetrate the radon barriers (thick clay layers).

The depth of 5.7 m also represents an estimate of what Groeneveld (1989) terms "maximum effective root depth" noting that isolated roots may grow well below this depth under special circumstances of water availability and aeration. As an example, Groeneveld cites the observation by Robinson (1958) of greasewood roots penetrating the roof of a mine tunnel approximately 19 m below the ground surface, suggesting that the 19 m maximum depth for greasewood is an artifact of preferential pathways created by the mining activities. These preferential pathways are not expected to occur in the constructed cover.

This barrier consists of two 1-ft thick layers of clay, with 3.5 ft of soils and cobble above. In this model the roots grow out horizontally across the top of the radon barrier, rather than developing deep taproots. The assumption of the current model is that the plants cannot penetrate the cover system. In the previous model a riprap cover was used but this is being replaced with an ET cover. The ET cover dries out the system more and includes two layers of clay. Based on previous work at the site, rooting depths were shallower than expected and plant roots were found to spread out horizontally and the deepest root excavated was 70 cm (Table 6, Figure 7, SWCA 2011). Based on this work, the phreatophytes at this site do not form deep taproots.

It may be possible for the species that occur at the site to create deep taproots at other sites, but there is no evidence that the conditions are right at this site to develop deep taproots. The model did not include deeper roots because it was assumed that the plants would grow out instead of down and based on the survey of the aboveground vegetation and root excavations at the site it does not appear that greasewood form deep taproots.

The above explanation will apply to the ET cover that is currently being modeled as a replacement for the riprap cover. Text is being modified as necessary to address the ET cover effects on plant roots.

Forage

The interrogatory claims the PA denies the possibility of forage at the site. It is not clear to what this comment is referring. A consideration of forage exposure is included in the Cattle and Game radionuclide uptake exposure factors that are provided on p. 8 of the Dose Assessment white paper.

Plant Uptake

The interrogatory also mentions that the PA denies the potential for plant uptake. Again, it is not clear to what this is referring and what additional changes are sought. Plant uptake is detailed in Section 3.6 Estimation of Plant Uptake.

151. INTERROGATORY CR R313-25-8(4)(A)-151/1: RADON BARRIER ATTENUATION

Describe the role performed by the design of the radon barrier in demonstrating that the exposures to humans from the release of radon will not exceed the limits in R313-25-19. Include the value of any diffusion coefficients used (and justification for their selection) and the basis for any radon attenuation calculated. If either of the diffusion coefficients or attenuation is different for the DU PA model from what were used for other facilities at the Clive site (e.g., the LLRW and 11e.(2) disposal facilities), provide justification for those differences.

EnergySolutions' Response: The role of the radon barrier in attenuating the release of generated radon into the environment for the evapotranspirative cover system is currently being modeled by Neptune and is being documented in their subsequent Modeling Report.

The calculations of radon migration in the Clive DU PA Model are based on a few straightforward concepts and values. The origin of radon anywhere in the model is from decay of parents (e.g. Ra-226 decaying to Rn-222) but its introduction into the environment wherein it would be subject to migration is attenuated by the escape/production ratio (E/P ratio, also known as the radon emanation factor). In the DU waste, the E/P ratio is defined by a distribution: beta(mean = 0.290, std. dev. = 0.156, min=0, max=1).

Elsewhere in the model, it is defined as 1, meaning that all radon produced is immediately available for transport. Anywhere that radon exists in the model, it is free to partition between air and water (according to its Henry's Law constant (\Materials\Air_Properties\Kh_Rn), which is about 4.6. It is also free to diffuse in air and water, according to its free air diffusivity (\Materials\AirDiffusivities\Da_Rn) of $0.11 \text{ cm}^2/\text{s}$, and the molecular diffusivity in water (\Materials\Water_Properties\Dm), with a mean value of $3 \times 10^6 \text{ cm}^2/\text{s}$.

Diffusion in porous media in the model is calculated internally by GoldSim, according to accepted mathematical approaches. Diffusion is a basic Fickian

process, driven by spatial concentration gradients and moderated by diffusion coefficients. When building definitions of diffusive flux between modeling cells in unsaturated porous media in GoldSim, the programmer must explicitly account for phasic tortuosity (τ_{air} or τ_{water}) and for the effects of saturation on the diffusive area. Once these connections are properly constructed, GoldSim does the rest, evaluating diffusion in concert with advection, biotic transport, and radioactive decay and ingrowth. To study the effects of diffusion in isolation, it is necessary to remove these coupled effects using the Diagnostics dashboard, accessible from the Control Panel.

In other words, there is no special diffusivity for radon, in either air or water, assigned to any given porous medium in the model. Effective diffusivities is being different in each porous medium, and indeed in the same medium under different conditions of water content. This results from having different tortuosities and saturations present in different places in the model. The diffusion of radon (and other species, for that matter) is thereby built up from first principles, in a manner of speaking, and GoldSim simply “does the math” to determine the result.

Unless other coupled processes (e.g. water advection, biotic processes, and even radioactive decay and ingrowth) are disabled, it is not possible to study the effects of diffusion in isolation, and the results may be confusing or even misleading. Consider, for example, the simple process of radioactive decay, wherein Rn-222 is generated by Ra-226. If radium is able to migrate through a “radon barrier” clay, then it provides a source for radon on the other side. This “stealth” radon migration, as the radium parent, can circumvent the effectiveness of a radon barrier, at least to some degree. Biotic effects complicate matters more, since animals will move bulk materials containing radon and its parents, and plants will move specific radionuclides preferentially. Predicting the outcome of all these coupled processes is fraught with potentially counterintuitive effects, which is why it is important to couple the processes in a model, like GoldSim.

152. INTERROGATORY CR R313-25-8(5)(A)-152/1: GOLDSIM INPUT PARAMETERS

Provide documentation and justification for the radon correction factors (RnDiffusivityCorrection) used in the GoldSim DU PA Model.

EnergySolutions’ Response: See response to Interrogatory CR R313-25-7(3)-60/1. The radon correction factors are not model inputs, which is why they do not appear in the Parameters Document. These are model calibration factors, set by the user as part of the radon calibration routine. As such, it is informative to run the radon calibration in order to gain an appreciation of where these values come from. To run this calibration, follow these instructions:

1. In the Control Panel, set the model duration to 10,000 years with the checkbox and input field on the upper left.
2. Go to the container \Disposal\ClassASouthCell\TopSlope and set the value of the AirDiffCalib_Switch near the bottom right of the page to “true”.
3. Enter the RnCalibCalcs container above it.
4. Take note of the values in the RnDiffCorrection_* data elements and run the model.
5. Dismiss any warnings about aborting calculations at 10,000 years.
6. Examine the result elements *_Comparisons, and look for agreement between the radon flux calculations using coarse cells (red dashed line) and fine cells (green dotted line).
7. If the red line is too high, reduce the value of the corresponding RnDiffCorrection_* factor a bit. If the red line is too low, increase the value.
8. Repeat steps 4 through 7, iterating on the values of the RnDiffCorrection_* until satisfied that the lines lie atop each other.

Note that each layer containing a different material requires its own correction factor. This is because the material properties and tortuosities are so different between the layers. It is recommended that the above procedure be performed by first calibrating the lowermost layer (waste), then the radon barrier clays, and finally the cap layers.

This radon calibration procedure need be performed only after making changes to the model that involve layer thicknesses, porous medium material properties, moisture contents, E/P ratio, diffusivity definitions—in short, any parameter that might affect the behavior of radon migration. Once the calibration is complete, be sure to set the AirDiffCalib_Switch to “false” so that these detailed calculations do not continue to use up computer cycles.

It is recognized that this was not documented in the model report, since it is not something that a user would typically do. It is more a tool for the model programmers to calibrate this part of the model. However, documentation is being added in the next version.

153. INTERROGATORY CR R313-25-8(4)(D)-153/1: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER

Demonstrate that the impact of pedogenic processes has been included in embankment cover performance, particularly with respect to effects on hydraulic conductivity.

EnergySolutions' Response: The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two order of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

A revised model of the engineered cover is being developed, based on an ET cover design.

With regard to the influence of biointrusion on model parameters, also refer to the response to Interrogatory CR R313-25-8(4)(A)-108/1 on biointrusion.

Also see the following three paragraphs from the response to Interrogatory CR R313-25-7(2)-05/1 on Radon Barriers:

A compromised radon barrier is being modeled. It is not considered necessary at this time because the ET Cover design will limit infiltration down to the radon barrier. With no infiltration down to that level, the naturalization of the radon barrier will have no effect on performance. However, for completeness, this issue is being addressed.

The topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. An expanded assessment of the radon barrier and assigned physical properties in models of cover performance must be

carefully designed for applicability to the climate and hydrogeological setting of the Clive disposal facility.

Confidence in the assessment of radon barrier performance can be enhanced through sensitivity and uncertainty analyses of the models. Modeling the uncertainty in cover performance involves alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty). Enhanced investigations of these components of uncertainty require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling.

There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. To provide a more comprehensive sensitivity analysis for infiltration modeling, it should not be based on selective and non-systematic changes in physical properties of cover materials. Instead what is required would be refined modeling of closure cover performance using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into the probabilistic performance assessment model.

154. INTERROGATORY CR R313-25-8(4)(D)-154/1: USE OF FIELD DATA TO VALIDATE DISPOSAL CELL COVER PERFORMANCE

Document the extent to which field data were used to validate the performance of the proposed Federal Cell cover design; include consideration of information from DOE disposal sites.

EnergySolutions' Response: In development of the new evapotranspirative (ET) cover design, *EnergySolutions* examined the performance of other similar cover systems in use in the arid west (Appendix D of *EnergySolutions*, 2013b). *EnergySolutions* also examined natural localized plateaus and land features in the Clive area similar in shape, surface soil type, and slope to that proposed for the Federal Cell (Appendix D of *EnergySolutions*, 2013b). Furthermore, *EnergySolutions* used as input to the models site-specific meteorological data obtain at their Clive meteorological station since 1993 (MSI, 2014).

Additionally, *EnergySolutions* has historically been required to consider bounding input and overly conservative assumptions in its various performance assessments. These in turn have always predicted infiltration at rates orders of magnitude higher than anything observed onsite via collection lysimeter and Cover Test Cell performance.

The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two order of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

With respect to unsaturated zone flow models one approach is comparison with analog sites. However, due to the complexity of the interaction of characteristics and processes in the vadose zone and the atmospheric boundary layer, true analog sites are scarce and any comparison of performance between sites must be done with care.

However, site-specific data help build confidence in model predictions. Data have been collected from scaled structures located at the disposal sites such as the lysimeters described in this Interrogatory and the Test Cell at Clive. This approach avoids the problems of differences in climate, vegetation, and material characteristics and can provide valuable information for model calibration and verification but can be vulnerable to issues resulting from differences in scale.

The topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. An expanded assessment of cover design components and assigned physical properties in models of cover performance must be carefully designed for applicability to the climate and hydrogeological setting of the Clive disposal facility.

Confidence in flow model predictions can also be enhanced through sensitivity and uncertainty analyses of the models. Modeling the uncertainty in cover performance involves alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty).

Enhanced investigations of these components of uncertainty require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling. There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. To provide a more comprehensive sensitivity analysis for infiltration modeling, it should not be based on selective and non-systematic changes in physical properties of cover materials. Instead what is required would be refined modeling of closure cover performance using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into the probabilistic performance assessment model.

System models such as the Clive DU PA model simulate numerous interacting processes. Confidence can be built in system model predictions through documenting the testing of single processes in the system model by comparison with results from other simulation codes.

155. INTERROGATORY CR R313-25-8(4)(D)-155/1: COVER PERFORMANCE FOR 10,000 YEARS

Document how expected climate changes and other FEPs that may degrade cell performance over 10,000 years have been factored into the cover cell design. Also discuss historical analogs of similar structures and how they have functioned over long periods of time.

EnergySolutions' Response: EnergySolutions currently plans to use an evapotranspiration (ET) cover design rather than the design requiring rip rap specified in the Clive DU PA model. In this ET design the rip rap and filter layers are being replaced with native soil that will be re-vegetated. With this design there are no longer issues concerning the effect of rock degradation on cover performance. The upper layers of the ET cover will resemble native conditions not requiring active maintenance at the time of successful completion of the re-vegetation program.

The long-term integrity of the clay radon barriers below the frost protection layer has been investigated in detailed biological surveys conducted at the site. These analyses indicate that penetration by deep rooting plants or biointrusion by small mammals will be minimized or eliminated in these layers. More discussion on the results of these surveys including references is provided in the response to Interrogatory CR R313-25-7(2)-05/1: Radon Barrier. Other evidence on the effect of animal burrowing on subsurface moisture content comes from a field experiment at the Hanford Site conducted by Landeen (1994). Over the course of five testing periods, three during the summer and two during the winter soil

moisture measurements showed no influence of burrowing activities on long-term water storage.

Additional site-specific analyses of the effectiveness of the frost protection layer have been conducted. These analyses concluded that calculated frost depths were consistent with the thicknesses proposed for the ET cover design. More discussion on the results of these analyses including references is provided in the response to Interrogatory CR R313-25-7(3)-60/1: Modeled Radon Barriers.

A compromised radon barrier is being modeled under the PA Maintenance program. It is not considered necessary at this time because the ET Cover design will limit infiltration down to the radon barrier. With no infiltration down to that level, the naturalization of the radon barrier has no effect on performance. However, for completeness, this issue will be addressed under PA Maintenance.

The topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. An expanded assessment of the radon barrier and assigned physical properties in models of cover performance must be carefully designed for applicability to the climate and hydrogeological setting of the Clive disposal facility. The Benson et al. (2011) reference is a credible report that emphasizes cover properties in general, not the specific cover types and materials proposed for the Clive site and the local climatic setting. The recommendations from the report, by itself, are not sufficient justification to require redesigning the cover system.

Confidence in the assessment of radon barrier performance can be enhanced through sensitivity and uncertainty analyses of the models. Modeling the uncertainty in cover performance involves alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty). Enhanced investigations of these components of uncertainty require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling. There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. To provide a more comprehensive sensitivity analysis for infiltration modeling, it should not be based on selective and non-systematic changes in physical properties of cover

materials. Instead what is required would be refined modeling of closure cover performance using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into the probabilistic performance assessment model.

The potential influence of erosion on cover performance must be considered in the context of all sediment transport processes occurring at the site. Erosion modeling using the SIBERIA landscape evolution model has been performed on a borrow pit at the site, the results of which will be abstracted and adapted to the disposal mound in the upcoming model of the ET Cover. Because of the slope differences, this will over-estimate sediment transport offsite, and will over-estimate depth of gullies formed but will provide some insight into the response of an embankment to water erosion processes that include both hillslope erosion and channel growth. This will be included in the next version of the model and the report. Note that under the scenario that the DU waste is disposed below grade, the erosion consequences are likely to be minimized. This is evident in the current model results by comparing the three pairs of scenarios.

Another sediment transport process that should be considered is the complicating but potentially advantageous feature of the Clive site; the aggrading depositional environment. The site is located on the east edge of Lake Bonneville, a dry playa lake. Depositional rates of windblown sand and silt (loess) has been shown to be significant near dry playa lakes of the arid southwest United States (> 0.1 mm/yr). We are considering studying well dated volcanic landforms in the Black Rock Desert volcanic field located in the southern Utah within the former footprint of Lake Bonneville (39.0 degrees N, 112.5 degrees W). A series of basaltic volcanic centers with associated lava flows in the volcanic field (Pavant Butte, Ice Springs and the Tabernacle volcanoes) range in age from 16,000 to 800 years BP (before present). The lava and scoria cone/tuff rings provide unique landforms that can be examined to establish benchmarks for the operation of erosional and depositional process that would likely effect a waste embankment at the Clive site. Data can be gathered to assess whether aeolian depositional rates are sufficient to blanket and/or protect a closure cover. The properties of the aeolian cover/soils can be examined to evaluate erosional and biological processes affecting materials comparable to closure covers providing information on the long-term stability of the disposal site.

156. INTERROGATORY CR R313-25-26(2-3)-156/1: SEPARATION OF WASTES IN FEDERAL CELL

Since the Federal Cell will have no isolation barrier or groundwater monitoring system, explain how the DU waste and 11e.(2) waste will be isolated from each other and how groundwater passing beneath the DU will be monitored before site closure and for 100 years after site closure so as to meet Utah rules and protect the

public from undue radiation exposure during the time before DOE takes stewardship of the Federal Cell.

EnergySolutions' Response: The interrogatory inaccurately states that the Federal Cell will have no isolation barrier or groundwater monitoring system. This statement is assumed to refer to the clay barrier between Class A and 11e.(2) wastes under the former Class A South cell design; and to groundwater monitoring proposed to occur beneath that barrier.

The former Class A South cell design was subjected to these additional buffer zone and monitoring requirements due to long-term stewardship being split between the State of Utah and DOE. The Federal Cell will be entirely within DOE stewardship and there will be no requirement to segregate Class A LLRW from 11e.(2) wastes; therefore, the additional requirements will not apply.

Nonetheless, the Federal Cell will have a radon barrier and ET cover system to isolate wastes from the environment; and the existing perimeter groundwater monitoring system will remain in place subject to Ground Water Quality Discharge Permit #UGW450005.

157. INTERROGATORY CR R313-25-8(5)(A)-157/1: INCLUSION OF DU AND OTHER WASTES IN PA

Provide documentation that the PA includes the total quantities of DU and other wastes.

EnergySolutions' Response: When the DEIS was prepared for Part 61, DU was considered, just not the large volumes stored by DOE. Contained in that analysis is a default value for DU disposal, which is manifested in R313-25-8(5)(c): "For purposes of this R313-25-8(5) only, "concentrated depleted uranium" means waste with depleted uranium concentrations greater than 5 percent by weight."

See the response to Interrogatory CR R313-25-7(9)-89/1 for documentation that DU disposed at the time R313-25-8(5)(a) went into effect was less than this 5 percent criteria.

In 2008, NRC noted that while,

"The licensing of new uranium enrichment facilities in the United States has brought DU to the forefront of low-level waste (LLW) disposal issues. The DU waste stream is unique; the relatively high concentrations and large quantities of DU that are generated by enrichment facilities were not considered in the Final Environmental Impact Statement (FEIS) supporting the development of 10 CFR Part 61. When the FEIS was issued in 1982, there were no commercial facilities generating large amounts of

DU waste, therefore, the FEIS considered only the types of uranium-bearing waste streams being typically disposed of by U.S. Nuclear Regulatory Commission (NRC) licensees at the time, (NRC, 1982). The NRC concluded that those waste streams posed an insufficient hazard to warrant establishing a concentration limit for uranium in the waste classification tables in 10 CFR 61 . . . Part 61 DEIS assumed 17 Curies (Ci) of ²³⁸U and 3 Ci of ²³⁵U would be disposed of in 1 million m³ of waste over a 20-year generic LLW site operating life (NRC, 1981),” (NRC, 2008).

Bulk Class A LLRW will be placed above the DU. Performance assessment for these nuclides is addressed via the ET cover performance assessment currently undergoing DRC review (EnergySolutions, 2013d). As such, the condition of the disposal of other Class A low-level radioactive bulk wastes within the Federal Cell is a modeled condition. Therefore, it is unnecessary to repeat this analysis in this Depleted Uranium Performance Assessment.

The Clive DU PA Model v1.0 addresses only certain proposed disposals of large quantities of depleted uranium waste. It does not address previously-disposed DU waste.

158. INTERROGATORY CR R313-15-1009(2)(B)(I)-158/1: WASTE PACKAGING

Address in the PA the use of soft-sided containers for the disposal of DU oxides, including how well these containers would survive long-distance transportation to and handling at the Clive low-level waste facility, how full of DU oxides each container would be and how much headspace would remain, the weight of the contents of each container, and the nature of the materials constituting the container.

EnergySolutions’ Response: The PA takes no credit for container type in terms of contaminant fate and transport; thus, the transportation container is irrelevant. Prior to acceptance at the Clive facility, transportation of radioactive materials is governed by the specific waste generator’s license and U.S. Department of Transportation (DOT) regulations.

DOT regulations ensure that the container selected for any hazardous material is appropriate for surviving long-distance transportation, considering the physical, chemical, and radiological characteristics of the material. There are no unique characteristics of the depleted uranium wastes or associated packages considered within this Performance Assessment that vary from those commonly being managed during EnergySolutions’ 25 year history. In fact, existing waste placement controls have successfully been applied in disposal of the current DU

inventory placed in the LARW, Class A, and Mixed Waste cells prior to the 2010 rulemaking.

Current Construction Quality Assurance/Quality Control (CQA/QC) specifications for waste placement require that headspace void be eliminated at disposal, regardless of the package type. This is accomplished through compaction and testing for uncontainerized wastes, and through use of a flowable grout (Controlled Low-Strength Material, or CLSM) for waste disposed in containers. In fact, similar soft-sided containers to those referenced in the Basis for this interrogatory from the DOE Fernald site have been disposed using CLSM in the 11e.(2) waste portion of the Federal Cell. Therefore, continued disposal of depleted uranium does not create an unanalyzed condition regarding the type of container or procedures required to safely manage and dispose of them.

159. INTERROGATORY CR R313-25-8(4)(D)-159/1: EMBANKMENT DAMAGE BY LAKE FORMATION

Explain how radon releases will be controlled when the embankment is destroyed by wave action and the intruding waters subsequently recede to levels below the current ground surface.

EnergySolutions' Response: There are two components to this response. The first is the timing of a lake return with erosion of the embankment and the second is the interplay between sedimentation and erosion – the two components are interrelated.

The first 10,000 year stage of the PA model assumes the lake will not return. The closure cover will degrade/erode but the radon barrier will remain. Moreover, the cover is likely to be partially buried over 10,000 years by aeolian deposition of silt and sand (loess). Depositional rates of aeolian deposits have not been measured at the Clive site but information is available on loess accumulation rates adjacent to playa lakes at multiple sites in the arid southwest United States. Accumulation rates can be highly variable but are likely to be > 0.1 mm/yr (1 meter per thousand years) during interpluvial conditions. The expected case for these conditions is progressive burial of the waste embankment by aeolian deposition until the return of the first lake.

The following events are expected during the return of the first glacial lake to the Clive elevation. Wave action at the lake shoreline will rework the loess deposits, erode the embankment and intermix DU waste with the lake sediments. The deep-time assessment makes the conservative assumption that the above grade embankment is completely eroded and all the DU waste is intermixed with sediments. The reality is that the degree of erosion and release of DU waste will be dependent on the timing of the arrival of the first lake (the longer the interval

the deeper the aeolian cover) and the dynamics and duration of lakeshore processes at the Clive elevation.

The latter topic was not examined in the deep-time model and instead the above-grade embankment was assumed to be completely eroded, (see the responses to interrogatories CR R313-25-8(4)(d)-129/1 Lake Erosion and CR R313-25-8(4)(d)-131/1 Potential Wave Energy). Subsequent lake cycles will affect the Clive site but the net result will be burial of the site through combined aeolian and lake sedimentation. The largest increase in radionuclide concentrations will be as a consequence of the first lake event, with concentrations decreasing as the sediment thickness increases (see Section 6.52 and Figure 13 of the Appendix 1 Clive DU PA Model Version 1.0 Final Report).

According to UAC regulations, quantitative assessments of radon flux are not required for the time frame following 10,000 years, when the analysis is expected to be qualitative. The deep time model assumption of sediment/waste mixing will spread and dilute DU waste (see the SiteDispersalArea parameter in Table 1 of the Appendix 13 Deep Time Assessment) and the sediment/waste mixture will be buried progressively with continuing lake cycles. The time of greatest radon flux/potential dose will be during the first lake return but it is difficult to identify a credible dose exposure scenario for a lake/shoreline at 10,000 years plus into the future.

160. INTERROGATORY CR R313-25-7(2)-160/1: COMPARISON OF CLASS A WEST AND FEDERAL CELL DESIGNS

Address the significant differences between the Class A West embankment and Federal Cell designs in order to justify why the existing Class A West design would suffice for the Federal Cell.

EnergySolutions' Response: The depleted uranium Performance Assessment is being revised to reflect the construction of an evapotranspirative cover over the proposed Federal Cell. As such, this Interrogatory is no longer applicable.

161. INTERROGATORY CR R313-25-7(2-3)-161/1: INCONSISTENT INFORMATION ON WASTE EMPLACEMENT

Resolve the conflicting statements about available thickness in the embankment for waste emplacement and emplacement depths. Explain and justify the plans given in the text of the PA given the information in Figure 1.2 and revise as necessary.

EnergySolutions' Response: Figure 1.2 has been clarified to reflect EnergySolutions' commitment that only a volume of depleted uranium that can be disposed of below grade in the Federal Cell will be managed. Because

EnergySolutions has committed to dispose of significant quantities of depleted uranium only below grade in the Federal Cell, the noted discrepancies in model scenarios for above-grade disposal need not be revised within the model.

162. INTERROGATORY CR R313-25-22-162/1: DISPOSAL CELL STABILITY

Address factors affecting stability, including wave-cutting erosion, gully erosion, catastrophic storms, differential settling driven by canister disintegration and cover rock degradation in greater detail to demonstrate long-term disposal system stability.

EnergySolutions' Response: Each of the subject topics is addressed in turn below.

Erosion by wave-cutting of embankment materials

Interrogatory CR R313-25-8(4)(d)-159/1 describes the lake erosion model of the embankment used in the deep time assessment (Appendix 13) and the effect on radon. To briefly summarize, lake erosion is not expected at the Clive site until after 10,000 years which is beyond the period of required dose calculations. The impact on the site is dependent on the time and dynamics of lake return, coverage of the site by aeolian deposits, and sediment/waste mixing and dispersal during lake erosion. The largest increase in radionuclide concentrations will be as a consequence of the first lake event, with concentrations decreasing as the sediment thickness increases (see Section 6.52 and Figure 13 of the Appendix 1 Clive DU PA Model Version 1.0 Final Report). The net result of multiple glacial cycles will be natural burial of the site through combined aeolian and lake sedimentation. This burial process does not require mitigation of lake erosion through design features of the disposal site.

Gully erosion

Other modeling options for gully erosion include the SIBERIA program for executing landform evolution studies of the embankment under PA maintenance. Results of this model provide estimates of the timing and extent of erosion.

Destruction of embankments by catastrophic storms

While tornados could initiate erosion of the embankment, they are low frequency events in Utah (see the response to Interrogatory CR R313-25-7(1)-46/1); the probability of a tornado strike at a specific point in Tooele County is extremely low.

Damage to the cover system from differential settlement

As discussed in the DUF₆ Waste Management Plan (UDS 2009), the U₃O₈ product of the deconversion process will be roll-compacted to a density of 2.4 to 2.7 g/cm³ before introduction to the 48 Y cylinders through a rotary valve

metering device. During the filling operation, the cylinder is held vertically and is vibrated to promote settling and compaction. EnergySolutions describes their current Construction Quality Assurance/Quality Control (CQA/QC) specifications for waste placement as requiring that headspace void be eliminated at disposal, regardless of the package type. This is accomplished through compaction and testing for uncontainerized wastes, and through use of a flowable grout (Controlled Low-Strength Material, or CLSM) for waste disposed in containers. For more detail see the response to Interrogatory CR R313-25-22-166/1.

Cover-system rock degradation

Partly in response to the documented weathering of certain facies of rocks used for rip rap on the Vitro UMT pile, the Federal Cell will adopt a different technology for cover design. The new design is an evapotranspirative (ET) cover that does not involve the use of rip rap from the source used for the Vitro pile. The PA Model is being rebuilt with this new design, so the question of the extent of weathering of rip rap is not applicable.

163. INTERROGATORY CR R313-25-8(5)(A)-163/1: GROUNDWATER COMPLIANCE FOR 10,000 YEARS

Include results describing groundwater concentrations for a minimum of 10,000 years and indicate whether a dose standard of 4 mrem/yr TEDE is met for the compliance period.

EnergySolutions' Response: See the response provided for Interrogatory CR R313-25--7(2)-91/1.

164. INTERROGATORY CR R313-15-1009-164/1: INCORRECT RULE CITATION

Correct the indicated rule citation.

EnergySolutions' Response: Section 4.2.2 of the Conceptual Site Model report is being corrected.

The Conceptual Site Model white paper is being corrected as follows:

[Conceptual Site Model white paper, Section 4.2.2, page 18, first sentence:]

“Rule R313-15 contains section R313-15-1009 Classification and Characteristics of Low-Level Radioactive Waste.”

[Conceptual Site Model white paper, Section 4.2.2, page 18, caption to Figure 5:]

Figure 5. Waste classification Table I from R313-15-1009

165. INTERROGATORY CR R313-15-1009(1)(C)(I)-165/1: INCORRECT CITATION OF RA-226 LIMIT

Ensure that the DU PA model and associated text use the correct limit for Ra-226 and that all other model input parameters correctly interpret the concentrations in Table 1 of R313-15-1009.

EnergySolutions' Response: Section 4.2.2 of the Conceptual Site Model report is being corrected to reflect the Class A waste concentration limit of 10nCi/g for Ra-226. As is reported in Table 6 of Appendix 4, “*Waste Inventory*,” the mean Ra-226 concentration of 316.8 pCi/g (with standard error of 19.1) was included in the GoldSim analysis (which is a small fraction of the limited promulgated in Table 1, R313-15-1009). The correction does not affect model input parameters or results.

The text on page 18 of the Conceptual Site Model report is being revised to the following:

“Rule R313-15 contains section R313-15-1009 Classification and Characteristics of Low-Level Radioactive Waste. The definitions in this section are essentially identical to those in 10 CFR 61.55, with one exception: Utah adds Ra-226 to the list of long-lived radionuclides in the regulations’ Table I (see Figure 5), with a concentration of 100 nCi/g (Utah, 2010).”

The mean concentration of Ra-226 in the SRS DU waste is 317 pCi/g, or 0.317 nCi/g, with a standard deviation of 0.019 nCi/g. As such it is well within the Class A limit (which is $0.1 \times 100 \text{ nCi/g} = 10 \text{ nCi/g}$). Note that the Clive DU PA Model does not explicitly consider waste classifications—rather, it performs calculations based on whatever inventories are provided.

166. INTERROGATORY CR R313-25-22-166/1: STABILITY OF WASTE

Analyze stability conditions as compaction of disintegrating drums and cylinders occurs. Consider the presence of any headspace in the waste containers and include a statement that the waste is **not** uncontainerized but rather is emplaced in drums and cylinders.

EnergySolutions' Response: There are no unique characteristics of the depleted uranium wastes or associated packages considered within this Performance Assessment that vary from those commonly being managed during EnergySolutions' 25 year history. In fact, existing waste placement controls have successfully been applied in disposal of the current DU inventory placed in the LARW, Class A, and Mixed Waste cells prior to the 2010 rulemaking.

Current Construction Quality Assurance/Quality Control (CQA/QC) specifications for waste placement require that headspace void be eliminated at disposal, regardless of the package type. This is accomplished through compaction and testing for uncontainerized wastes, and through use of a flowable grout (Controlled Low-Strength Material, or CLSM) for waste disposed in containers. In fact, similar soft-sided containers from the DOE Fernald site have been disposed using CLSM in the 11e.(2) waste portion of the Federal Cell.

Therefore, continued disposal of depleted uranium does not create an unanalyzed condition regarding the type of container or procedures required to safely manage and dispose of them.

167. INTERROGATORY CR R313-15-1009(2)(A)(VII)-167/1: PYROPHORICITY OF DUO₂

Address the pyrophoric tendencies of DUO₂. Either provide for the exclusion of uranium dioxide (UO₂) from the waste or justify the disposal of waste container UO₂ at the site. Consider development of finely divided particles and possible pyrophorism during physical transport by rail or road, placement in an embankment, or geochemical modification subsequent to burial.

EnergySolutions' Response: The risk from pyrophoricity of UO₂ is minimal.

While it is true that finely-divided UO₂ can be pyrophoric, the waste form being produced by the deconversion plants in Piketon (Portsmouth), OH and Paducah, KY contains “very minor” amounts of UO₂, especially in consideration of the “high-volume pneumatic transfer” used in bulk materials operations, which would tend to further oxidize the uranium oxides (personal communication from Jack Zimmerman, Babcock & Wilcox Conversion Services, to John Tauxe, Neptune and Company, Inc., 28 Mar 2014).

Disposal of the GDP DU is to occur using the same 48 Y DU cylinders that the waste was placed in at the deconversion plant. The cylinders are welded shut, and so their contents have no contact with atmospheric oxygen outside the container. Even if particles of UO₂ were to spontaneously ignite, they would quickly use up any available oxygen in the container, producing U₃O₈. In the disposed environment, EnergySolutions operators will infill and cover the cylinders with grout or flowable concrete, further sealing them from the elements. Subsequently, the DU would be buried under other low-level waste, and the isolation of the DU would be such that no contact with the atmosphere would occur.

The Savannah River Site DU is all UO₃, according to the shipping manifests, so UO₂ pyrophoricity is not an issue with that population.

No products from International Isotopes Fluorine Products have been reviewed or considered for this PA.

168. INTERROGATORY CR R313-25-7(2)-168/1: RIP RAP SIZING

Resolve the discrepancy in descriptions of the side slope in the Erosion Modeling report and the 2013 Compliance Report, Revision 1.

EnergySolutions' Response: Since the depleted uranium Performance Assessment is under revision to model the proposed Federal Cell with an evapotranspirative cover, Interrogatory CR R313-25-7(2)-168/1 is no longer applicable.

Section 3.0, page 2, of the Erosion Modeling report could be modified to include the information on rip rap sizes for the top and side slopes. EnergySolutions, however currently plans to use an evapotranspiration (ET) cover design rather than the design requiring rip rap specified in the Clive DU PA model. Given the change in design, description of rip rap characteristics is no longer applicable.

169. INTERROGATORY CR R313-25-7(9)-169/1: CLARIFICATION OF STATISTICAL TREATMENT OF CHEMICAL AND ISOTOPIC ASSAYS

Clarify issues related to the statistical treatment of uranium chemical and isotopic assays as presented in the Waste Inventory report.

EnergySolutions' Response:

1. The data used came from a Waste Profile Record file that is labeled Waste Profile Record SRS DU 9021-33_r0.pdf, as referenced in the Waste Inventory report. It is an EnergySolutions radioactive waste profile record that is signed by a DOE representative (Glenn Siry). The DOE signature is dated November, 2009. It is clear in this Waste Profile Record that the original 33 samples were used to characterize most radionuclides, and that the same (six) samples were used for the atom% data. However, it is not clear why Sample #8 is missing from the atom% table (listed as Attachment 2 in the Waste Profile Record), or why there are duplicate results presented for each of the six samples that are included.
2. The U-233 atomic% values were treated as non-detects. Since they were reported as 0.000000at%, an assumption was made that the actual value is less than 0.0000005at%. Further explanation is being added to the Report.
3. These documents are being included with the next submittal.
4. These references are being included in the next submittal.
5. The appropriate reference is:

Fussell, G.M, and D. L. McWhorter, 2002. Project Plan for the Disposition of the SRS Depleted, Natural, and Low-Enriched Uranium Materials. WSRC-RP-2002-00459, Washington Savannah River Site, November 21, 2002.

6. Clarification is being included in the Report. The units are pCi/g of DU waste.

170. INTERROGATORY CR R313-25-7-170/1: DU WASTE FORM RELEASE MECHANISMS AND RATES

Provide a detailed description of the conceptual mechanisms, equations, and assumptions used in the model to determine the rate of release of contaminants from the DU waste material (solid phase) to infiltrating waters (liquid phase).

EnergySolutions' Response: The Clive DU PA model does not take into account waste containers (largely because it is assumed that the containers will rust in the very saline environment in a relatively short time frame compared to the time frame of the PA – see CSM, Section 8.1 p.44, and Geochem WP, section 2.0). The waste release rate would depend on the solubility of the element in the waste layer. The Geochemical Modeling report, Section 2.0, page 3, describes in some detail the assumptions of the waste and its release to the environment. The waste is assumed to be homogenized with the sand / alluvial fill material so that the properties of the waste layer are approximately the same as the sand.

This topic is indirectly mentioned in FRV1, Section 4.1.2.5, page 30, where the report says that the waste leaving the waste cell initially starts off as solubility-limited. As time goes on and more radionuclides dissolve, Kds may control the release of radionuclides from the waste layer.

Clarification can be added to FRV1 on the release of waste from the waste. Thermodynamically, U_3O_8 is much less soluble (and more stable) than UO_3 . Over time, it is apparent that U_3O_8 is immobile, whereas the UO_3 would be more mobile and thus more likely to leave the system.

More clarification can be added to the Deep Time report to clarify the question of how and why the soluble U (UO_3) leaves the system within 50,000 years.

171. INTERROGATORY CR R313-25-7-171/1: ADEQUACY OF DU CELL BUFFER ZONE

Describe the location, dimensions, and attributes of the buffer zone at the proposed DU disposal cell, and explain and justify how it will be adequate for environmental monitoring and future mitigative actions, if needed.

EnergySolutions' Response: The location, dimensions, and attributes of the buffer zone for the proposed Federal Cell are detailed in Section 1.2.2.2 of the License Amendment Request for the Class A West Embankment (EnergySolutions 2012). Note that this discussion speaks of the 11e.(2) cell, i.e.,

the footprint for the proposed Federal Cell. This buffer zone was approved by DRC with approval of the Class A West Embankment on November 26, 2012.

Note that the former Class A South cell design was subjected to additional buffer zone and monitoring requirements due to long-term stewardship being split between the State of Utah and DOE. The Federal Cell will be entirely within DOE stewardship; therefore, the additional requirements of Morton, 2008, do not apply.

172. INTERROGATORY CR R313-25-20-172/1: INADVERTENT INTRUDER PROTECTION

Provide a comprehensive analysis of possible inadvertent human intrusion scenarios.

EnergySolutions' Response: See the response to Interrogatory CR R313-25-8(4)(B)-07/1.

The response to Interrogatory #7 covers the local site conditions and regulatory basis for selection of inadvertent human intrusion scenarios. The response also cites guidance from the Performance Assessment Work Group (PAWG) of the NRC that recommends against excessive speculation about future events. The first scenario identified in the basis for interrogatory is a statement about erosion and embankment stability associated with future sand and gravel operations – it is not an intruder scenario. The second scenario is concerned with buildings that may or may not remain after site maintenance and long-term closure activities. However, these buildings are outside of the buffer zone and therefore any activities are by definition public rather than intruder scenarios.

173. INTERROGATORY CR R313-25-7(2)-173/1: STABILITY OF EMBANKMENT

Demonstrate that the loading created by the high-density DU waste form will not result in subsidence in the disposal embankment that will compromise the performance of the cover/radon barrier system.

EnergySolutions' Response: Section 5 provides a loading calculation demonstrating that the DU waste form meets existing criteria for waste liner loading. This criterion encompasses scenarios considering in prior embankment settlement evaluations, thus confirming there is not an unanalyzed condition for embankment stability.

174. INTERROGATORY CR R313-25-7(6)-174/1: WASTE EMPLACEMENT IN CLASS A SOUTH DISPOSAL CELL

Provide a more detailed description of the manner in which waste is emplaced in

the Class A South disposal cell:

1. Define the terms “clean uranium” in waste layers 13–26 (and layer WasteOut) and “contaminated uranium” in waste layers 7–12.
2. Elaborate on what type of native soil will be used in the “no waste” section (layers 1–6) of the embankment profile or cross-reference where this information can be found. If non-DU waste is to be placed at these intervals, explain and justify why the waste will not contain any nuclides known to be in the SRS or GDP DU waste streams. As an alternative, explain how the model adequately accounted for SRS and GDP radionuclides in these layers as a part of the waste source term or inventory in the PA model.
3. Describe how incoming DU shipments will be controlled and managed to ensure that construction honors the analyzed condition.

EnergySolutions’ Response:

1. EnergySolutions has committed to dispose of significant quantities of depleted uranium only below grade, regardless of whether it is “contaminated” or “clean”. Therefore, the distinction is irrelevant.

These terms “clean uranium” in waste layers 13–26 (and layer WasteOut) and “contaminated uranium” in waste layers 7–12 are defined in the Waste Inventory white paper. Simply defined, “clean uranium” refers to depleted uranium oxide that has no contaminants that get introduced from the processing of reactor returns. That is, it consists only of uranium isotopes and their progeny.

“Contaminated uranium”, on the other hand, contains some amount of fission products (e.g. Tc-99) and transuranics (e.g. Np-237, Am-241, Pu-X) resulting from the processing of reactor returns. While the inventory of DUF6 to be converted to oxides at the Piketon (Portsmouth) site are believed to be largely clean, a small fraction of the Paducah inventory is contaminated, and all the SRS DU is contaminated.

It is noted that the Interrogatory refers to Figure 9, page 13, of the Conceptual Site Model for the figure showing waste layers, but this figure is from the Embankment Modeling white paper.

2. The “no waste” designation in the model refers to Class A LLRW and native soils other than significant quantities of depleted uranium. Since the waste is Class A, it could in fact contain of nuclides in the SRS or GDP DU waste streams; but it will not contain significant quantities of depleted uranium. Performance assessment for these nuclides is addressed via the ET cover performance assessment currently undergoing DRC review.

If the model dashboard option of “No Waste” is selected in the

specification of the layering of the waste cell, Unit 3 soils are assumed to occupy the space. If generic “Class A Low-Level Waste” is selected, then the material “Generic_Waste” is modeled. Until such time as this waste is better defined, this generic waste is assigned the properties of Unit 3 soil as well, and has no inventory of radionuclides currently assigned. Therefore, the end effect of selecting either of these choices is the same. No radionuclide inventory is assigned to Generic_Waste, since this PA Model is focused on the assessment of future risks from the proposed disposals of DU waste, without regard to wastes already disposed, or non-DU wastes proposed to be disposed.

To account for SRS and GDP DU wastes in the model, the user selects the layering of the various waste types, using the Waste Layer dashboard (accessible through the Control Panel). A check is made to assure that the total volume of the various types of DU wastes proposed for disposal is less than the cumulative volume of the layers selected for the disposal of each type. The inventory of each type of DU is then distributed evenly throughout the total volume of the layers selected by the user. As it turns out, the entire SRS DU inventory will fit into a single layer, as will the entire contaminated GDP DU inventory. The clean GDP DU inventory requires at least four layers be assigned to hold it.

EnergySolutions has committed to dispose of significant quantities of depleted uranium only below grade, regardless of whether it is “contaminated” or “clean”. Therefore, additional controls on placement elevation are not needed.

3. *EnergySolutions* has committed to dispose of significant quantities of depleted uranium only below grade, regardless of whether it is “contaminated” or “clean”. Therefore, additional controls on placement elevation are not needed.

175. INTERROGATORY CR R313-25-7(2)-175/1: INFILTRATION RATES FOR THE FEDERAL CELL VERSUS THE CLASS A WEST CELL

Justify that the Federal Cell infiltration rates are comparable to those predicted for the Class A West cell.

EnergySolutions' Response: Since the depleted uranium Performance Assessment is under revision to model infiltration into the proposed Federal Cell with an evapotranspirative cover, Interrogatory CR R313-25-7(2)-175/1 is no longer applicable.

176. INTERROGATORY CR R313-25-8(5)(A)-176/1: REPRESENTATIVE HYDRAULIC CONDUCTIVITY RATES

Model the migration of DU and other associated wastes, including bulk Class A waste components, assuming corrected hydraulic conductivity values provided in NRC guidance (NUREG/CR-7028).

EnergySolutions' Response: The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration. Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model.

Note that these sensitivity cases have not historically been applied to the frost-protected radon barrier under the traditional rock armor mulch design. The ET cover design reduces predicted infiltration by two order of magnitude compared with the rock armor mulch. Any further degradation of radon barrier for the rock armor mulch design would only further reduce its performance relative to an ET cover.

The Benson et al. (2011) reference emphasizes cover properties in general, not the specific cover types and materials proposed for the Clive site and the local climatic setting. The recommendations from Benson (2011), by itself, are not sufficient justification to require redesigning the cover system nor is it contradictory with the steady state infiltration rates developed from the HELP modeling.

The topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly

dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. An expanded assessment of cover design components and assigned physical properties in models of cover performance must be carefully designed for applicability to the climate and hydrogeological setting of the Clive disposal facility.

This interrogatory spans two topics: alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty). Enhanced investigations of these components of uncertainty require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling. There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. If a more comprehensive sensitivity analysis is needed for the infiltration modeling, it should not be based on selective and non-systematic changes in physical properties of cover materials. Instead what is required would be refined modeling of closure cover performance using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into the probabilistic performance assessment model.

177. INTERROGATORY CR R313-25-8(5)(A)-177/1: DOSE FROM PLANT UPTAKE

Include a quantitative analysis of dose resulting from plant uptake through “other wastes” in addition to DU.

EnergySolutions’ Response: The PA is specific to depleted uranium and does not encompass “other wastes”; i.e., other wastes were not included in the scope of the PA. Therefore, this response focuses on the final statement of the Basis for Interrogatory,

“The plant pathway needs to receive full consideration within the PA model and text.”

The discussion of black greasewood, shadscale saltbush, and four-wing saltbush in the Basis for Interrogatory is presumed to relate to the cited Compliance Report text (Section 3.1.5, page 3-4) which states that:

“...deep-rooted native plants present in the site vicinity do not have root depths sufficient to penetrate the Division-approved cover systems, overlying wastes, and into the depth at which depleted uranium is modeled for disposal (i.e., greater than 5 meters below the base of the cover).”

The identification of plant groups for modeling root uptake of radionuclides as a transport mechanism is discussed in Section 3.2 of Appendix 9 of the Final Report (Biological Modeling). Black greasewood and shadscale saltbush are specifically identified in Table 3 of Biological Modeling as species identified at Clive and were the basis for naming two of the three present-day vegetative associations (Black Greasewood and Shadscale – Gray Molly) used to support parameterization of the plant transport component of the PA computer model. Additionally, black greasewood and shadscale saltbrush at Clive were among the plant species excavated to obtain root profile measurements (Biological Modeling; page 8) used in the PA computer model.

In addition to serving as a contaminant transport pathway for vertical migration of radionuclides, plants are assumed to serve as browse for cattle and game and therefore contribute to meat ingestion dose for receptors in the Ranching and Recreation exposure scenarios. This is described in Section 4.2 of Appendix 11 of the Final Report (Dose Assessment). Sheep are not considered, as there is no evidence that sheep are currently or have been routinely grazed in the area in the past. Therefore, the plant transport pathway has been fully considered in the PA.

178. INTERROGATORY CR R313-25-8(5)(A)-178/1: SURFACE WATER PATHWAY

Analyze potential doses to humans through the surface water exposure pathway.

EnergySolutions' Response: The Clive facility is sited in an area of extremely low topographic relief, and surface water features such as stream channels are rare. The ancestral lake bed is quite flat, so there is little in the way of land surface gradients which might drive surface water flow. Most if not all meteoric water that lands on the ground is assumed to be returned to the atmosphere by evapotranspiration, and essentially none is abstracted by runoff except on the rip rap covers. The embankment cells on the waste disposal site have significant relief, and surface water runoff should be expected from these structures. The runoff and associated sediment transport will be local, and is likely to remain in the vicinity of the site.

The interrogatory describes an historical event when a large storm resulted in an overflow condition for a retention pond. This is water that flowed from surface and intermediate layers of the cover system without contacting the waste. When cover maintenance ceases, radionuclide concentrations can increase at the cover surface due to burrowing and translocation by plants. Runoff events under these conditions could lead to movement of contaminated sediment. However, given the lack of topographic relief and few stream channels, even the impacts of rare large runoff events are likely to remain local.

The retention pond is an operational feature that will be replaced with a dispersion ditch transition to general overland flow as part of site closure. See detail J on drawing 14004-V5, which carries forward the design currently approved by DRC on drawing 9407-5, rev. I (Table 2A of the Ground Water Quality Discharge Permit). Therefore, there will be no standing bodies of surface water except immediately following storm events.

179. INTERROGATORY CR R313-25-7(2)-179/1: RIP RAP

Clarify the thickness, source, and availability of the rip rap.

EnergySolutions' Response: Since the depleted uranium performance assessment is under revision to model the proposed Federal Cell with an evapotranspirative cover, Interrogatory CR R313-25-7(2)-179/1 is no longer applicable.

180. INTERROGATORY CR UGW450005 PART I.D.1-180/1: COMPLIANCE PERIOD

Indicate how pertinent performance standards will be met for groundwater for a compliance period of at least 10,000 years, or justify why those standards do not need to be met. Correct the discussion of the type of analysis needed to comply with UAC R313-25-8(5)(a).

EnergySolutions' Response: See response to Interrogatory CR R313-25-7(2)-91/1.

181. INTERROGATORY CR R313-25-19-181/1: GROUNDWATER MORTALITY

Provide more detailed justification, including more specific references, for the risk factors and the calculated mortalities presented in Table 3-2 of the 2013 Compliance Report, Revision 1.

EnergySolutions' Response: Projection of mortality from the ingestion of Clive's natural groundwater is estimated using the average concentrations from up-gradient well GW-19A, as reported in EnergySolutions, (2012). Mortality slope factors for the ingestion of non-radioactive constituents were obtained from EPA's IRIS database EPA (2013). Mortality slope factors for the ingestion of radioactive constituents were obtained from EPA (1999). As such, it is clear that Clive's natural groundwater is unpotable (meaning that doses from its ingestion are inconsistent with current practices at Clive and beyond the intent of the U.S. nuclear Regulatory Commission performance assessment guidance) as discussed in the response to Interrogatory CR R313-25-7(2)-91/1.

182. INTERROGATORY CR R313-25-19-182/1: GROUNDWATER EXPOSURE PATHWAYS

Expand the discussion in Section 1.3.1, page 1-9, of the 2013 Compliance Report, Revision 1, to include other pathways in addition to ingestion and explain whether or not these additional pathways can significantly contribute to doses.

EnergySolutions' Response: See responses to Interrogatory CR R313-25-8(4)(A)-96/1 and Interrogatory CR R313-25-7(2)-91/1.

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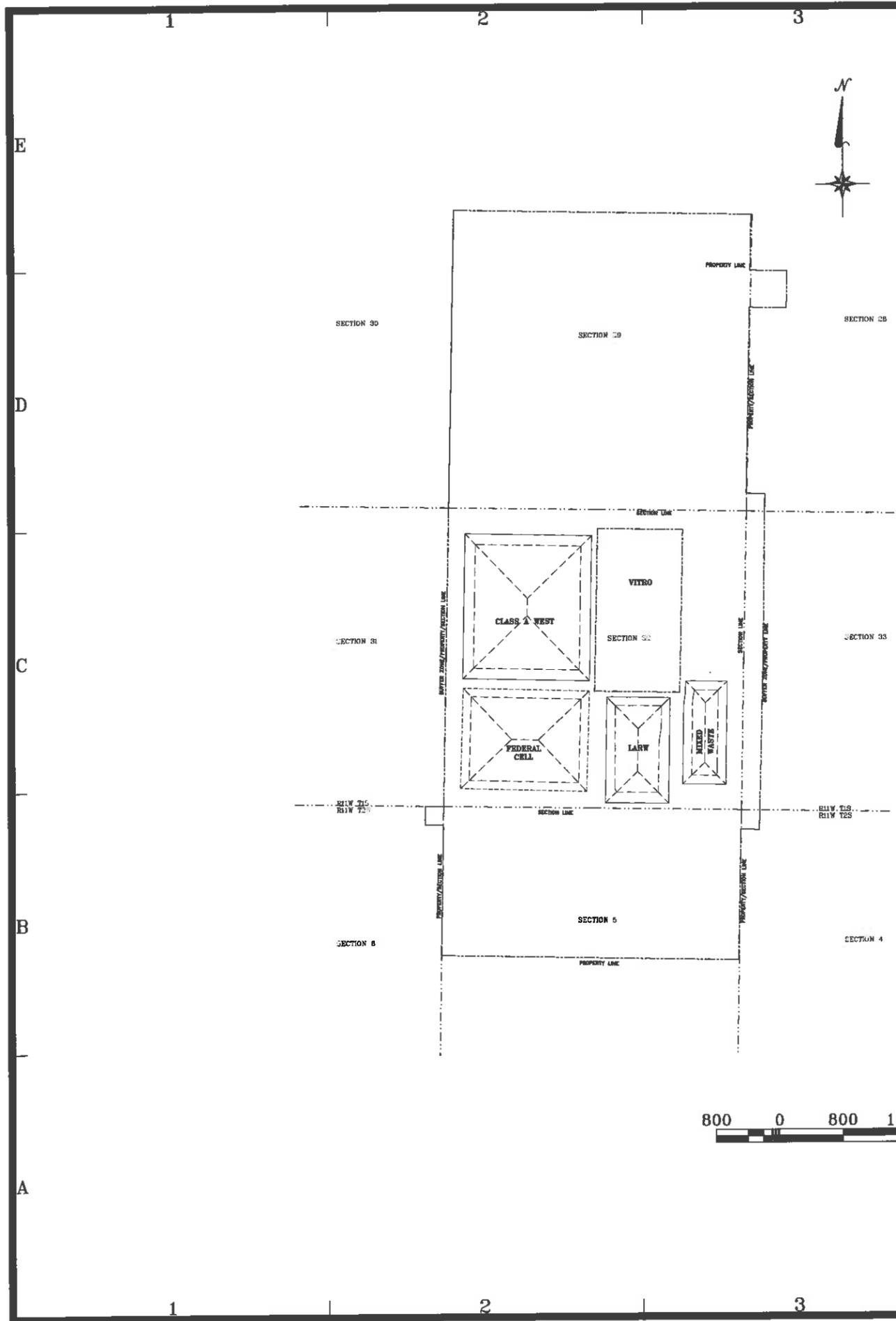
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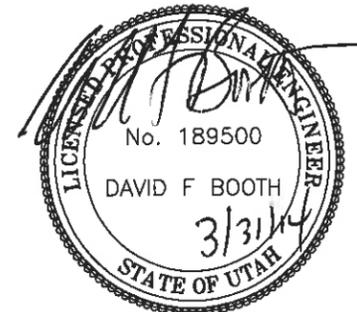
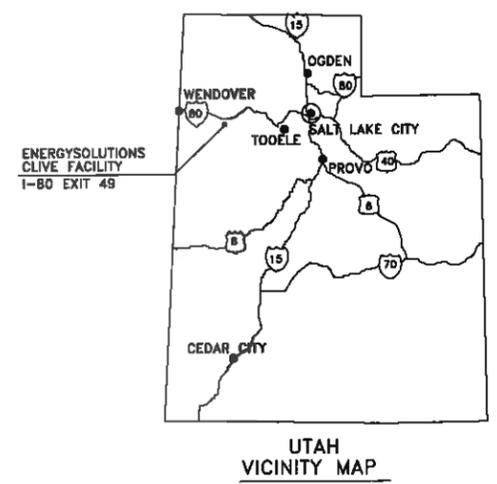
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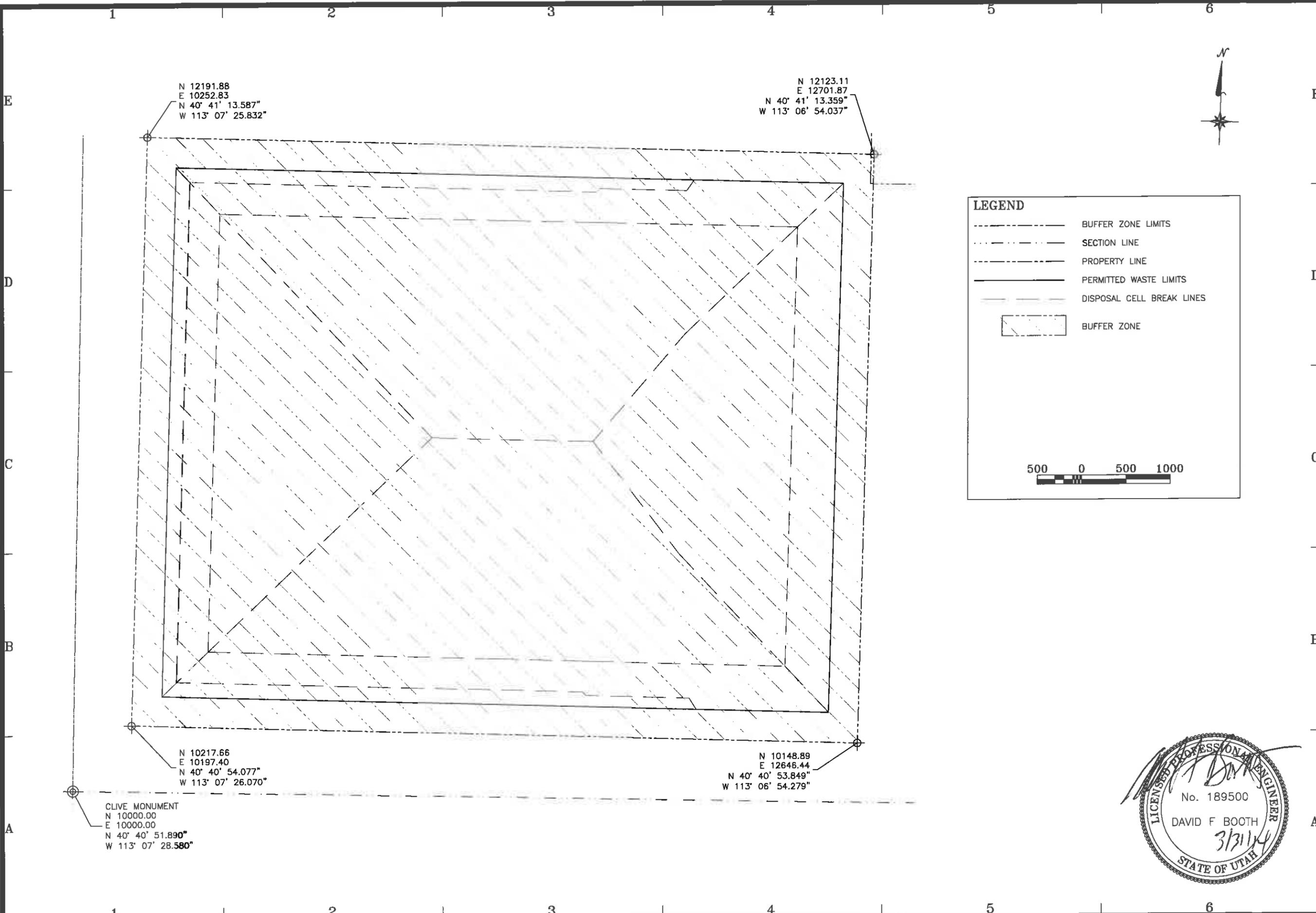
4. FEDERAL CELL PRELIMINARY DRAWING PACKAGE



FEDERAL WASTE DISPOSAL CELL	
DWG. NO.	DESCRIPTION
14004-G1	PROJECT TITLE SHEET
14004-U1	DISPOSAL CELL BUFFER ZONE
14004-U2	DISPOSAL CELL WASTE LIMITS-LATITUDES & LONGITUDES
14004-U3	DISPOSAL CELL ENVIRONMENTAL MONITORING
14004-V1	CELL LAYOUT
14004-V2	CELL COVER LAYOUT
14004-V3	CELL CROSS SECTIONS 1 OF 2
14004-V4	CELL CROSS SECTIONS 2 OF 2
14004-V5	CELL CONSTRUCTION DETAILS 1 OF 2
14004-V6	CELL CONSTRUCTION DETAILS 2 OF 2
14004-V7	COVER CROSS SECTIONS AND GRADATIONS
14004-L1	CONCEPTUAL DU DISPOSAL PLAN



		CLIVE FACILITY	
		FEDERAL WASTE CELL	
		PROJECT TITLE SHEET	
		CLIVE, UTAH	
DESIGNED BY D. BOOTH	CHECKED BY C. DUTSON	DATE 03/28/14	BY DESCRIPTION OF CHANGE 3/31/14 DFB PRELIMINARY
14004 G1			



N 12191.88
E 10252.83
N 40° 41' 13.587"
W 113° 07' 25.832"

N 12123.11
E 12701.87
N 40° 41' 13.359"
W 113° 06' 54.037"

N 10217.66
E 10197.40
N 40° 40' 54.077"
W 113° 07' 26.070"

N 10148.89
E 12646.44
N 40° 40' 53.849"
W 113° 06' 54.279"

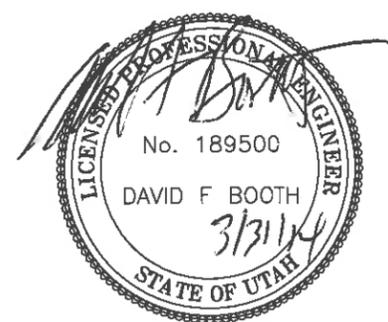
CLIVE MONUMENT
N 10000.00
E 10000.00
N 40° 40' 51.890"
W 113° 07' 28.580"



LEGEND

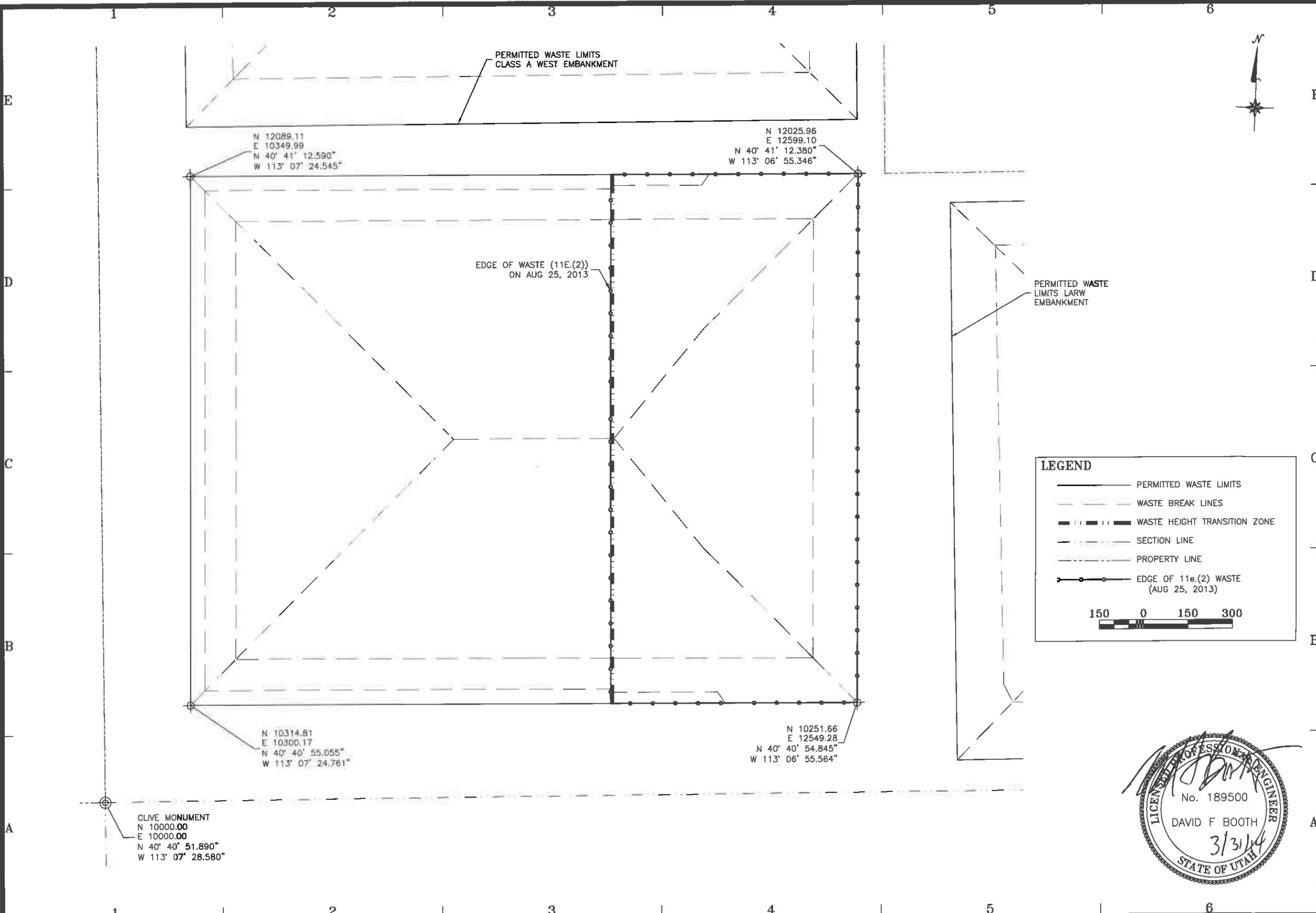
- BUFFER ZONE LIMITS
- SECTION LINE
- PROPERTY LINE
- PERMITTED WASTE LIMITS
- DISPOSAL CELL BREAK LINES
- BUFFER ZONE

500 0 500 1000



ENERGYSOLUTIONS		CLIVE FACILITY	
		FEDERAL WASTE CELL	
		DISPOSAL CELL BUFFER ZONE	
		CLIVE, UTAH	
PRELIMINARY		DESIGNED BY	D. BOOTH
		CHECKED BY	G. DUTSON
		DRAWN BY	D. BOOTH
		DATE	03/28/14
PROJECT NO.		14004	
		U1	

3/31/14 DFB PRELIMINARY BY DESCRIPTION OF CHANGE



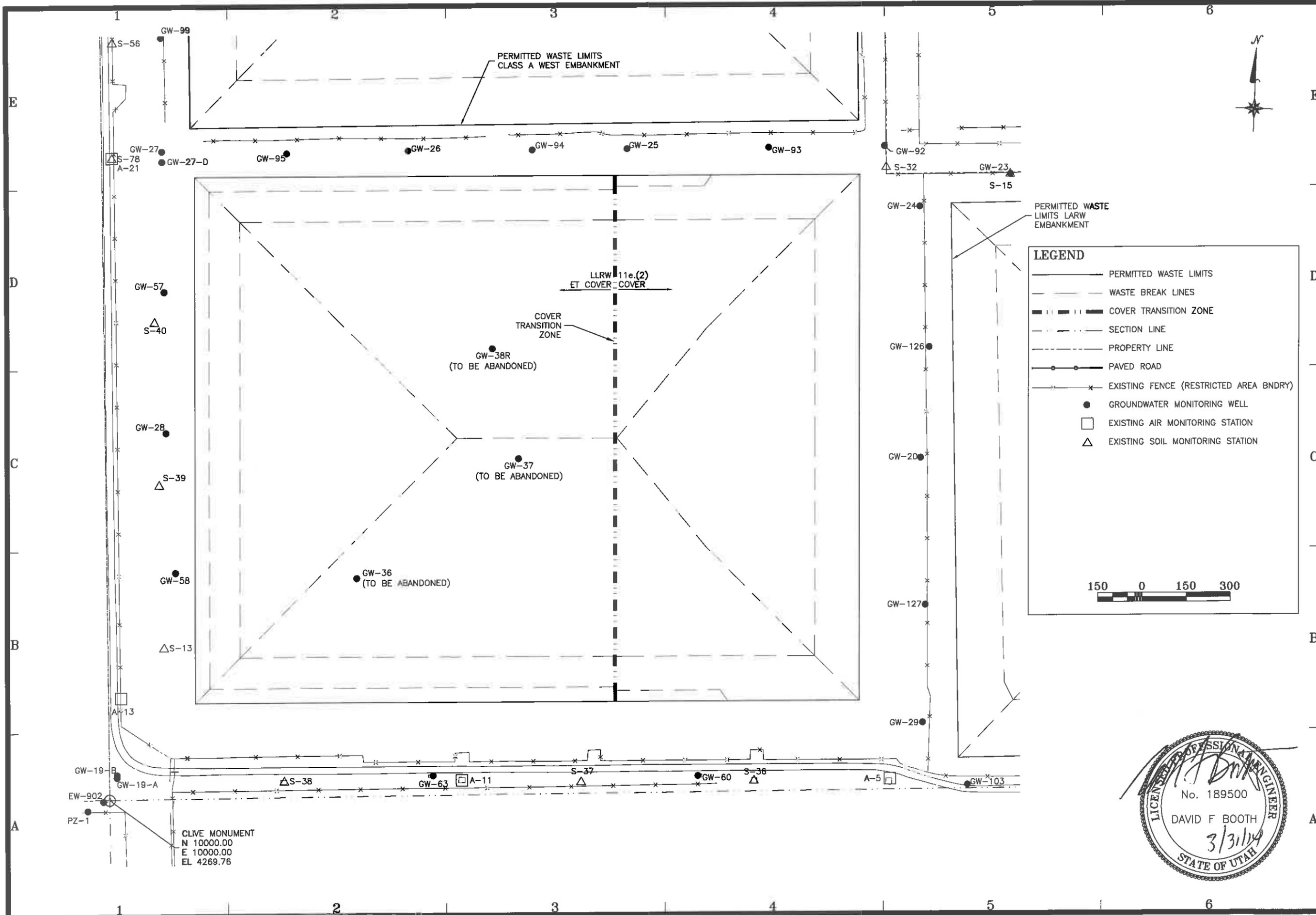
LEGEND

- PERMITTED WASTE LIMITS
- - - WASTE BREAK LINES
- · - · - WASTE HEIGHT TRANSITION ZONE
- · - · - SECTION LINE
- - - PROPERTY LINE
- · - · - EDGE OF 11e.(2) WASTE (AUG 25, 2013)

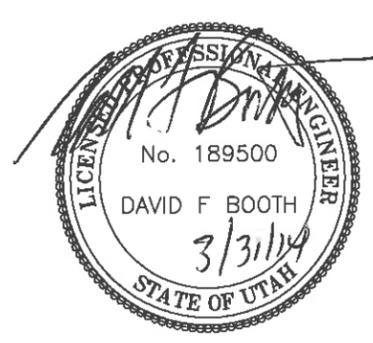
150 0 150 300

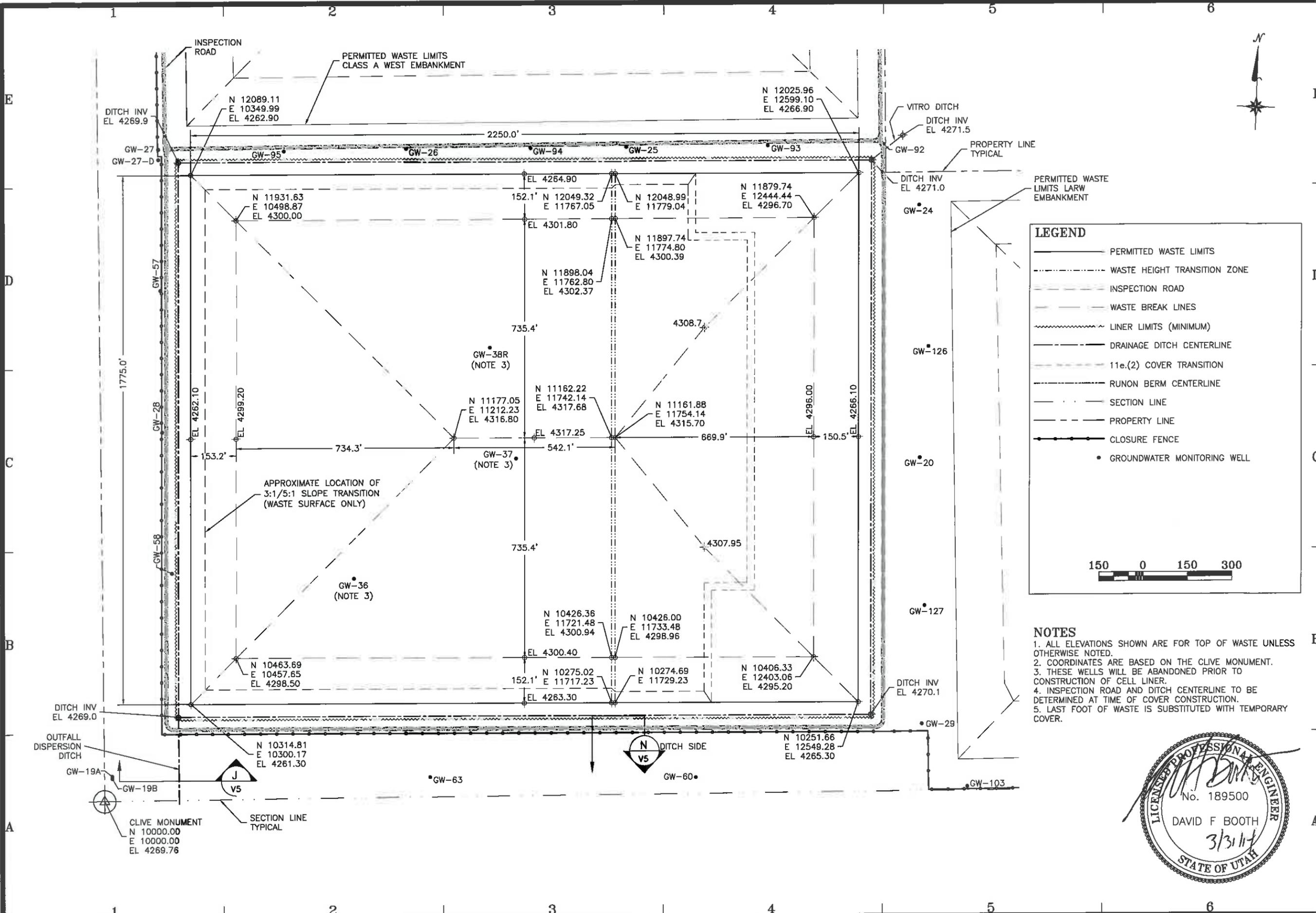


DATE		3/31/14	DFB	PRELIMINARY
BY				DESCRIPTION OF CHANGE
ENERGYSOLUTIONS				
CLIVE FACILITY FEDERAL WASTE CELL				
DISPOSAL CELL WASTE LIMITS-LATITUDES & LONGITUDES CLIVE, UTAH				
PRELIMINARY				
DESIGNED BY	D. BOOTH			
REVIEWED BY	G. DUTSON			
APPROVED BY	D. BOOTH			
SCALE	AS SHOWN			
DATE	03/28/14			
PROJECT NO.	14004 U2			



ENERGYSOLUTIONS		CLIVE FACILITY	DATE	BY DESCRIPTION OF CHANGE
FEDERAL WASTE CELL		DISPOSAL CELL ENVIRONMENTAL MONITORING	3/31/14	DFB PRELIMINARY
PRELIMINARY		CLIVE, UTAH		
DESIGNED BY	D. BOOTH	APPROVED BY	G. DUTSON	
DATE	3/31/14	SCALE	AS SHOWN	03/28/14
14004		U3		



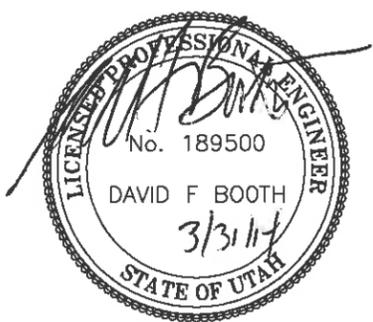


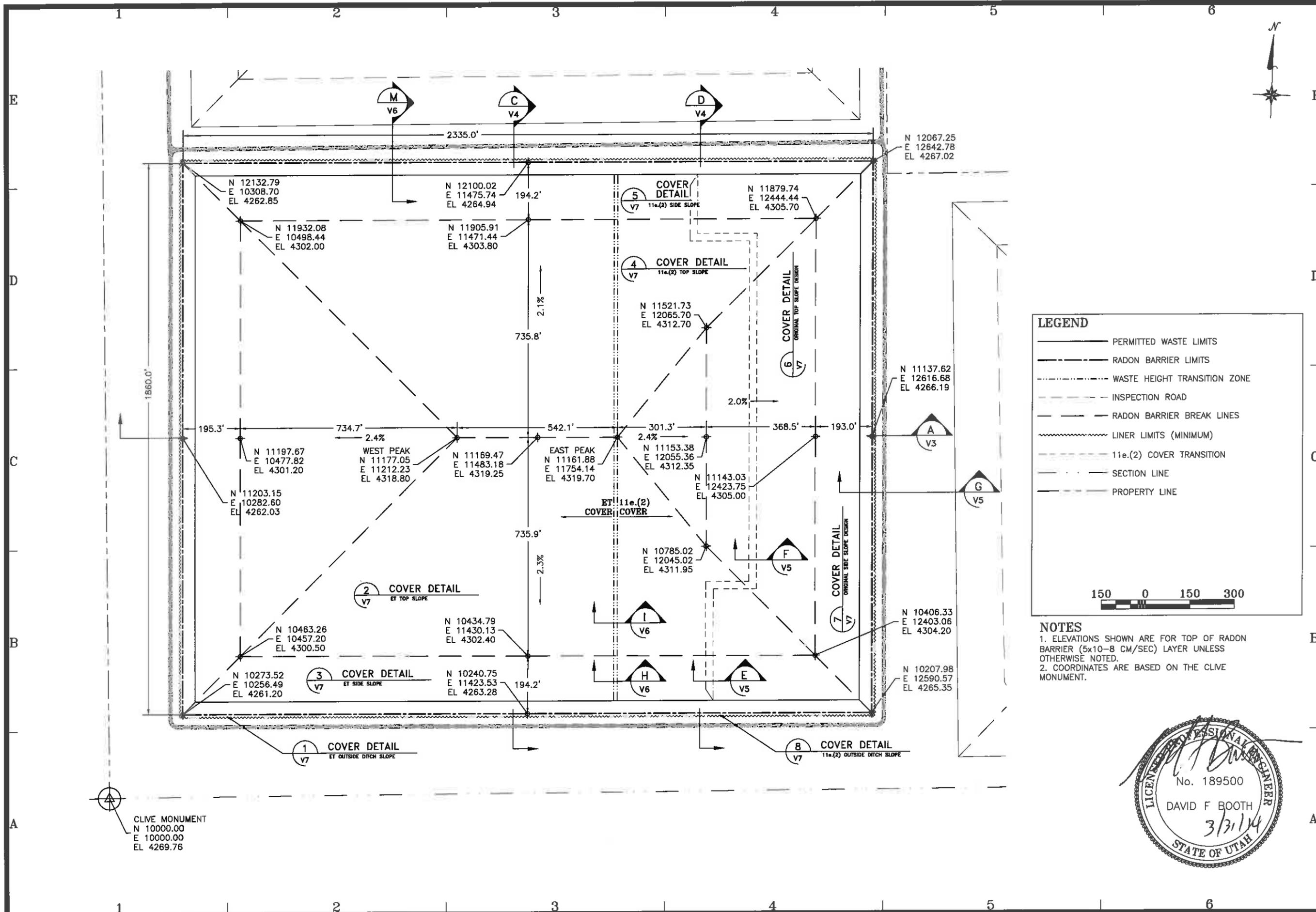
DATE: 3/31/14 BY: DFB PRELIMINARY

ENERGYSOLUTIONS
CLIVE FACILITY
FEDERAL WASTE CELL
CELL LAYOUT
CLIVE, UTAH

PRELIMINARY

DRAWN BY: D. BOOTH	REV.:
CHECKED BY: G. DUTSON	DATE: 03/28/14
DESIGNED BY: D. BOOTH	BY: D. BOOTH
PROJECT NO. 14004 V1	





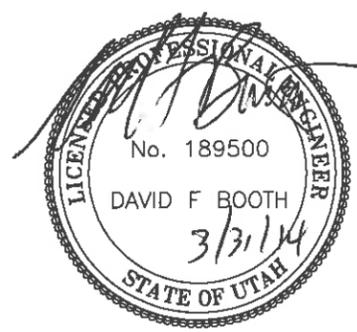
LEGEND

- PERMITTED WASTE LIMITS
- RADON BARRIER LIMITS
- - - WASTE HEIGHT TRANSITION ZONE
- - - INSPECTION ROAD
- - - RADON BARRIER BREAK LINES
- ~ LINER LIMITS (MINIMUM)
- - - 11e.(2) COVER TRANSITION
- SECTION LINE
- PROPERTY LINE

150 0 150 300

NOTES

- ELEVATIONS SHOWN ARE FOR TOP OF RADON BARRIER (5x10-8 CM/SEC) LAYER UNLESS OTHERWISE NOTED.
- COORDINATES ARE BASED ON THE CLIVE MONUMENT.

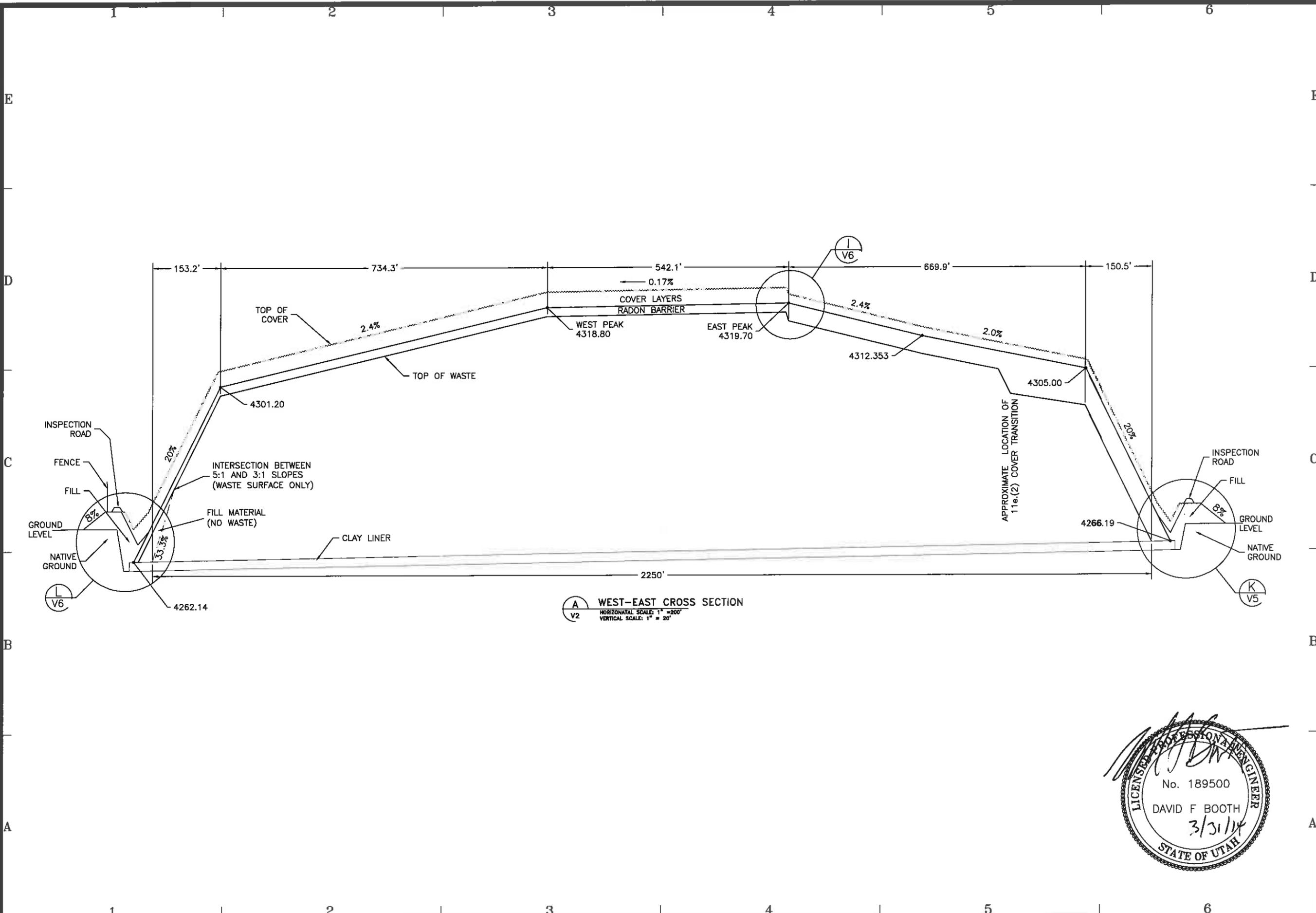


ENERGYSOLUTIONS		CLIVE, UTAH
CLIVE FACILITY		DATE: 3/31/14
FEDERAL WASTE CELL		BY: DFB
CELL COVER LAYOUT		REVISION: PRELIMINARY
CLIVE, UTAH		DESCRIPTION OF CHANGE:

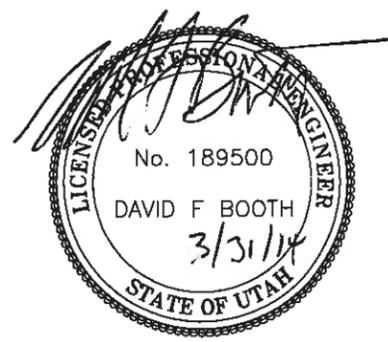
PRELIMINARY

DESIGNED BY	D. BOOTH
PROJECT BY	G. DUTSON
APPROVED BY	D. BOOTH
DATE	03/28/14
SCALE	AS NOTED

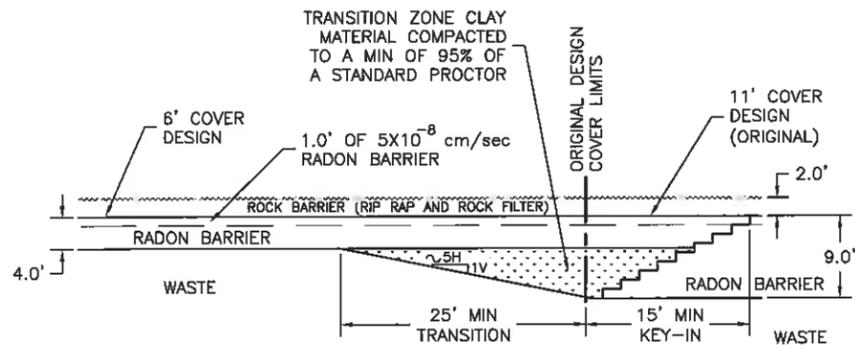
14004
V2



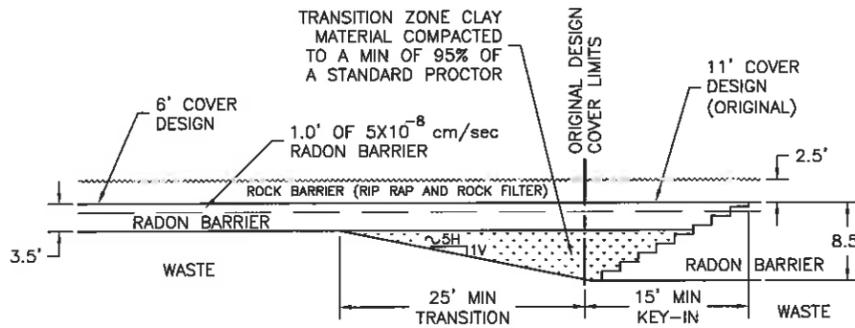
A
V2
WEST-EAST CROSS SECTION
 HORIZONTAL SCALE: 1" = 200'
 VERTICAL SCALE: 1" = 20'



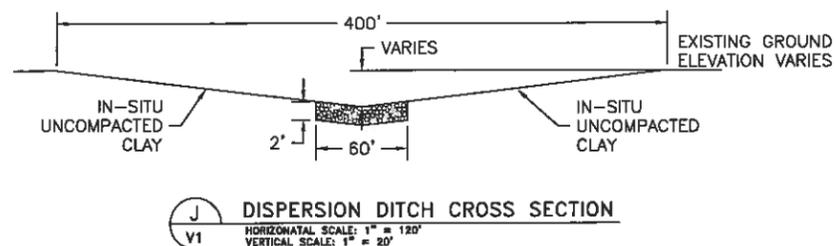
ENERGYSOLUTIONS		CLIVE FACILITY		FEDERAL WASTE CELL		CELL CROSS SECTIONS 1 OF 2		CLIVE, UTAH	
PRELIMINARY		DATE		3/31/14		PRELIMINARY		BY DESCRIPTION OF CHANGE	
DESIGNED BY		D. BOOTH		CHECKED BY		G. DUTSON		APPROVED BY	
NTS		03/28/14							
14004		V3							



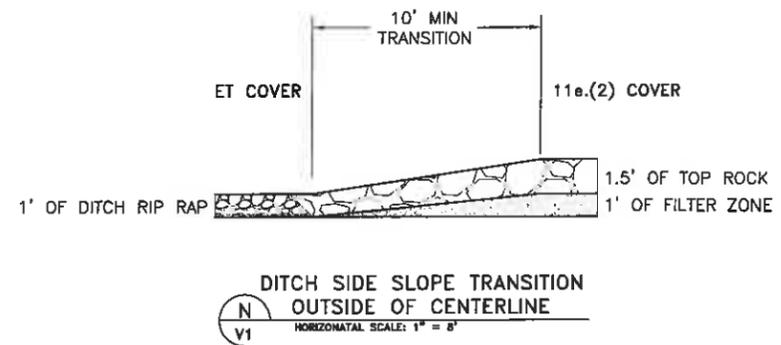
11e.(2) TOP SLOPE COVER TRANSITION
 F V2 NOT TO SCALE



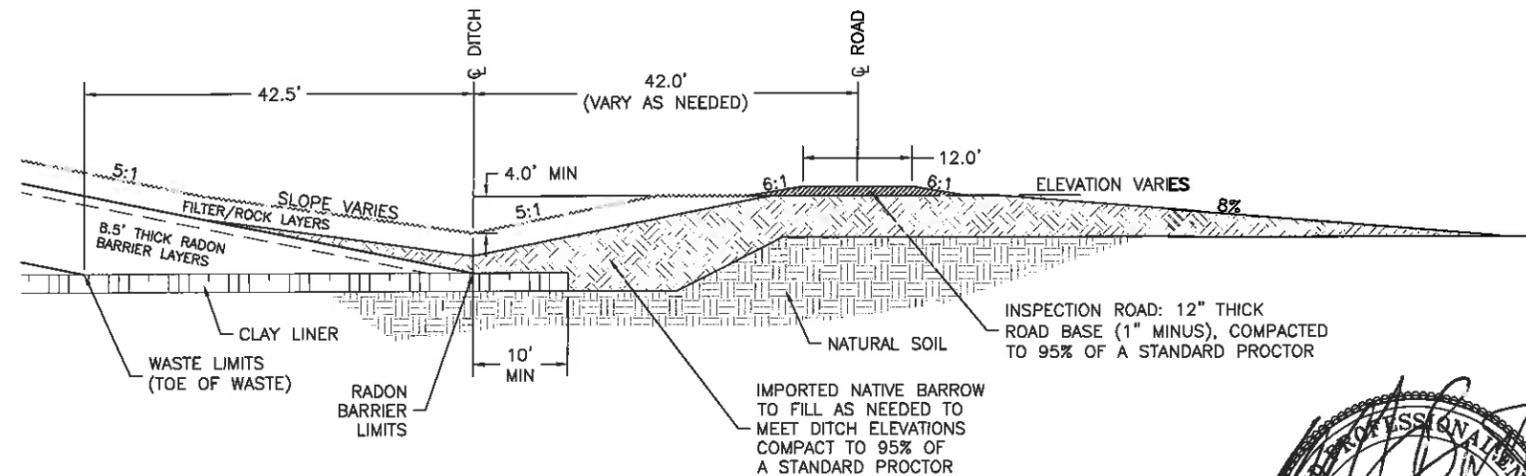
11e.(2) SIDE SLOPE COVER TRANSITION
 E V2 NOT TO SCALE



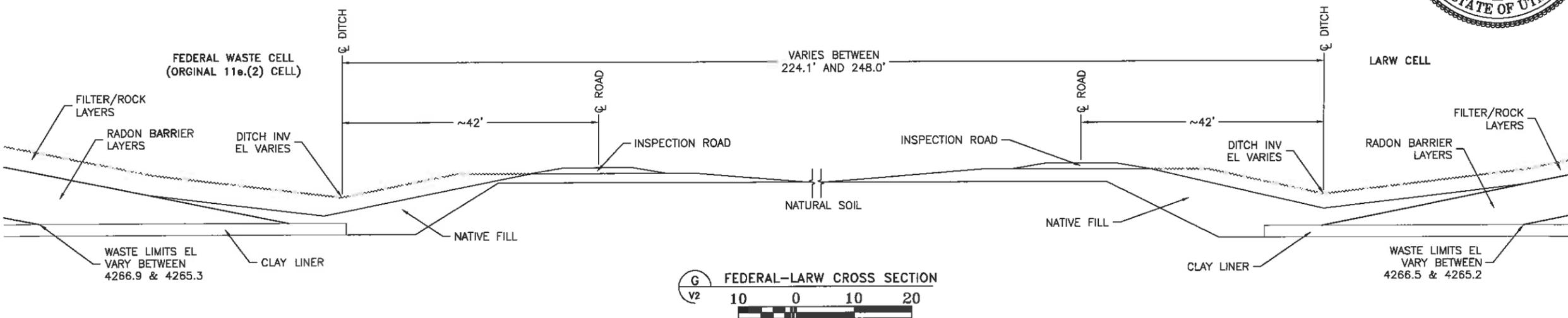
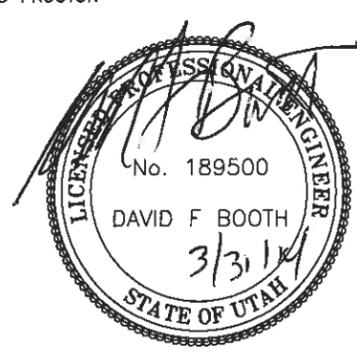
J DISPERSION DITCH CROSS SECTION
 J V1 HORIZONTAL SCALE: 1" = 120'
 VERTICAL SCALE: 1" = 20'



N DITCH SIDE SLOPE TRANSITION OUTSIDE OF CENTERLINE
 N V1 HORIZONTAL SCALE: 1" = 8'



K ORIGINAL DITCH CROSS SECTION
 K V3 10 0 10 20



G FEDERAL-LARW CROSS SECTION
 G V2 10 0 10 20

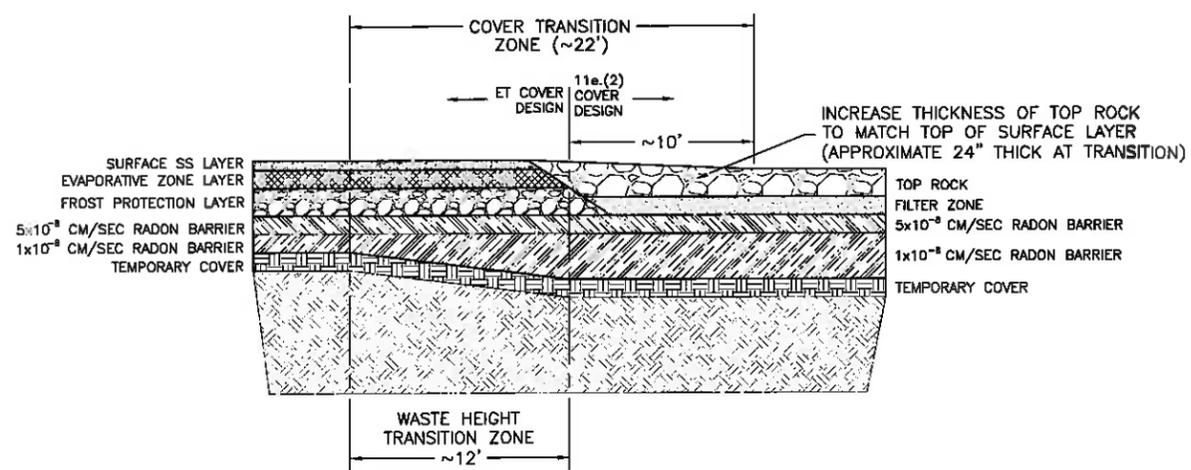
DATE	3/31/14
BY	DESCRIPTION OF CHANGE

ENERGYSOLUTIONS
 CLIVE FACILITY
 FEDERAL WASTE CELL
 CELL CONSTRUCTION DETAILS 1 OF 2
 CLIVE, UTAH

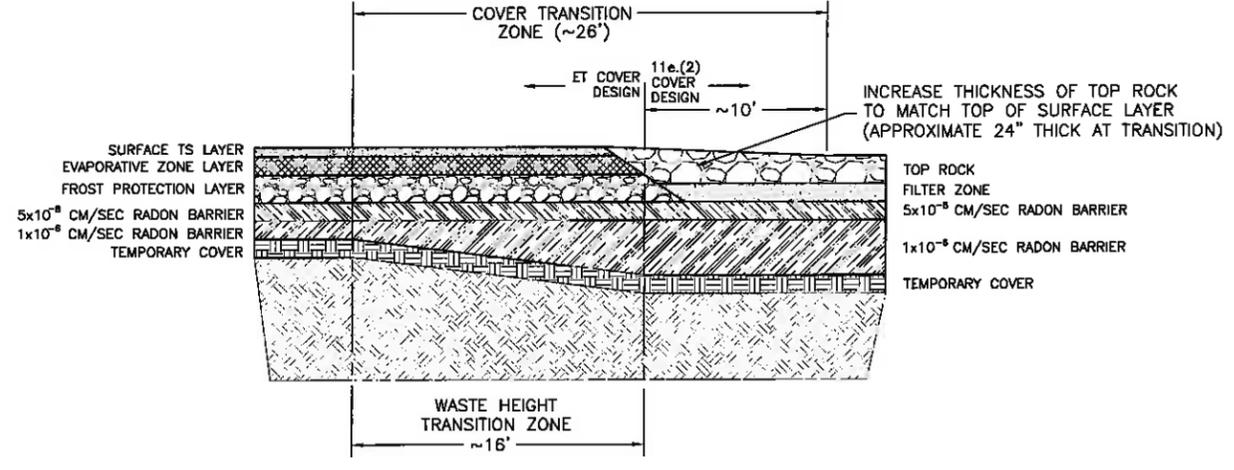
PRELIMINARY

DESIGNED BY: D. BOOTH
 CHECKED BY: G. DUTSON
 APPROVED BY: D. BOOTH
 DATE: 03/28/14

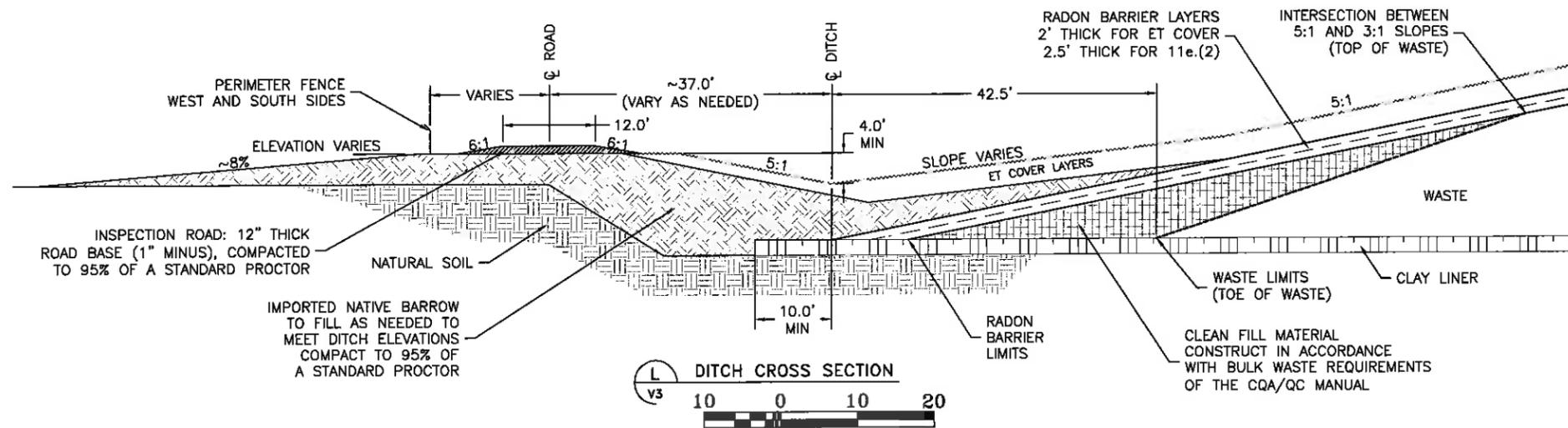
14004
 V5



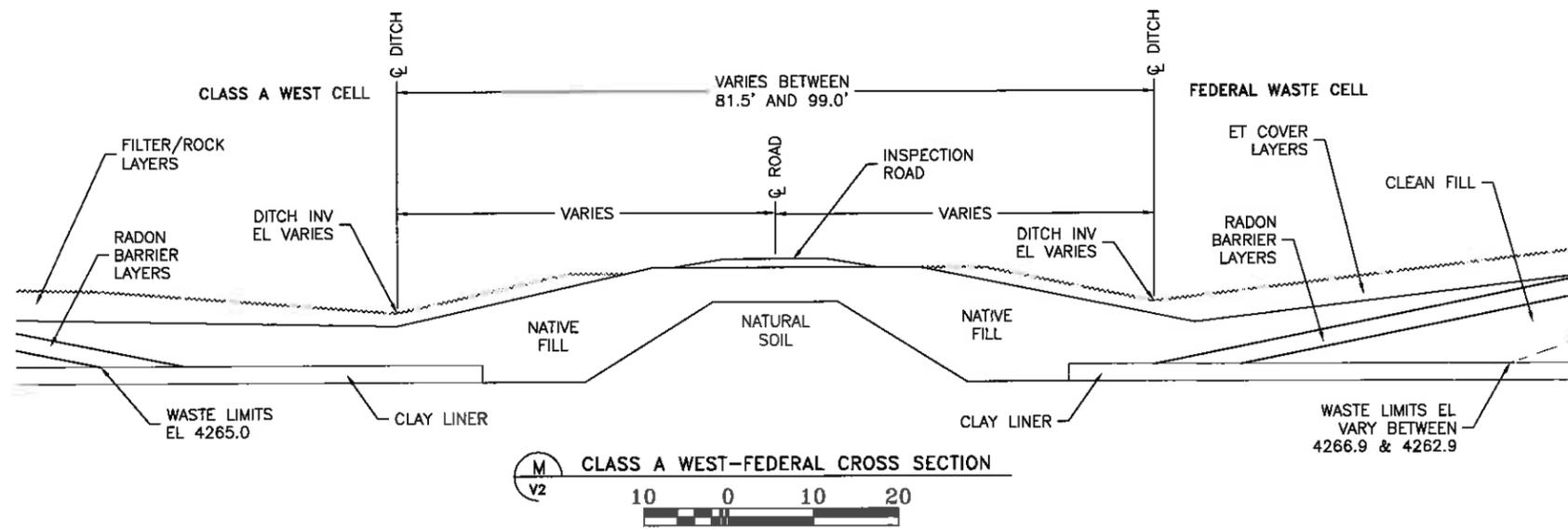
H
V2
SCALE: 1" = 10'



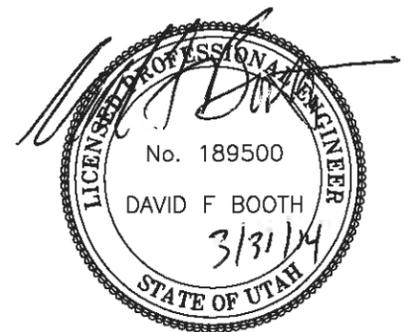
I
V2
SCALE: 1" = 10'



L
V3
SCALE: 1" = 10'



M
V2
SCALE: 1" = 10'



DATE	3/31/14	BY	PRELIMINARY
DATE		BY	DESCRIPTION OF CHANGE

ENERGYSOLUTIONS
CLIVE FACILITY
FEDERAL WASTE CELL
CELL CONSTRUCTION DETAILS 2 OF 2
CLIVE, UTAH

PRELIMINARY

DESIGNED BY	D. BOOTH
CHECKED BY	G. DUTSON
APPROVED BY	D. BOOTH
SCALE	NTS
DATE	03/27/14
PROJECT NO.	14004 V6

ORIGINAL 11e.(2) CELL COVER DESIGNS

ROCK 12" THICK TOP ROCK
 12" THICK FILTER ZONE
 12" OF 5 X 10⁻⁸ CM/SEC RADON BARRIER

CLAY 3' OF 1 X 10⁻⁸ CM/SEC RADON BARRIER

4 11e.(2) TOP SLOPES
 V2

ROCK 12" THICK TOP ROCK
 12" THICK FILTER ZONE
 12" OF 5 X 10⁻⁸ CM/SEC RADON BARRIER

CLAY B' OF 1 X 10⁻⁸ CM/SEC RADON BARRIER

6 11e.(2) TOP SLOPES
 ORIGINAL DESIGN
 V2

ROCK 18" THICK SIDE ROCK
 12" THICK FILTER ZONE

NATURAL GROUND OR IMPORTED NATIVE BARROW MATERIAL

8 PERIMETER DITCH
 OUTSIDE SLOPE ONLY
 V2

ROCK 18" THICK SIDE ROCK
 12" THICK FILTER ZONE
 12" OF 5 X 10⁻⁸ CM/SEC RADON BARRIER

CLAY 2.5' OF 1 X 10⁻⁸ CM/SEC RADON BARRIER

5 11e.(2) SIDE SLOPES
 V2

ROCK 18" THICK SIDE ROCK
 12" THICK FILTER ZONE
 12" OF 5 X 10⁻⁸ CM/SEC RADON BARRIER

CLAY 7.5' OF 1 X 10⁻⁸ CM/SEC RADON BARRIER

7 11e.(2) SIDE SLOPES
 ORIGINAL DESIGN
 V2

GRADATIONS - ASTM C-136

TOP ROCK
 D₁₀₀ 2-1/2 TO 4-1/2 INCHES
 D₅₀ 1-1/8 TO 3 INCHES
 D₁₅ 3/4 TO 1-1/2 INCHES

SIDE ROCK
 D₁₀₀ 12 TO 16 INCHES
 D₉₅ 8 TO 12 INCHES
 D₅₀ 4-1/2 TO 8 INCHES
 D₁₅ 2 TO 4 INCHES

FILTER ZONE
 D₁₀₀ = 1.5 TO 3.0 INCHES
 D₈₅ = 1.0 TO 2.5 INCHES
 D₅₀ = 0.75 TO 2.0 INCHES
 D₁₅ = 0.3125 TO 0.625 INCHES
 D₁₀ >= #10 SIEVE (2.0 mm)
 D₅ >= #200 SEIVE (0.074 mm)

FEDERAL WASTE CELL COVER DESIGNS

ROCK 12" THICK DITCH RIPRAP
 BORROW MATERIA OR EVAPORATIVE ZONE MATERIAL

1 PERIMETER DITCH
 OUTSIDE SLOPE ONLY
 V2

COVER 6" THICK SURFACE TS LAYER (15% GRAVEL/85% CLAY)
 12" THICK EVAPORATIVE ZONE LAYER
 18" THICK FROST PROTECTION LAYER

CLAY 12" OF 5 X 10⁻⁸ CM/SEC RADON BARRIER
 12" OF 1 X 10⁻⁸ CM/SEC RADON BARRIER

2 ET COVER TOP SLOPES
 V2

COVER 6" THICK SURFACE SS LAYER (50% GRAVEL/50% CLAY)
 12" THICK EVAPORATIVE ZONE LAYER
 18" THICK FROST PROTECTION LAYER

CLAY 12" OF 5 X 10⁻⁸ CM/SEC RADON BARRIER
 12" OF 1 X 10⁻⁸ CM/SEC RADON BARRIER

3 ET COVER SIDE SLOPES
 V2

ET COVER MATERIAL SPECIFICATIONS

SURFACE LAYER, SIDE SLOPE (SS):
 50% UNIT 4 MATERIAL AMENDED WITH 50% (±3%),
 BY VOLUME, GRAVEL. REFER TO NOTE 2.

SURFACE LAYER, TOP SLOPE (TS):
 85% UNIT 4 MATERIAL AMENDED WITH 15% (±3%),
 BY VOLUME, GRAVEL. REFER TO NOTE 2.

EVAPORATIVE ZONE LAYER:
 UNIT 4 MATERIAL (CLAY). REFER TO NOTE 2.

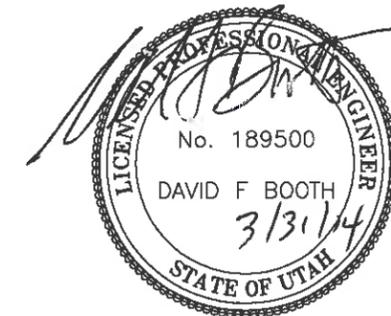
FROST PROTECTION LAYER:
 16" MINUS BANK RUN COBBLE/GRAVEL/SOIL
 MATERIAL. REFER TO NOTE 2.

DITCH RIPRAP:
 FINE GRADED ROCK WITH A D₅₀ OF 6". SEE NOTE 2.

NOTES:

1. EXTEND THE SIDE SLOPE SURFACE LAYER ONTO THE TOP SLOPE A MINIMUM OF 3 FT PAST THE BREAK OVER BETWEEN THE TOP AND SIDE SLOPES.

2. REFER TO THE CURRENT APPROVED LLRW/11e.(2) CQA/QC MANUAL FOR ADDITIONAL MATERIAL SPECIFICATIONS, GRADATIONS, CONSTRUCTION AND TESTING REQUIREMENTS.



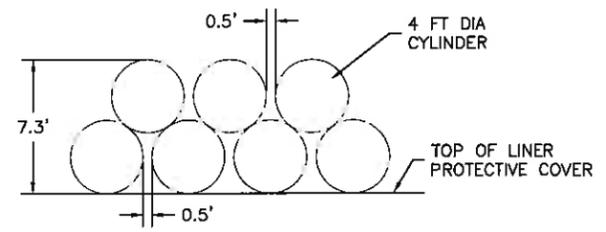
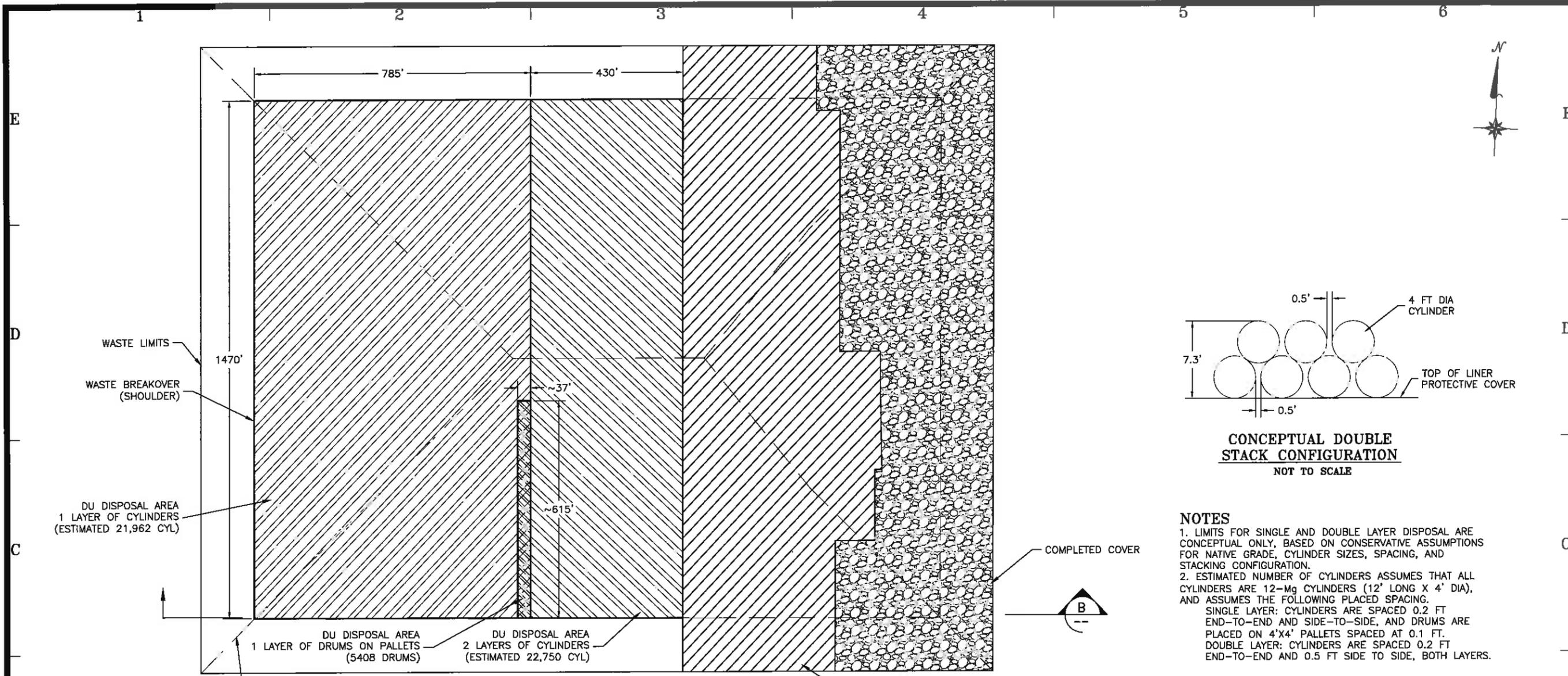
ENERGYSOLUTIONS
 CLIVE FACILITY
 FEDERAL WASTE CELL
 COVER CROSS SECTIONS AND GRADATIONS
 CLIVE, UTAH

PRELIMINARY

DATE BY D.B.OOTH
 CHECKED BY G.DUTSON
 APPROVED BY D.B.OOTH
 SCALE NTS DATE 03/27/14

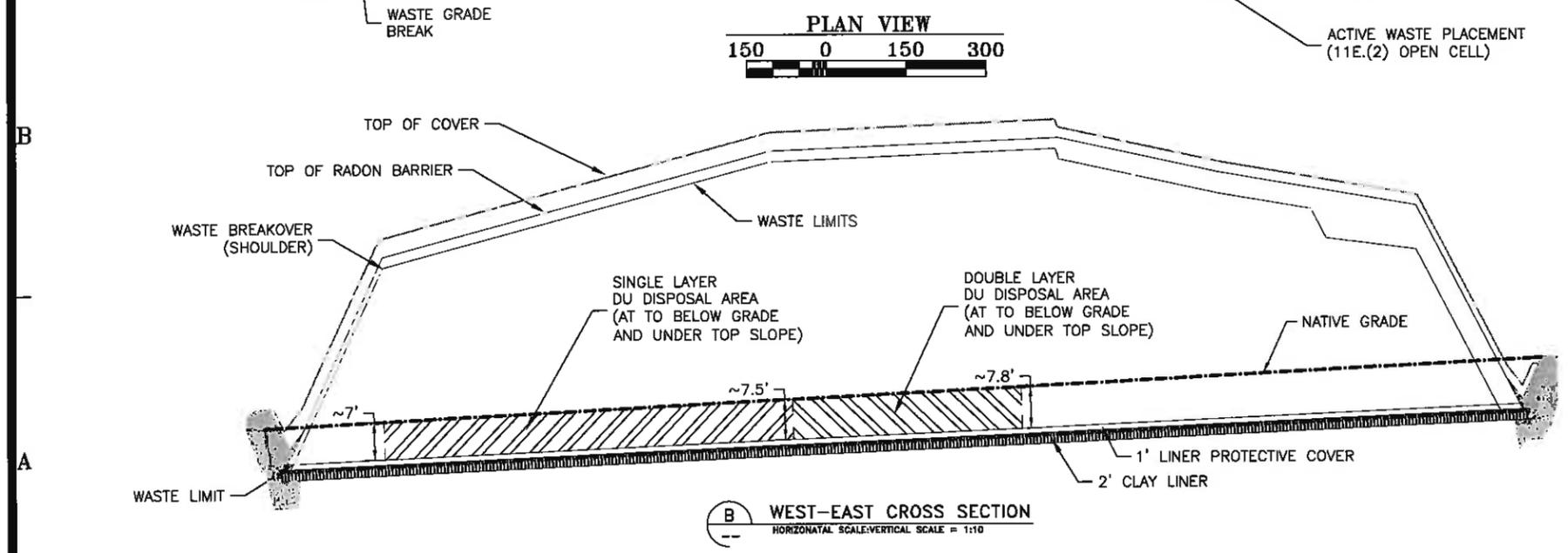
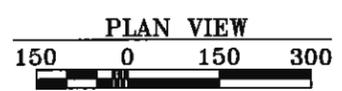
14004
 V7

DATE 3/31/14
 BY DFB
 DESCRIPTION OF CHANGE PRELIMINARY

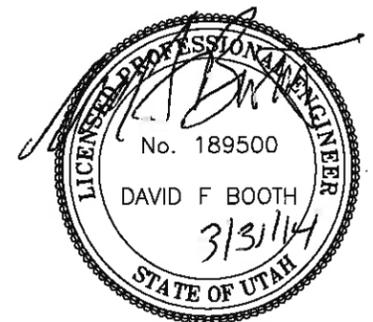


CONCEPTUAL DOUBLE STACK CONFIGURATION
NOT TO SCALE

NOTES
 1. LIMITS FOR SINGLE AND DOUBLE LAYER DISPOSAL ARE CONCEPTUAL ONLY, BASED ON CONSERVATIVE ASSUMPTIONS FOR NATIVE GRADE, CYLINDER SIZES, SPACING, AND STACKING CONFIGURATION.
 2. ESTIMATED NUMBER OF CYLINDERS ASSUMES THAT ALL CYLINDERS ARE 12-Mg CYLINDERS (12' LONG X 4' DIA), AND ASSUMES THE FOLLOWING PLACED SPACING.
 SINGLE LAYER: CYLINDERS ARE SPACED 0.2 FT END-TO-END AND SIDE-TO-SIDE, AND DRUMS ARE PLACED ON 4'X4' PALLETS SPACED AT 0.1 FT.
 DOUBLE LAYER: CYLINDERS ARE SPACED 0.2 FT END-TO-END AND 0.5 FT SIDE TO SIDE, BOTH LAYERS.



WEST-EAST CROSS SECTION
HORIZONTAL SCALE: VERTICAL SCALE = 1:10



ENERGYSOLUTIONS		CLIVE FACILITY	DATE: 3/31/14	BY: DFB
		FEDERAL WASTE CELL	DATE: 3/31/14	BY: DFB
		CONCEPTUAL DU DISPOSAL PLAN	DATE: 3/31/14	BY: DFB
		CLIVE, UTAH	DATE: 3/31/14	BY: DFB
PRELIMINARY				
DESIGNED BY:	D. BOOTH	NO.:	189500	
CHECKED BY:	G. DUTSON	DATE:	3/31/14	
APPROVED BY:	D. BOOTH			
SCALE:	AS NOTED	DATE:	03/28/14	REV.:
PROJECT NO.:	14004			
	L1			

5. DU WASTE FORM LINER LOADING CALCULATIONS

DU Drum Bearing Capacity Calculations

31-Mar-14

Bearing Weight Limit **3000** psf

Find the bearing pressure of a DU drum weight in Double Stack DU Drum Configuration to verify compliance with the 3,000 psf allowable bearing pressure.

Details of DU Drum(s):

Assume DU Drum is 12' long x 4' diameter, made of 3/8" thick steel: assume cylinder weight of 2500 lbs.

Assuming the the particle density of U3O8 is 8.3 g/cm3 (Wikipedia 2014) from the Interrogatory:

Waste weight: 8.3 gm/cm3 = 518.086 lb/cf

Assume a drum placed in the lower tier and center of the area supports the weight of 1/2 of two upper tier drums: so calculate the bearing capacity using the weight of two 100% filled drums.

Size of Drum:	Length (ft)	Diameter (ft)	Volume (cf)	Area (sf)	Weight (lbs)
Maximum DU Drum total waste weight (doubled)	12.0	4.0	150.7	48.00	158,672

Soil Cover:	Thickness	Unit Weight
Soil Protective Cover	1 feet	125 pcf

Calculations:

Use Westergaard Theory (Fig. 8.26) to determine loading at level of Clay Liner. Center controls.

m value	2.00
n value	6.00
I-sigma value from Fig 8.26	0.193

Bearing Pressure of Component:	2,677 psf < 3,000 psf allowable
---------------------------------------	-------------------------------------------

Assumptions:

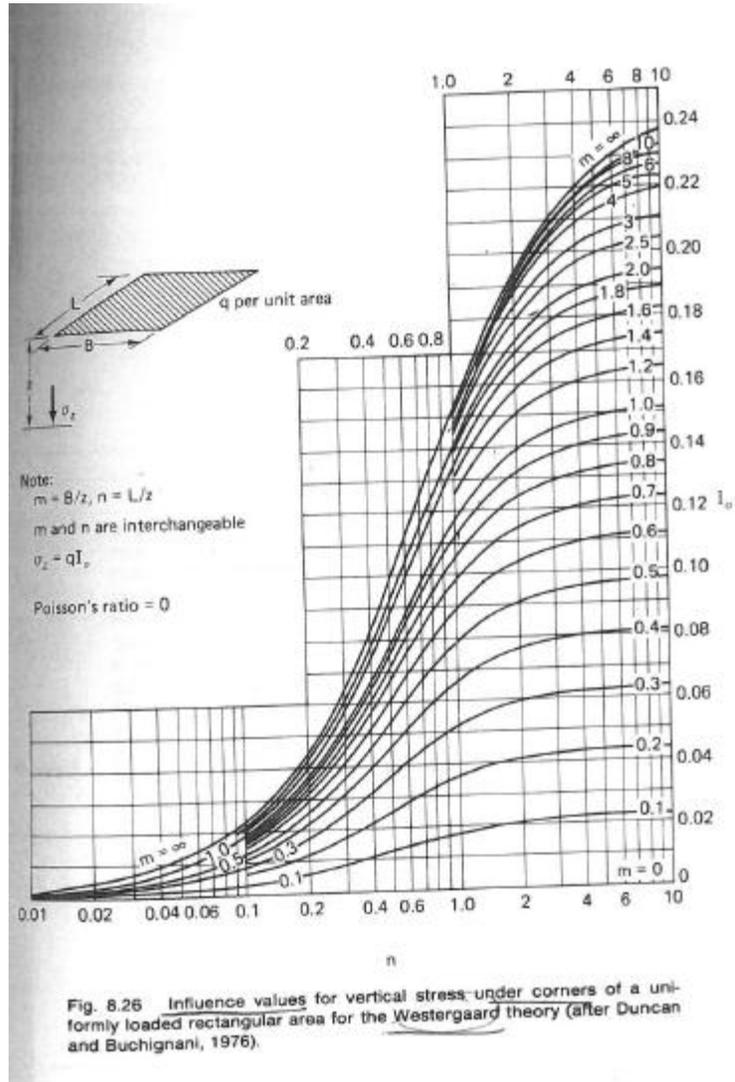
Assume worst case scenario: Drums in double stack orientation at base of Federal Cell over one foot of protective cover over clay liner.

Single Drum orientation will impart a lower bearing pressure to the clay liner than will the double stack orientation.

weight of drum			
density of DU	8.3 gm/cm3	518.086 pcf	
weight of drum		78085.922 lbs	
assume 2500 lbs cylinders...	100% full... du... wt cylinder...		
1/4 thick steel...	10.2 psf		
3/8 thick steel	15.38 psf		

engineeringtoolbox.com

2:1 try spread value...
one on one....



APPENDIX D

Responses to March 27, 2014 Round 2 Interrogatories



**RML UT2300249 – CONDITION 35
COMPLIANCE REPORT
RESPONSES TO ROUND 2
INTERROGATORIES**

JUNE 18, 2014





**RESPONSES TO MAY 27, 2014 – ROUND 2 INTERROGATORIES
UTAH LLRW DISPOSAL LICENSE RML UT 2300249
CONDITION 35 COMPLIANCE REPORT**

June 18, 2014

**For
Utah Division of Radiation Control
195 North 1950 West
Salt Lake City, UT 84114-4850**

**EnergySolutions, LLC
423 West 300 South, Suite 200
Salt Lake City, UT 84101**

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1. INTRODUCTION

EnergySolutions, headquartered in Salt Lake City, Utah is a worldwide leader in the safe recycling, processing and disposal of nuclear material, providing innovations and technologies to the U.S. Department of Energy (DOE), commercial utilities, and medical and research facilities. At its Clive Facility, located 75 highway miles west of Salt Lake City, EnergySolutions operates a commercial treatment, storage and disposal facility for Class A low-level radioactive waste and Class A low-level mixed waste.

Historically, EnergySolutions' authorization for disposal of depleted uranium (DU) was approved by the Utah Division of Radiation Control at a concentration of 110,000 pCi/g beginning with License amendment 2 of Utah Radioactive Material License UT2300249, (approved December 3, 1990). This concentration was later increased to the specific activity of depleted uranium; i.e., pure form; with approval of the Performance Assessment submitted in support of the October 22, 1998 License renewal (limiting the depleted uranium within a container to no greater than 370,000 pCi/g, upon receipt). Under this License authorization, approximately 18,400 Ci of depleted uranium were safely disposed at Clive between 1990 and 2010.

In 2010, the Utah Radiation Control Board initiated rulemaking to require a site-specific analysis before authorizing the disposal of additional large quantities of depleted uranium. This rulemaking also applies to 3,577 metric tons (5,408 drums) of uranium trioxide (DUO₃) waste received by EnergySolutions from the Savannah River Site (SRS) in December 2009. In compliance with the depleted uranium Performance Assessment prerequisite, EnergySolutions is temporarily holding these drums in storage (awaiting Director approval of this depleted uranium Performance Assessment). In the future, EnergySolutions is also considering disposal of significant quantities of depleted uranium from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky.

As is illustrated in Figure 1-1, EnergySolutions is evaluating a new Federal Cell, using an evapotranspirative cover design, as the ultimate destination for significant quantities of depleted uranium. As initially submitted in 2009, the Federal Cell was named the "Class A South" cell, with a revised application and completeness review response package dated June 9, 2009 (EnergySolutions, 2009). EnergySolutions' records show that the Division indicated interrogatories on this design were under preparation, but not received prior to its withdrawal on May 2, 2011. The former Class A South cell included a clay isolation barrier as well as a proposed system for monitoring groundwater beneath this barrier; in order to differentiate the source of any potential groundwater contamination as being from Class A or 11e.(2) wastes. The former Class A South cell design was subjected to these additional buffer zone and monitoring requirements due to long-term stewardship being split between the State of Utah and DOE. The Federal Cell will be entirely within DOE stewardship and be physically and hydrologically separate from EnergySolutions' Class A West embankment; therefore, the additional requirements will not apply.



Figure 1-1, EnergySolutions' Proposed Federal Cell Location

On June 1, 2011, (in compliance with Condition 35.B of its Radioactive Material License UT2300249), EnergySolutions submitted to the Division the Report, “*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*,” documenting the depleted uranium Performance Assessment. In response, EnergySolutions received on October 25, 2013 from the Utah Department of Environmental Quality “*Task 1: Preliminary Completeness Review*.” Following examination of the Preliminary Completeness Review, EnergySolutions submitted revision 1 of its depleted uranium Performance Assessment Report titled, “*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*,” (EnergySolutions, 2013a).

On February 28, 2014, EnergySolutions received Round 1 Interrogatories from the Division, requesting clarification and additional information to support the Division’s continued review of EnergySolutions’ depleted uranium Performance Assessment. As a result of ongoing research EnergySolutions has conducted regarding cover design and in review of the Round 1 Interrogatories, EnergySolutions revised the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. As a result, EnergySolutions created version 1.2 of its depleted uranium Performance Assessment GoldSim model. In parallel to constructing the revised GoldSim model to address the performance of the evapotranspirative cover, EnergySolutions submitted responses on March 31, 2014 to the Round 1 Interrogatories. Version 1.199 of the depleted uranium Performance Assessment GoldSim model was provided to DEQ reviewers on May 2, 2014 with an update to version 1.2 provided on May 15, 2014.

On May 27, 2014, EnergySolutions received Round 2 Interrogatories from the Division, requesting additional clarification from some of the responses provided to the Round 1 Interrogatories. EnergySolutions has prepared responses contained herein to the Round 2 Interrogatories.

In order to facilitate public access during the public review and comment period, EnergySolutions will provide the Division with a complete, self-contained Report with the final revised GoldSim model, responses to Preliminary Completeness Review, and responses to the Division’s other rounds of Interrogatories.

2. RESPONSES TO MAY 27, 2014 - ROUND 2 INTERROGATORIES

Responses to the Division’s Round 2 Interrogatories, requesting clarification and additional information to support the Division’s continued review of EnergySolutions’ depleted uranium Performance Assessment, are presented herein. As part of the review and response preparation for the Round 1 Interrogatories, EnergySolutions has revised the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. Refer to drawing series 14004, attached. In parallel to revising the GoldSim model to address performance of the evapotranspirative cover, EnergySolutions responds herein to the Round 2 Interrogatories of May 27, 2014.

1. INTERROGATORY CR R313-25-19-01/1: INTERGENERATIONAL CONSEQUENCES

Round 1 Interrogatory Response is satisfactory.

2. INTERROGATORY CR R313-25-8(5)(A)-02/1: DEEP TIME

Round 1 Interrogatory Response is satisfactory.

3. INTERROGATORY CR R313-25-8(5)(A)-03/2: DEEP TIME – SEDIMENT AND LAKE CONCENTRATIONS

In response to the request to explain why FRV1 does not provide any health or environmental concentration limits for future lake water or sediments for comparison, ES stated that: “The purpose of the deep time analysis is to provide a ‘qualitative analysis with simulations.’ Although the intent of this requirement could be debated, calculating doses in deep time is neither required nor informative.” We agree that calculating doses is not required by the current regulations. Nonetheless, we feel that once concentrations are provided (either in the water or sediment or both), those concentrations will be converted into doses (if not by ES, then perhaps by the Utah Department of Environmental Quality (DEQ) or by a third party). Additionally, in order to provide perspective, it is difficult to envision a “qualitative analysis” that does not compare the deep time concentrations provided by ES to some metric (e.g., a similar regulation, background concentrations, occupational exposures). If ES declines to provide the “metric,” then in order to support the conclusions of the ES “qualitative analysis,” DEQ will define it.

In response to the request to resolve discrepancies in concentration values, ES states that it will make corrections as indicated and that these revisions will be available with the next version of the GoldSim model for the DU PA. We look forward to reviewing the revised report.

In response to the request to provide a basis for presenting only the U-238 sediment concentrations, as well as the basis for concluding that these concentrations are small, ES stated that it will include information on other radionuclides in the revised PA. Any determination of the adequacy of the ES response will await a review of that submittal.

In response to the request to indicate why the soil criteria in 40 CFR Part 192 should not apply to the deep time assessment, the explanation by ES does not recognize a similar regulatory concentration (15 pCi/g Ra-226) for a radioactive materials license exemption under R313-19-13(2)(a)(i)(B). Similar to 40 CFR Part 192, this state rule is designed to protect the public from the adverse health effects of radon exposure. As stated above, if ES declines to compare the deep time concentrations to some “metric,” then DEQ will perform that comparison, and the 15 pCi/g Ra-226 “metric” will be used in the “qualitative analysis.”

EnergySolutions’ Response: EnergySolutions appreciates the Division’s warning that “*once concentrations are provided (either in the water or sediment or both), those concentrations will be converted into doses . . . by the Utah Department of Environmental Quality . . .*” However, while academically interesting, such exercises diametrically oppose NRC guidance,

“Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]” [emphasis added] (NUREG-1573, pg. 3-10)

As such, it is appropriate to assume zero exposures or resulting doses for any scenario including “*major changes in climate*” or “*rise in sea level.*” Therefore, dose should NOT be converted from resulting concentrations as a result of any qualitative assessment of the fate and transport of depleted uranium resulting from “*changes in climate*”, “*glaciations*”, or “*interglacial rise in sea level that occur in response to changes in global climate.*” By doing so, the Division invalidates the express purpose for the qualitative deep time evaluation.

4. INTERROGATORY CR R313-25-8(4)-04/1: REFERENCES

Round 1 Interrogatory Response is satisfactory.

5. INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER

In addition to the regulatory requirements listed above, note also that NRC's NUREG-1573, Appendix D, page D-1 (section D-2, item 1), states that: "The use of Probabilistic Risk Assessment (PRA) technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data and in a manner that complements NRC's deterministic approach and supports NRC's traditional defense-in-depth philosophy."

The radon barrier sensitivity analysis that ES has performed only evaluates the sensitivity of infiltration rates to changes in radon barrier integrity. This exercise involved holding the hydraulic conductivity (K) values of all soil materials overlying the radon barrier constant at proposed as-built values, and changing the hydraulic conductivity values of the upper and lower radon barriers. Due to the high evapotranspiration rates and low permeability of the soils overlying the radon barriers, the infiltration rates were shown to be insensitive to the permeability of the radon barriers. Although this analysis provides some insight into the behavior of the system under static conditions, the analysis needs to be extended to more realistic future conditions. As described in NUREG/CR-7028 (Benson et al. 2011), cover-system soils that are in service degrade over a period of several years because of a number of natural degradative processes, and the hydraulic conductivity values of these soils tend to rise to those found in a specific, identified range. Depending on the as-built hydraulic conductivity of the soils when the embankment is constructed, the in-service hydraulic conductivity values several years later typically range from one to three orders of magnitude greater than the as-built values.

The Utah Division of Radiation Control (DRC) has asked ES to adjust the hydraulic conductivity and van Genuchten alpha values of all shallow soil materials overlying the radon barrier to values within the range recommended by NUREG/CR-7028 or values correlated with this range. DRC provided ES with a possible log-alpha/log-Ks correlation, based on U.S. Nuclear Regulatory Commission (NRC) values in Table 6.1 of NUREG/CR-6346 (NRC 1996). The log-alpha/log-Ks correlation was $\log(\alpha) = 0.42 \cdot \log(Ks) - 1.8853$. The R2 value for this equation was 0.91. ES has not reported on the results of this experiment, conducted several weeks ago, except to mention to John Hultquist (manager of the DRC License Section) in a conversation (based on his verbal report to DRC staff) that ES performed the exercise but did not accept the results. A simple equation relating alpha to Ks is also provided by Guarracino (2007). He shows, using a well-known soil database, that a strong correlation exists between

van Genuchten alpha values and hydraulic conductivities for the soil classes in this database, and he provides the theoretical basis for this correlation.

It has been demonstrated very effectively in NUREG/CR-7028 that, based on some of the largest studies ever undertaken to date of alternative cover systems, representing many years of careful research, the hydraulic conductivities of nearly all cover-system shallow soil materials of low to moderate as-built hydraulic conductivity tested have dramatically increased over the as-built values within several years after emplacement in an actual cover system. A number of processes are believed to be responsible for this. NUREG/CR-7028 unequivocally states that, for these relatively shallow soils, “saturated hydraulic conductivity of earthen barrier and storage layers will increase over time....” Often, increases reported are of two or three orders of magnitude.

Relatively few studies have been conducted on long-term performance of cover systems for containment facilities. NUREG/CR-7028 states that “The most comprehensive of these studies is the Alternative Cover Assessment Program (ACAP), which evaluated the performance of 27 different final cover profiles at 12 locations in 8 states in the US (Albright et al. 2004).” This is the focus of much of NUREG/CR-7028, although considerable additional information is also referenced through the 112 different citations in the text and the corresponding 112 references provided at the end of that document. Twenty-seven test sections were exhumed at the ACAP sites, providing invaluable information on cover-system soil degradation, with increases in hydraulic conductivity, over time. The study found that nearly all soils at the sites studied underwent dramatic increases in hydraulic conductivity within several years after being emplaced. As noted in NUREG/CR-7028, “Larger changes were observed for soils with lower as-built saturated hydraulic conductivity and soils with a greater proportion of clay particles in the fines fraction.”

Such a characterization appears to be applicable to the proposed upper radon-barrier clay soil at the Federal Cell, which would consist of a soil “with lower as-built saturated hydraulic conductivity,” and which includes “a greater proportion of clay particles in the fines fraction.” Lesser fractional changes would be expected for other coarser textured soils in the cover system, such as the more-shallow soils mentioned previously, but it is important that changes in hydraulic conductivity and alpha values of these soils should still be considered.

NUREG/CR-7028 speaks of as-built hydraulic conductivity (K_{sa}) of each studied soil layer and compares it with the in-service hydraulic conductivity (K_{si}) years after cover construction. It reports that “for sites with lower K_{sa} , the in-service hydraulic conductivity can be more than 10,000 times higher than K_{sa} .” Figure 6.8 from NUREG/CR-7028 below shows some of these changes:

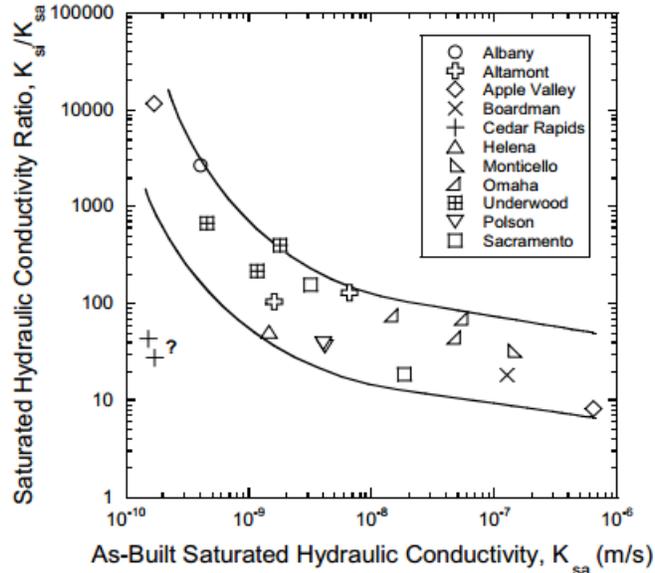


Figure 6.8 from NUREG/CR-7028 (Benson et al. 2011)

This graph shows the ratio of in-service to as-built hydraulic conductivity values for a number of important alternative cover system sites. The ratio is plotted against as-built hydraulic conductivity, expressed in meters per second (m/s) (not centimeters per second (cm/s)). The upper radon barrier, with a relatively small as-built hydraulic conductivity of 5×10^{-10} m/s (equivalent to 5×10^{-8} cm/s), can thus be expected to have an in-service hydraulic conductivity value in the range of 100 to 1,800 times as great as the as-built value. Even soils with small to moderate as-built hydraulic conductivity values increased in hydraulic conductivity value while in service, by, on average, one to two orders of magnitude. NUREG/CR-7028 found that these increases in hydraulic conductivity, as carefully measured using field tests, occurred for all soils found within about 10 feet of the ground surface.

NUREG/CR-7028 found that “the saturated hydraulic conductivity of in-service storage and barrier layers that were evaluated is sensitive to scale. Saturated hydraulic conductivities determined from testing conventional small-scale specimens (< 76-mm diameter) in the laboratory are appreciably lower (more than 1000x in some cases) than the actual field hydraulic conductivity.” This is significant because the hydraulic conductivities assumed in the PA model are based on testing in a laboratory setting of conventional small-scale soil specimens (core samples), the hydraulic conductivities of which may be orders of magnitude smaller than actual field-scale hydraulic conductivities.

ES also stated that the “compromised radon barrier need not be modeled at this time because the ET Cover design will limit infiltration down to the radon barrier.

With no infiltration down to that level, the naturalization of the radon barrier will have no effect on performance.” However, once the K values in the soil units overlying the radon barriers are changed, the infiltration rates may be found to be sensitive to the K of the radon barriers.

Furthermore, the demonstration of the long term integrity of the radon barrier/cover system is particularly important since the cover design does not have the multiple independent and redundant layers of defense to compensate for potential human and mechanical failures that are typical of NRC’s defense-in-depth strategy.

In summary:

The ES response began by referring to two documents (*EnergySolutions* 2013b and *EnergySolutions* 2014), which obviously were not included in FRV1. ES needs to integrate the information from these two documents into the revised report. Then DRC can review and comment on how that information is being used in the DU PA.

The ES response indicates that the evapotranspirative (ET) cover would reduce infiltration by two orders of magnitude compared with the rock armor mulch cover. The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers, 2014), does not support this statement. The original mean infiltration rate (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas with the ET cover the rate is about 0.04 cm/yr—reduced by only a factor of three.

The ES response indicates that the ET cover design will limit infiltration down to the radon barrier. However, the response does not address what impact (if any) burrowing animals, plant roots, gullies, and similar mechanisms would have on the radon diffusion upwards to the surface.

Finally, in its response ES described the cover performance modeling that is required. DRC looks forward to receiving and reviewing this refined modeling effort.

EnergySolutions’ Response: (1) The proposed ET cover was designed to mimic local, native ecosystems (SWCA, 2013). Beginning at the top of the cover the layers above the waste used for the ET cover design are:

- Surface layer: This layer is composed of native vegetated Unit 4 material with 15 percent gravel mixture on the top slope and 50 percent gravel mixture for the side slope. This layer is 6 inches thick.

- Evaporative Zone layer: This layer is composed of Unit 4 material. The thickness of this layer is 12 inches.
- Frost Protection Layer: This material ranges in size from 16 inches to clay size particles. This layer is 18 inches thick. The purpose of this layer is to protect layers below from freeze/thaw cycles, wetting/drying cycles, and inhibit plant, animal, or human intrusion.
- Upper Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.
- Lower Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.

The upper layers of silty clay provide storage for water accumulating from precipitation events, enhance losses due to evaporation, and provide a rooting zone for plants that will further decrease the water available for downward movement. The upper layers duplicate site soil depths observed in association with the target vegetation community and have the same properties as the native soils on and near the Clive site that are associated with the vegetation community planned for the cover (SWCA, 2013). The frost-protection layer is the primary biointrusion barrier proposed for the cover. This layer consists of a 10–16 inches (25–41 cm) gravel and cobble mixture in-filled with small gravel, sand, and other fines (cobble and gravel to 16 inches diameter). SWCA (2013) describes the functioning of this layer to prevent biointrusion by using,

“1) large- and medium-sized cobble that is large enough that it cannot be moved by small animals; 2) pore sizes that cannot be circumvented by small animals; and 3) gravel and fines-filled interspaces that are a further deterrent to small burrowing animals.”

The frost protection layer material provides a barrier of cobbles that are much larger than the prey species but with pore sizes between the cobbles that are too small for these species to penetrate or inhabit. Many pore spaces between the cobbles will be filled with gravel and fines that have been demonstrated to be unattractive to burrowing animals (SWCA, 2013). An additional impediment to biointrusion to the radon barriers is the overlying soil layer that is deep enough to allow for some biointrusion and soil displacement to occur without impacting the lower layers (SWCA, 2013).

Another important component of effective biointrusion barriers is an overlying soil layer that is sufficiently deep to allow for some burrowing and soil displacement without compromising underlying layers. Additional factors influencing the extent of burrowing are the proposed ET cover vegetation composition and low shrub densities that will act to limit densities of small mammals and thus limit predator foraging (SWCA, 2013).

Based on site-specific observations and documented demonstrated practice SWCA (2013) concludes that,

“It is not expected that the biointrusion prevention mechanisms included in the cover design will eliminate all biointrusion into lower soil layers or the frost protection zone, but that these measures will minimize any biointrusion to an insignificant level.”

Site-specific observations of soil disturbance due to natural vegetation and demonstrated practices for minimizing disturbance were documented by SWCA (2013). Multiple soil excavations at the site demonstrated root growth behavior indicating that roots would tend to accumulate in locations to take advantage of available water rather than penetrate the radon barrier clay. These excavations showed that greasewood tap roots and other biotic activity such as fine roots and tunnels did not extend below the compacted clay layer at 24 inches. Rather, both taproots and fine roots were found to extend laterally along the upper surface of the compacted clay layer, likely making use of any water that is perched above the clay (SWCA, 2013). The impact of natural vegetation disturbance at the site was summarized by SWCA (2013).

“The potential natural vegetation that will develop on the ET cover will not result in significant levels of soil disturbance in upper soil layers, or penetration of compacted clay layers due to the presence of multiple inhibitory layers (cobble, capillary barriers) that physically prevent root growth, or direct root growth laterally toward available water below the frost protection zone rather than vertically into clay barriers.”

The effect of burrowing ants is not expected to have a large influence on transport because ant nests are not expected to penetrate to the waste layer, which is about 5m or more below ground surface for the disposal configurations considered. This is based on site-specific investigations indicating most ant burrowing will occur in the upper layers of the cover and be minimal below a depth of 42 inches (SWCA, 2013).

(2) The two order of magnitude reduction in infiltration between the rock armor cover and the ET cover described in the Rebuttal relates to a comparison using single, deterministic values for the hydraulic model parameters. Version 1.2 of the Model represents an enhanced assessment of the performance of the store and release layers in the upper part of the cover and the radon barriers. This assessment was provided in addition to the biological surveys described above that indicated insignificant disturbance of the cover due to plant and animal intrusion.

A statistical experimental design was developed to provide net infiltration and water content results using the variably saturated flow and transport model HYDRUS. The purpose of the experimental design was to capture the effect of variable hydraulic properties on water balance parameters for abstraction into version 1.2 of the Model.

The Rebuttal comments on hydraulic properties are closely linked to the Benson et al. (2011) report published by the NRC (NUREG/CR-7028). This report provides recommendations for ranges of hydraulic parameters that may be used to represent in-service conditions of store-and-release and barrier layers in covers. While this is a useful report, the topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources.

The Surface and Evaporative Zone layers in the Clive ET cover system correspond to store-and-release layers. For the infiltration modeling, values of the van Genuchten parameter alpha for these two layers were drawn from a statistical distribution with a mean of 0.016 1/cm. The value for alpha recommended for in-service layers by Benson et al. (2011, p. 10-4) is 0.2 1/kPa which corresponds to a value of 0.02 1/cm, similar to the mean used for the infiltration simulations. The distribution used for the van Genuchten n parameter for the HYDRUS simulations had a mean of 1.32. The value for n recommended for in-service layers by Benson et al. (2011, p. 10-4) is 1.3. A single value 4.46 cm/day based on site-specific measurement was used in the experimental design for the saturated hydraulic conductivity (Ks) of the Surface and Evaporative Zone layers. Mean values of the Ks of store-and-release layers of in-service covers are listed in Table 6.6 of Benson et al. (2011). The geometric mean of these results is 8.7×10^{-7} m/s or 7.5 cm/day. This value is less than twice the value used for the infiltration modeling.

The experimental design for the infiltration modeling used a K_s distribution developed from a minimum value of 4×10^{-3} cm/day corresponding to the design specification for the upper radon barrier (Whetstone 2007, Table 8), and 50th and 99th percentile values of 0.7 cm/day (7.5×10^{-8} m/s rounded to 8×10^{-8} m/s) and 52 cm/day (6×10^{-6} m/s), respectively, which are from a range of in-service (“naturalized”) clay barrier K_s values described by Benson et al. (2011, Section 6.4, p. 6-12). The value for K_s recommended by Benson et al (2011, p. 10-3) for modeling in-service cover layers is 5×10^{-7} m/s which is well within the distribution used for version 1.2 of the Modeling Report infiltration. Single values of α and n determined from site-specific measurements were used for the radon barrier in the infiltration modeling. A value of 0.003 1/cm was used for α and a value of 1.17 was used for n . Benson et al. (2011, p. 10-4) recommend using the result from a single measurement at a single site for α . This is a value of 0.02 1/cm. Two other values are available for sample sizes considered to be unaffected by scale for the K_s measurements (Benson et al, 2011, Table 6-9). The geometric mean of the three measurements is 0.002. A range from 1.2 to 1.4 is recommended by Benson et al. (2011) for the n parameter. The value used for the infiltration modeling is slightly below the low end of that range. More detailed descriptions of distribution development and abstraction in version 1.2 of the Model are provided in Appendix 5 - Unsaturated Zone Modeling of version 1.2 of the Modeling Report.

(3) Version 1.2 of the Model does address the impact burrowing animals, plant roots, and similar mechanisms would have on the radon diffusion upwards to the surface. Radon diffusion is given by the product of the radon concentration gradient and the effective diffusion coefficient. The effective diffusion coefficient is a function of the air-filled porosity, increasing with increasing porosity. The model for the volumetric water content of the radon barriers developed from the HYDRUS simulations and used in version 1.2 of the Model is

$$\theta = 0.3 - 0.00361 K_s + 0.314 \alpha - 0.013 n$$

where

- θ is the volumetric water content [-]
- K_s is the saturated hydraulic conductivity [cm/day]
- α is a van Genuchten hydraulic model parameter [1/cm] for the Surface and Evaporative Zone layers
- n is a van Genuchten hydraulic model parameter [-] for the Surface and Evaporative Zone layers.

As an example consider using mean values from the distributions for α and n of 0.016 1/cm and 1.32 for the Surface and Evaporative Zone layers and calculating the air-filled porosity for K_s values of 4×10^{-3} cm/day (4.6×10^{-10} m/s) and 51.8 cm/day (6×10^{-6} m/s) which represent the minimum value and the 99th percentile of the distribution for K_s used in version 1.2 of the Modeling Report. The volumetric water contents for the low and high K_s values are 0.29 and 0.10 respectively. For a porosity of 0.43 the air contents for the low and high K_s values are 0.14 and 0.33 respectively.

For version 1.2 of the Model the effective diffusion coefficient is calculated as the product of the diffusion coefficient in free air and the tortuosity. The equation for tortuosity equation used in the model is

$$\tau_a = \frac{\theta_a}{\phi^{2/3}}$$

where

θ_a is the air-filled porosity
 ϕ is the total porosity.

It can be seen that the tortuosity is directly proportional to the air-filled porosity so the radon flux for a given concentration gradient will be directly proportional to the air-filled porosity. For the example above, changing the saturated hydraulic conductivity from the as-built value to an in-service value will more than double the radon flux due to diffusion.

(4) See response to item (2).

6. INTERROGATORY CR R313-25-7(2)-06/1: GULLY MODEL ASSUMPTIONS

Round 1 Interrogatory Response is satisfactory.

7. INTERROGATORY CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS

We do not agree with the ES interpretation that UAC R313-25-7(8) limits consideration of intruder scenarios to those involving known natural resources. As stated in Interrogatory CR R313-25-20-82/1: Limitation on Inadvertent Intruder Scenarios:

Section 1.3.2.2, page 1-13, of the 2013 Compliance Report, Revision 1, states the following:

“While an unlimited number of inadvertent intruder scenarios can be developed, known natural resources at the disposal site whose exploitation could result in inadvertent intrusion into the wastes after removal of active institutional control.” UAC R313-25-7(8).

DRC does not agree with this interpretation of the regulation. The full section of R313-25-7, of which R313-25-7(8) is a sub-section, describes specific technical information that the applicant must provide: “The following information is needed to determine whether or not the applicant can meet the performance objectives and the applicable technical requirements of R313-25:....” Nothing in the regulatory language suggests that DRC plans to limit intrusion scenarios to those related to the exploration and exploitation of natural resources. Certainly, if there are known natural resources, DRC will likely wish to ensure the consideration of intruder scenarios involving their exploration and exploitation. More to the point, the definition of “inadvertent intruder” does not limit the DRC Director to only considering discovery and exploitation of natural resources. Instead, as stated in UAC R313-25-2—

Inadvertent intruder means a person who may enter the disposal site after closure and engage in activities unrelated to post closure management, such as agriculture, dwelling construction, or other pursuits which could, by disturbing the site, expose individuals to radiation.

Hence, the emphasis is not only on natural resources but also on human activities and pursuits at the disposal site after facility closure.

Interrogatory CR R313-25-8(4)(b)-07/1 requested evaluation of four scenarios, one of which included surface mining of clay, sand, and gravel. We do not find in the ES response to this interrogatory any compelling arguments as to why this scenario for inadvertent human intrusion should be excluded, particularly since it involves known natural resources. Since R313-25-8(1)(a) recognizes NUREG-0782 as a fundamental supporting document for the low-level radioactive waste rules at 10 CFR Part 61, it is reasonable to expect that the PA model report should at least consider the same intrusion scenarios the NRC staff used in 1981. These include intruder construction, intruder discovery, intruder agriculture, and intruder well. If any of these are omitted from the PA analysis, ES needs to discuss and justify why they should not be included.

EnergySolutions' Response: EnergySolutions recognizes that UAC R313-25-2 defines an Inadvertent Intruder as,

“Inadvertent intruder means a person who may enter the disposal site after closure and engage in activities unrelated to post closure management, such as agriculture, dwelling construction, or other pursuits which could, by disturbing the site, expose individuals to radiation.”

While specifically defined to engage in “*activities unrelated to post closure management,*” NRC has repeatedly cautioned that this definition does not create a need to analyze every possibly-conceivable intrusion activity. To the contrary, NRC specifically,

“does NOT expect separate intruder scenario dose analyses would be included in an LLW performance assessment because 10 CFR 61.13(b) requires that analyses of the protection of individuals from inadvertent intrusion must include a demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided.” [EMPHASIS ADDED] (NUREG-1573, piii).

This is further emphasized by NRC in their very clear statement,

“The PAWG emphasizes that there should be a limit on the range of possible site conditions, processes, and events to be considered in an LLW performance assessment and that unnecessary speculation in the assessment should be eliminated. Additionally, consideration of societal changes would result in unnecessary speculation and therefore should NOT be included in a performance assessment.” [emphasis added] (NUREG-1573, pg xii)

To the contrary, NRC suggests limiting speculation,

“With respect to human behavior, it may be assumed that current local land-use practices and other human behaviors continue unchanged throughout the duration of the analysis,” (NUREG-1573, p3-11),

These basic concepts have recently been reinforced by the Commissioners in a Staff Requirements memorandum regarding the ongoing rulemaking for 10 CFR Part 61,

“...the intruder assessment should be based on intrusion scenarios that are realistic and consistent with expected activities in and around the disposal site at the time of site closure.” (SECY-13-0075)

As such, “*current local land-use practices and human behaviors*” (projected in version 1.2 of the Modeling Report include ranching, OHV, hunting, and industrial activities. “*Current local land-use practices and human behaviors*” do not include farming, residential construction, or direct ingestion of valley-produced groundwater. Because of this, in 20 years of numerous licensing actions, EnergySolutions has never been required to model groundwater ingestion inadvertent intruder scenarios unrepresentative of current practice in the Clive area.

Gravel resources are mined in the western desert to fulfill needs of Clive and other landfills, as well as the Utah Department of Transportation. Gravel sources are found in the foothills, such as those in the Grayback Hills currently being mined by EnergySolutions. No significant sources of gravel are located in the west desert valleys. Therefore, mining of gravel resources is not within “*current local land-use practices and human behaviors.*”

By contrast, clays and sands are being mined principally by landfills from west desert valley locations for local use only; i.e., as cover and fill material within the adjacent landfill. The cost of transportation plus availability of similar resources closer to urban areas in the Tooele and Salt Lake valleys limits the extent of clay and sand mining in the west desert.

Since NRC,

“does NOT expect separate intruder scenario dose analyses would be included in an LLW performance assessment because 10 CFR 61.13(b) requires that analyses of the protection of individuals from inadvertent intrusion must include a demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided,”

the defense-in-depth offered by the engineered cover, height of the Federal Cell (discouraging cost to excavate down additional associated depths), and volume of material between the Federal Cell cover and the depleted uranium, it is extremely unlikely that any clay and sand mining would commence directly on top of the Federal Cell (40 feet above ground surface).

Since current local practices for the area surrounding Clive that share similar groundwater characteristics and yields do not include groundwater drinking wells, application of the 4 mrem/year limit promulgated in UAC R313-25-20 is inappropriate and counter to NRC guidance.

However, EnergySolutions recognizes occasional regional pumping of water from the deeper confined aquifer (which is still considered a Class IV aquifer) for industrial uses (such as dust suppression). See the response to Interrogatory CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS for the analysis of an inadvertent industrial intruder well scenario.

See also responses to Interrogatories CR R313-25-8(5)(A)-29/2: LIMITATION TO CURRENT CONDITIONS OF SOCIETY AND THE ENVIRONMENT, CR R313-25-8(5)(A)-38/2: FIGURES 5 AND 11 IN FRV1, CR R313-25-20-82/2: LIMITATION ON INADVERTENT INTRUDER SCENARIOS, CR R313-25-20-83/2: INTRUDER-DRILLER AND NATURAL RESOURCE EXPLORATION SCENARIOS, CR R313-25-20-92/2: INADVERTENT INTRUDER DOSE STANDARD AND SCENARIOS, CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water, CR R313-25-8(4)(a)-105/2: Human Use of Groundwater, CR R313-25-8(4)(a)-106/2: Desalination Potential, CR R313-25-19-135/2: EXPOSURE TO GROUNDWATER, CR R313-25-8(5)(a)-163/2: Groundwater Compliance for 10,000 Years, CR R313-25-20-172/2: INADVERTENT INTRUDER PROTECTION, CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD, and CR R313-25-19-182/2: Groundwater Exposure Pathways.

8. INTERROGATORY CR R313-25-8(4)(A)-08/1: GROUNDWATER CONCENTRATION ENDPOINTS

Round 1 Interrogatory Response is satisfactory.

9. INTERROGATORY CR R313-25-19-09/1: DEFINITION OF ALARA

Round 1 Interrogatory Response is satisfactory.

10. INTERROGATORY CR R313-22-32(2)-10/2: EFFECT OF BIOLOGICALS ON RADIONUCLIDE TRANSPORT

The interrogatory had asked ES to support its statement that the effect of plants, ants, and burrowing mammals on radionuclide transport might be small. The response instead discussed how the effects related to such transport would decline as distance from the ground surface increases. However, this response does not satisfy the interrogatory with regard to how the effect of plants, ants, and burrowing mammals on radionuclide transport itself was determined to be small.

EnergySolutions' Response: Section 4.1.2.8 will be revised to delete the phrase “the severity of their effect on radionuclides transport might be small.” The revised text will read:

“Based upon the rooting profiles of the site flora and burrowing characteristics of site fauna, impacts from biota will be limited to the top several meters. As discussed in the Biological Modeling white paper (Appendix 9), burrowing profiles of mammals and ants are expected to occur within the top 2.2 meters. Rooting of grasses, forbs and shrubs (other than greasewood) currently found on site occur primarily in the top 1.5 meters. SWCA (2013) found that both taproots and fine roots of plants at the site tended to spread laterally across the top of the compacted clay layer present approximately 60 cm below ground surface at the site. Greasewood may extend taproots as deep as 5.7 meters, though the bulk of the root biomass remains in the upper layers. Details for all three categories can be found in the Biological Modeling white paper (Appendix 9).”

11. INTERROGATORY CR R313-25-20-11/1: INADVERTENT HUMAN INTRUDER

Interrogatory Response will be evaluated after resolution of Interrogatory CR R313-25-8(4)(B)-07/2: Applicability of NRC Human Intrusion Scenarios.

EnergySolutions' Response: See the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

12. INTERROGATORY CR R313-25-20-12/2: SELECTION OF INTRUSION SCENARIOS

Although correct, the statement above does not address the main point of the interrogatory, namely that several inadvertent intruder scenarios should be considered, similar to the need to consider surface mining of clay, sand, and gravel, as mentioned in the comments on Interrogatory CR R313-25-8(4)(b)-07/1: Applicability of NRC Human Intrusion Scenarios. ES should also address the remaining scenarios or explain and justify why they are not relevant.

EnergySolutions' Response: See the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

13. INTERROGATORY CR R313-25-7-13/1: REFERENCE FOR LONG-TERM CLIMATIC CYCLES

Round 1 Interrogatory Response is satisfactory.

14. INTERROGATORY CR R313-25-8(4)(D)-14/2: SEDIMENT MIXING

ES did not address the situation in which sediments from the first lake are not yet covered and mixed with sediments from the second lake. During the teleconference on April 9, 2014, ES committed to evaluate a deep time scenario in which in situ DU waste is not scoured by pluvial lake wave action and is left at or near the ground surface after the lake recedes, which should address this concern. We await the results of that evaluation. For subsequent lakes, complete mixing ensures that the DU would be near the ground surface, rather than buried beneath a layer of newly deposited sediment.

EnergySolutions' Response: EnergySolutions recognizes that the Division is of the opinion that the Burmester and Knolls cores are not sufficiently representative of the Clive area. In an interview conducted to evaluate this concern, Jack Oviatt (2014b) made the following observations:

1. For the types of information considered so far (sedimentation rate per 100ky), Oviatt thinks that the Knolls and Burmester cores are sufficiently representative (so long as the cores are in the same basins), of what is expected for Lake Bonneville or any other deep lake that would cover Clive. Under these conditions, Oviatt (2014b) considers that the deposition patterns would be similar (confirming EnergySolutions' claims). However, Oviatt (2014b) does acknowledge that some differences may be observable, if further detailed information about specific biology or chemistry were sought. However, since the Deep Time sub-model is a high level qualitative model, a less-detailed level of information is sufficient.
2. In preparation of responses to Round 2 interrogatories and Oviatt (2014b), EnergySolutions has recognized that the concentration of approximately 1,500 pCi/g U-238 reported in Deep Time sediment is a typographical error and should be reported as 770 pCi/g. This typographical error will be corrected in the ultimate comprehensive deliverable. As a reminder, even though EnergySolutions commits to only disposing of depleted uranium below grade, version 1.2 of the Model disperses all of the waste at the time the overburden material is obliterated (as an overly conservative assumption). When more representative assumptions are modeled, sediment concentrations closer to background are projected.
3. In further assessment of the Burmester and Knolls cores, Oviatt (2014b) also compared the pit wall to the Knolls core. Both the pit wall and the Knolls core date back to approximately 150ky. However, the Knolls core is actually deeper than the pit wall. Like the Burmester and Wendover cores, the Knolls core currently resides at the University of Utah. Although these cores are old (1960s) they still exist and provide information to further inform this Model.

Oviatt (2014b) cautions, though, that information is quite “old” and was not originally developed to support this model.

4. One other issue Oviatt (2014b) addresses is the impact on grade elevation of the aerial deposition rates. While not specifically included in version 1.2 of the Model, such an effect would provide additional stabilization at the Clive site.

See also the response to Interrogatory CR R313-25-8(5)(A)-86/2:
CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL.

15. INTERROGATORY CR R317-6-6.3(Q)-15/2: URANIUM CHEMICAL TOXICITY

As discussed in several interrogatories (e.g., Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water), ES has not provided convincing evidence that ingestion of groundwater is not a potential exposure pathway. Consequently, ES needs to provide a revised response to this interrogatory.

EnergySolutions’ Response: See the response to Interrogatory CR R313-25-19-182/2: Groundwater Exposure Pathways.

16. INTERROGATORY CR R313-25-8(4)(A)-16/2: RADON PRODUCTION AND BURROWING ANIMALS

Round 1 Interrogatory Response is satisfactory.

17. INTERROGATORY CR R317-6-6.3(Q)-17/1: URANIUM PARENTS

Round 1 Interrogatory Response is satisfactory.

18. INTERROGATORY CR R313-25-8(5)(A)-18/2: SEDIMENT ACCUMULATION

ES stated: “However, recent research suggests that it is unlikely that a lake will inundate Clive in the current 100ky glacial cycle.” As stated with regard to Interrogatory CR R313-25-8(4)(d)-122/2: Size of Pluvial Lakes, ES must consider climatic change intervals that are localized to the Great Basin and not rely on global cycles. Inundation of the Clive site (at an elevation of about 4,270 feet or about 70 feet above the level of the modern Great Salt Lake) could occur as a result of a “small” or “intermediate” lake forming during one of these shorter term climate cycles. This has been discussed in other interrogatories. For example, in response to Interrogatory CR R313-25-8(5)(a)-44/1: Occurrence of Intermediate Lakes, ES indicated that it will add the statement that: “Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive....”

ES also stated that: “Aeolian sedimentation rates at Clive are expected to be between 0.1 and 3 mm/yr during the current inter-pluvial period based on analogue measurements at dry pluvial lake sites throughout the world and in the arid SW United States.” However, ES did not provide a reference for this statement, which appears to be flawed. If these accumulation rates were correct, the entire Great Basin would now be covered by an average of 1 to 3 meters of Aeolian sediment that has been accumulating since the onset of the Holocene, masking significant areas of bedrock, shorelines, and other subtle geomorphic features. Aeolian material almost certainly forms the substrate for desert soils in this part of the world, but this mantling material has thicknesses of tens of centimeters, not meters. Many places of the Great Basin have no mantling Aeolian material whatsoever.

Cursory efforts located the following summary table indicating Aeolian accumulation rates about one order of magnitude lower than that indicated in ES’ response. The data do not appear to support the idea that the ES site will be covered by a thick layer of dust before the onset of the next shallow lake cycle.

Table 9.1 Annual dust deposition rates on land (after Middleton, 1997 and Goudie, 1995)

References	Location	Deposition rate	
		(t km ⁻² a ⁻¹)	(mm 1000 a ⁻¹) ^a
<i>Sahara</i>			
Mediterranean region			
Löye-Pilot <i>et al.</i> (1986)	Corsica	14	16
Yaalon and Ganor (1975)	Israel	22–83	25–93
Goossens (1995)	Negev	15–30	10–20
Bücher and Lucas (1975)	Pyrenees	18–23	20–26
Pye (1992)	Crete	10–100	11–112
Harmattan plume			
Maley (1980)	S Chad	109	122
McTainsh and Walker (1982)	N Nigeria	137–181	154–203
Drees <i>et al.</i> (1993)	SW Niger	200	100–150
<i>USA</i>			
Smith <i>et al.</i> (1970)	High Plains	65–85	73–96
Péwé <i>et al.</i> (1981)	Arizona	54	61
Gile and Grossman (1979)	New Mexico	9.3–125.8	10–141
Muhs (1983)	California	24–31	27–35
Reheis and Kihl (1995)	California/Nevada	4.3–15.7	5–18
<i>Middle East</i>			
Safar (1985)	Kuwait	100	112
Behairy <i>et al.</i> (1985)	W Saudi Arabia	13–109	15–122
<i>Miscellaneous</i>			
Inoue and Naruse (1991)	Japan	3.5–6	4–7
Tiller <i>et al.</i> (1987)	SE Australia	5–10	6–11
Kukal (1971)	Caspian Sea	39.5	44

^a Calculated on bulk density of dust of 0.89 g cm³ where not derived in original reference.

Source: Goudie *et al.* 1997.

EnergySolutions’ Response: The text in Appendix 13 – Deep Time Assessment from the version 1.2 Modeling Report has been extensively revised, with many clarifications added. The “*deep*”, “*intermediate*”, and “*small*” lake classifications are simply defined for convenience in the heuristic deep time model.

EnergySolutions has revised the following statement in Section 3.3 of Appendix 13:

“For modeling purposes, a distinction is made between shallow, intermediate and large lakes. Large lakes are assumed to be similar to Lake Bonneville, and occur no more than once per 100 ky glacial cycle (assumption of the heuristic model approach). Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large (or deep) enough that carbonate sedimentation is the dominant mode of lake deposition. The Bonneville and Provo shorelines of Lake Bonneville are examples of large lakes; the transgressive and

regressive phases of the Bonneville and Provo shoreline lakes represent intermediate lakes during the transient phases of the lakes where they exceeded the elevation of the Clive site and sedimentation was dominated by clastic deposition associated with wave activity and reworking of lake sediments (see Table 2 for the chronology of the lake cycles). Shallow lakes are assumed to exist at all other times. The current Great Salt Lake is an example as is the reinterpreted Gilbert shoreline lake (Oviatt, 2014a) that has now been shown to have not reached the elevation of the Clive site (contrast with Currey et al. 1984). For the purpose of modeling, the specific depths of small, intermediate and large lakes are not important in the Deep Time Model. Under current climate conditions, it is assumed that intermediate lakes will not occur (only small lakes). Under future climate conditions, some glacial cycles will produce a large lake in the Bonneville Basin, and intermediate lakes will occur during the transgressive and regressive phases of a large lake, or during glacial cycles that do not exhibit a large lake. The approximate timing of the return of the first intermediate lake is relatively important in the Deep Time Model, because it is assumed that the Clive waste disposal site is destroyed upon the occurrence of the first intermediate lake,”

Thus, by definition, “large” lakes (e.g., Bonneville, Provo) will cover the Clive site; “intermediate” lakes are lakes that reach and exceed the altitude of Clive, but are not large or deep) enough that carbonate sedimentation is the dominant mode of lake deposition; and smaller lakes will not reach the elevation of the Clive site at all. A small lake, by definition, is not of concern with regard to stability or sedimentation germane to the Clive site.

The Rebuttal text quoting an EnergySolutions response with aeolian sedimentation rates of 0.1 to 3 mm/year are not included in Appendix 13. Sedimentation rates for aeolian deposition were not used in the model prior to the formation of the first intermediate or deep lake; instead an assumption was made that the next lake would destroy the disposal mound. The concept of aeolian sedimentation, to the extent it occurs, was introduced as an additional defense in depth consideration.

19. INTERROGATORY CR R313-25-8(5)(A)-19/1: REFERENCE FOR SEDIMENT CORE RECORDS

Round 1 Interrogatory Response is satisfactory.

20. INTERROGATORY CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS

It is unclear why the formation of gullies that would erode through the barriers and focus surface water would result in only minor local changes in infiltration.

Furthermore, it is unclear where the PA models increased recharge (due to gully formation) to demonstrate that the groundwater concentrations do not change. The ES response also referenced doses due to the thinning cover. It may be true that the radon dose is so much higher than the potential groundwater dose (increases in groundwater concentrations are insignificant), but that does not explain why the groundwater concentrations are conceptualized so that they do not increase when the cover is compromised.

ES should provide more information to explain and reconcile these concerns.

EnergySolutions' Response: Justification for the size and number distributions for gully formation is documented in Section 5 of Appendix 10 – Erosion Modeling from version 1.2 of the Modeling Report. As stated therein,

“A random number of gullies sampled from a discrete distribution is chosen to occur, simply to evaluate the effect a variable number of gullies would have on dose. Each of these gullies is identical for a given realization, in order to keep the gully model simple. The fraction of the cover surface area that is consumed by gullies is calculated in order to determine if the quantity of erosion is physically reasonable for an intact embankment.” (Appendix 10, pg 23)

While the formation of some of the gullies may actually erode through significant depths of the evapotranspirative cover, the ratio of gully footprint to total evapotranspirative cover surface area remains minimal. As such, the overall evapotranspirative cover surface continues to perform and limit infiltration, as designed. The gullies' influences are further tempered when including the effects of the extreme depth between the bases of the deepest probable gullies to the below-grade depleted uranium waste, resulting in insignificant increases in resulting groundwater concentrations.

Under the conditions of inadvertent intruder created gullies, NRC warns that,

“Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite [that may result in subsequent exposure to members of the general public].” (NUREG-1573, pg. 3-11).

Therefore, NRC considers it inappropriate to model doses to the general public that result from the actions of an inadvertent intruder.

21. INTERROGATORY CR R313-25-8(4)(D)-21/2: INFILTRATION RATES

Previous ES infiltration modeling for the facility used the unsaturated flow model UNSAT-H to overcome such HELP model overestimation. ES should explain and justify why HYDRUS, with its variable saturation equations, could not eliminate the flux overestimation problem. Note that SC&A is currently investigating the reasonableness of the recharge rates predicted by HYDRUS.

EnergySolutions' Response: Numerous peer-reviewed studies have been conducted comparing the accuracy of the HYDRUS and HELP models under a variety of conditions. One such representative study was conducted for the U.S. Air Force to evaluate evapotranspirative landfill cover performance using a variety of hydrologic models in arid conditions (Air Force, 2004). The evaluation examined,

- Accuracy of model estimates of evapotranspiration, surface runoff, and deep percolation
- Plant parameter inputs, their use within the model, and appropriateness for the design problem
- Soil parameter inputs, their use within the model and appropriateness of estimates that affect plant growth, and water use and storage
- Climate parameter inputs or generation
- Completeness of the hydrologic system evaluation
- Model output and satisfaction of design needs
- Level of support required from other models or other sources
- Model characteristics that may affect accuracy and completeness of ET cover design and/or evaluation

Over a variety of conditions, the Air Force analysis found,

“The HELP model was designed to evaluate the hydrology of complete, barrier-type landfill covers, including the cover, waste, bottom liner, and leachate collection. As explained in Section 4.3, the focus of the HELP model is on the manmade features of landfills and waste properties and not on natural systems that control the water balance of the cover. The HELP model achieves the goal set for it for manmade structures and waste but it is less accurate than desired for natural systems. . . The HELP

model [as compared to other models] has limited usefulness in design or evaluation of ET landfill covers.” (Air Force, 2004, pg 51)

In a similar assessment of model accuracy conducted for the U.S. Environmental Protection Agency by Desert Research Institute (2002) found,

“Three concerns with HELP were (i) a non-realistic response of increased drainage as available water capacity increased, (ii) insensitivity of drainage to thickness of the cover surface layer, (iii) consistent overprediction of drainage. The over-prediction of drainage was found to be as much as an order of magnitude for the arid site. For water-balance codes such as HELP . . . in which evapotranspiration is removed only from an arbitrary evaporative zone, it is critical that the evaporative depth be accurately characterized. Since evaporative depth is a fairly nebulous property that is extremely difficult to characterize, implies that model calibration is needed with these codes.” [emphasis added] (EPA, 2002, pg ii).

By comparison, EPA (2002) found that,

“HYDRUS-2D exhibited the most physically realistic response patterns in the sensitivity tests. . . For the Coshocton lysimeter, all codes were better able to predict the measured drainage than observed for the arid conditions, however, . . . HYDRUS-2D exhibited superior ability.” (EPA, 2002, pg iii)

Finally, EPA (2002) concludes,

“This study suggests that the Richards’ Equation-based codes (HYDRUS-2D, UNSAT-H) were better able to capture the behavior of alternative earthen covers under both arid and humid conditions than the simple water-balance codes (HELP, EPIC).” (EPA 2002, pg. iii)

22. INTERROGATORY CR R313-25-7-22/1: DEFINITION OF FEPS

Round 1 Interrogatory Response is satisfactory.

23. INTERROGATORY CR R313-25-7(2)-23/1: CANISTER DEGRADATION AND CORROSION

Round 1 Interrogatory Response is satisfactory.

24. INTERROGATORY CR R313-15-101(1)-24/1: UTAH REGULATIONS

Round 1 Interrogatory Response is satisfactory.

25. INTERROGATORY CR R313-25-7(9)-25/1: DISPOSITION OF CONTAMINANTS IN UF6

Round 1 Interrogatory Response is satisfactory.

26. INTERROGATORY CR R313-25-8(4)(A)-26/2: RADON DIFFUSION IN THE UNSATURATED ZONE

The PA should also indicate which processes are being modeled by GoldSim for the transport of radon, particularly in the unsaturated zone (e.g., diffusion, advection).

EnergySolutions' Response: The text in Section 6.6 of Appendix 2 - Conceptual Site Model for Disposal of Depleted Uranium at the Clive Facility to version 1.2 of the Modeling Report has been modified to clarify that the transport of radon in the saturated and in the unsaturated zone from the waste to the ground surface is included in the PA model, resolving the apparent inconsistency.

27. INTERROGATORY CR R313-25-8(4)(A)-27/2: DIFFUSION PATHWAY MODELING

It is not clear what is meant by PA maintenance and whether quantification will in fact be included in a forthcoming revised PA report. DEQ is not aware of any formal plans by ES for PA maintenance. Any such plans should be described.

In addition, “difficult to quantify” is not a sufficient reason for not performing the modeling if it is necessary. In response to this interrogatory, ES should provide modeling that quantitatively accounts for these processes and effects, taking into account NRC guidance such as that in NUREG/CR-7028. Alternatively, it should explain why DRC should not require ES to perform the quantification effort now, rather than in the future.

EnergySolutions' Response: Unless they become necessary as a result of preparation of responses to the upcoming Round 3 Interrogatories, no further revision or PA maintenance is planned to version 1.2 of the Modeling Report.

See responses to items (2) and (3) of INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

28. INTERROGATORY CR R313-25-8(4)(A)-28/2: BIOTURBATION EFFECTS AND CONSEQUENCES

1. The ES response began by referring to two documents (*EnergySolutions* 2013d and *EnergySolutions* 2014), which obviously were not included in FRV1. ES needs to integrate the information from these two documents into the revised report. Then DEQ can review and comment on how that information is being used in the DU PA.
2. The ES response indicates that the ET cover would reduce infiltration by two orders of magnitude compared with the rock armor mulch cover. The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers 2014), does not support this statement. The original mean infiltration rate (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas with the ET cover the rate is about 0.04 cm/yr—reduced by only a factor of three.
3. The ES response indicates that an increase in the radon barrier hydraulic conductivity resulted in no increase in infiltration. However, the response does not address what impact (if any) burrowing animals, plant roots, gullies, and similar mechanisms would have on the radon diffusion upwards to the surface.
4. Finally, in its response ES indicated that the “mammal burrowing model” would be updated at an unspecified time in the future, as part of PA maintenance. DEQ looks forward to receiving and reviewing this refined modeling effort. ES should provide a schedule for the completion of PA maintenance.

EnergySolutions’ Response:

1. See the response to interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.
2. See the response to interrogatory CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER.
3. See the response to interrogatory CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER.
4. See the response to interrogatory CR R313-25-8(4)(D)-27/2: DIFFUSION PATHWAY MODELING.

29. INTERROGATORY CR R313-25-8(5)(A)-29/2: LIMITATION TO CURRENT CONDITIONS OF SOCIETY AND THE ENVIRONMENT

We concur with this position. However, as indicated elsewhere in this document, we are not convinced that it is appropriate to exclude as human intrusion scenarios mining of sand, clay, and gravel, or exploration drilling for resources, or extraction of deeper lying groundwater for a variety of beneficial uses. ES needs to address these scenarios. Further, NUREG-1573 also provides guidance for the PA model developer when a proposed disposal site currently lacks residents, as follows:

Finally, with respect to the portion of this question concerning how the critical group approach would be implemented if there were no residents near a candidate disposal site, the PAWG expects that the LLW disposal facility developer would identify some analog site, of comparable geology and climate, and define the critical group in terms of the analogue site. Again, the LLW disposal facility developer needs to document the technical basis for his or her decision-making - regarding how both the analogue site was selected and the critical group subsequently defined. [page B-60]

ES should also consider this information as it selects the various human intrusion scenarios for the 10,000-year compliance period PA analysis. We look forward to reviewing the revised report.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: Groundwater Exposure Pathways.

30. INTERROGATORY CR R313-25-8(5)(A)-30/1: INCLUSION OF SRS-2002 DATA IN THE SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

31. INTERROGATORY CR R313-25-8(5)(A)-31/2: TC-99 CONTENT IN THE WASTE AND INCLUSION IN THE SENSITIVITY ANALYSIS

We look forward the updated results regarding Tc-99 inventory and its effects on dose results. We presume the new analyses will include, among other considerations, an indication of the sensitivity of Tc-99 content to compliance with the GWPL and doses from groundwater over 10,000 years.

EnergySolutions' Response: The Tc-99 groundwater concentrations at 500 years have been updated in Section 6.1.1 of version 1.2 of the Modeling Report. The updated sensitivity analysis in Section 6.1.2 indicated that the K_d for technetium in sand was the most sensitive parameter. A new appendix containing all the

sensitivity analysis results is included with Appendix 15 (II) – Sensitivity Analysis Results. EnergySolutions reminds the Division that, under conditions of their Ground Water Quality Discharge Permit, EnergySolutions is required to protect the Clive groundwater resource for a period of 500 years following initial startup of waste placement. Since this is a concentration-limited standard and that the groundwater pathway is specifically not a dose pathway, the projecting of the GWQDP limit beyond 500 years is expressly contrary to NRC guidance.

See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

32. INTERROGATORY CR R313-25-8(4)(A)-32/1: EFFECT OF OTHER POTENTIAL CONTAMINANTS ON PA

Round 1 Interrogatory Response is satisfactory.

33. INTERROGATORY CR R315-101-5.3(6)-33/1: CLARIFICATION OF THE PHRASE “PROOF-OF-PRINCIPLE EXERCISE” AND SENSITIVITY TO URANIUM ORAL REFERENCE DOSE FACTORS

Round 1 Interrogatory Response is satisfactory.

34. INTERROGATORY CR R313-25-8(5)(A)-34/1: INTENT OF THE PA

With the following edits (in **bold**), the Round 1 Interrogatory Response is satisfactory:

“The role of PA in a regulatory context is often restricted to the narrow use of evaluating compliance. In the present case, the Clive DU PA **GoldSim Model v1.0** can be used to evaluate compliance—and inform a PA document that presents the argument that demonstrates compliance—with 10 CFR 61 Subpart C and the corresponding provisions of the Utah Administrative Code, **including (1) quantitative PA modeling for at least 10,000 years and (2) complete additional PA simulations for a 1,000,000 year timeframe**. In addition to that role, however, and because of the long-term nature of the analysis, the intent of the Model is not necessarily to estimate actual long-term human health impacts or risks from a closed facility. Rather, the purpose is to provide a robust analysis that can examine and identify the key elements and components of the site, the engineered system, and the environmental setting that could contribute to potential long-term impacts. Because of the time-scales of the analysis and the associated uncertainty in knowledge of characteristics of the site, the waste inventory, the engineered system and its potential to degrade over time, and changing environmental conditions, a critical part of the PA process is also the consideration of uncertainty and evaluation of model and parameter sensitivity in interpretation of PA modeling results.”

EnergySolutions' Response: Edits noted without comment.

35. INTERROGATORY CR R313-25-19-35/1: REFERENCE FOR COST PER PERSON-REM

Round 1 Interrogatory Response is satisfactory.

36. INTERROGATORY CR R313-25-8(4)(A)-36/1: ANT NEST EXTRAPOLATIONS

Round 1 Interrogatory Response is satisfactory.

37. INTERROGATORY CR R313-25-8(5)(A)-37/2: DISTRIBUTION AVERAGING

This is a complex topic, and DRC believes that more information is needed to understand how distribution averaging is actually implemented in GoldSim:

1. ES described a scaling process that is specific to a given model cell. Provide additional details and numerical examples of specific parameters in support of these statements contained in the response: "Data that represent points in time and/or space cannot be used directly in this type of model. The data range and variance is too broad for the large spatial or temporal effects that are being modeled."
2. Provide a more detailed description, with examples of how the input parameter distributions are applied when calculating an average response for cells with linear response, and the types of modifications required for cells with non-linear response.
3. Describe how the final model outputs are calculated using the cell-specific averages.

EnergySolutions' Response:

- 1) The scaling of distributed parameters is best illustrated by example. The first example considers spatial variation. Consider the porosity of a given porous medium. This is estimated from the analysis of several samples taken at different locations, or even at the same location. Each sample represents the porosity of the sample, and each sample is part of a larger population of samples for the entire expanse of, for the sake of argument, Unit 4 sediments. A model that requires a representative porosity for Unit 4, such as an infiltration model built in HYDRUS, or version 1.2 of the Model, considers the Unit 4 sediments to be homogeneous in space. That is, local variations in porosity (and other bulk material properties) are not considered, as this would impose a tremendous computational burden with no real benefit for the larger

scope of decision making. So, every part of the model that contains the Unit 4 sediments uses the same value of porosity. The porosity is not perfectly known, of course, so the uncertainty in this representative porosity value is captured in a statistical distribution from which a porosity value is selected. This value must reasonably represent the average porosity of the entirety of Unit 4 as represented in the model domain. This volume is much larger than any sample, and although it includes all the samples, its estimated average value has much less variation than is found in the individual samples. If the input distribution, from which an average porosity is chosen, were to be based on the porosity data, then there would be the possibility of selecting some extreme porosity value to represent the entire Unit 4, and this would not be a reasonable representation of the average value. This is why it is inappropriate to build a distribution simply from the data points. Doing so does build a distribution of the data, and could be used to estimate porosities of a sample here or there, but does not produce a distribution of the average value that would apply across large volumes of Unit 4. What is needed is a distribution of the average porosity of Unit 4. This is done through the application of statistical techniques such as bootstrapping to generate a distribution of the average. The distribution of the average value is invariably narrower than the distribution of the data.

Another example illustrates averaging in both time and space. Consider the pattern of rainfall over a given area and length of time. At one extreme there may be intense storms, local and brief, and at the other extreme may be long extensive dry spells. The monthly, daily, or hourly behavior depends quite strongly on the intervals of time and space chosen for recording the measurement. In a model that runs simulations for thousands of years, the daily and even yearly events all get “averaged out” into a spatiotemporal average value. If the fine-scale data were used to build a distribution of rainfall that is to be applied over a large area and time, there would be the possibility of having a hundred-year return period storm every day for thousands of years, or no rain at all—neither of which is a reasonable representation of the climatic behavior at the site. Again, what is needed is an average value that will produce average results, with an appropriate amount of uncertainty. But even the extremes of the input distribution for rainfall must be reasonable for a long-term and large-area average. As in the former example, the distribution of the average will be narrower than the distribution of the data.

Note that these spatiotemporal scaling relationships are not limited to definitions of Cell pathway elements in GoldSim. These concepts extend to system level modeling in general.

- 2) Version 1.2 of the Model does not contain “cells of linear response” or “cells of non-linear response”. Depending on their location, Cell pathway elements may be subject simultaneously to one or more non-linear processes, and to many linear ones, as well as events that may change rates or conditions, potentially altering those processes. The state of the contents of the Cell (including what we are most concerned with, the array of radionuclides defined in the Species element) depends on so many variables and processes that it is difficult to predict exactly in advance, unlike a purely linear model.

Again, some examples may help to illustrate some linear and non-linear aspects of the model. One example of a linear process, or at least one that is modeled as linear, is the dose response to the concentration of a radionuclide in some exposure medium. The dose conversion factor, or DCF, for ^{210}Pb in the dust inhalation exposure pathway is a linear function of both the concentration of ^{210}Pb in airborne dust and of the rate of inhalation. If either one doubles, the resulting dose doubles. If they both double, the dose is increased by a factor of four. This is, of course, a simplification of reality, but it is what is called a first-order approximation, and depending on the results of the sensitivity analysis, it may be sufficient for informing decision making.

An example of nonlinear behavior in the model is the aqueous concentration of uranium in a given cell pathway element. This concentration is also a function of several processes which independently have linear relationships to concentration, but together become non-linear: One set of processes are those involved in partitioning between phases, whereby the mass of uranium in the cell is partitioned between Water and Loess or whatever porous medium constitutes the cell volume. At low concentrations, the uranium is allocated between water and solid using a simple linear ratio of concentrations (the soil/water partition coefficient, or K_d). As the water concentration or uranium increases, however, a limit is encountered and no more uranium can be dissolved in the water. The rest of it is allocated to the solid phase, and the simple linear K_d ratio is lost, and with it the linearity of the system. Once the solubility limit is reached, the system becomes non-linear. This is why, for example, adding more uranium to a source or inventory does not result in higher concentrations emanating from the waste—rather it reaches a constant concentration but maintains it for a longer period of time.

Given that the concentration of uranium in a given cell may be non-linear at times, and given that the isotopes of uranium are tightly linked to the fate and transport of their progeny, the non-linearities in the model spread.

The linear or non-linear response of a model does not depend on parameter distributions, or on specific cells. Distributions of input parameters such as K_d , solubility, or DCF are developed with no regard for the model’s degree of

linear or non-linear behavior. There are no modifications to a parameter depending on whether a particular cell is behaving linearly or non-linearly.

3) See responses 1 and 2, above.

38. INTERROGATORY CR R313-25-8(5)(A)-38/2: FIGURES 5 AND 11 IN FRV1

We find this position to be reasonable with regard to the unconfined aquifer. However, groundwater is being extracted for beneficial uses in the Clive area, presumably from the confined aquifer that lies below the shallow unconfined aquifer. For example, ES uses groundwater from a local well to suppress dust.

Several deep wells have been drilled near Clive, Utah. A log for one well just west of the Clive turnoff from Interstate 80 was drilled in 1969 to a depth of 350 feet for the Cox Construction Company. The intended use was for highway construction sprinkling and compaction (see <http://waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-545>). The location is said to have been S 2100 ft E 1100 ft from NW cor, Sec 18, T 1S, R 11W, SLBM. The well is reported to have produced groundwater during a pumping test in 1969 at a rate of 600 gpm over 10 hours of testing (click on Well Log link at <http://waterrights.utah.gov/cgi-bin/docview.exe?Folder=welllog427264>). The well is now associated with Utah water right 16-722, with a well whose location is said to be at S 1900 ft W 1400 ft from NE cor, Sec 18, T 1S, R 11W, SLBM. The well log shown on the Utah Water Rights website is the same as that for the well previously described for water right 16-545. Groundwater pumped from the well is reported to be used for dust suppression and control and truck washdown (<http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-772>). The well reportedly had produced about 15,313,800 gallons of groundwater by 2008.

Another well, located about 3 miles east of the Clive low-level waste disposal facility, is related to Utah groundwater right 16-190 by Skull Valley Company for water for livestock (see <http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-190>). The depth is 293 feet, with water down at 263 feet. The flow is given as only 0.0377 cfs. Another reference shows a map for the Grassy Mountain Facility, northwest of Clive, with wells called the North USPCI Water Supply Well and the South USPCI Water Supply Well (Hansen, Allen and Luce, Inc., 2010). USPCI also drilled a well west of the Clive facility (<http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-796>). That well was drilled in 1992, and a well test was conducted then with an air lift yield of 0.134 cfs. Repairs were attempted in 1997, along with pumping at 350 gpm, before the well was abandoned.

The ES response has not addressed the possibility that drawdown associated from these or similar wells located just off-site at Clive could pull contamination from the Federal Cell through the underlying unsaturated and saturated zones via discontinuities in the confining layer into the confined aquifer from where it could be pumped to the surface. Water from the deeper aquifer would probably be too saline for domestic uses without treatment but could be used for dust suppression and similar purposes.

It is also possible that this water could be treated by techniques such as reverse osmosis and be used as drinking water as is currently happening at the nearby Delle Auto Truck Stop. We understand that water quality at this location is governed by state regulations since, as defined in R209-100(4), (1) “A public drinking water system is a system, either publicly or privately owned, providing water for human consumption and other domestic uses, which: (b) Serves an average of at least 25 individuals daily at least 60 days out of the year....”

It is also our understanding that regulation of small sources that do not meet the test of a public water system as described in R309-100-4 are regulated by local health organizations. In the case of Tooele County, the county health department requires that for any culinary water use, the water user needs to pay for what the County Health Department refers to the “full chemical test” based on EPA standards. These EPA standards do not include “radiologicals,” unlike the situation with public drinking water systems. Thus, the water user would not know about potential exposure to radioactive contaminants. In the case of reverse osmosis treatment, the contaminants would partition between the treated water and the wastewater creating multiple exposure pathways.

Another pathway that should be examined is the flow of contaminants from the unconfined aquifer to the confined aquifer through the annulus between borehole and the well casing. We recognize that drilling regulations require boreholes to be sealed. In Tooele County, borehole sealing inspections are performed by the county health department. However, failure to properly seal the annular space is not unusual in well drilling.

Both of these groundwater exposure pathways need to be examined and the results compared to the R313-25-19 groundwater dose limit.

After the additional information discussed here is provided, disposition of this and related interrogatories can be addressed. These include the following:

Interrogatory CR R313-25-8(4)(a)-96/1: Current and Future Potability of Water

Interrogatory CR R313-25-8(4)(a)-97/1: Need for Potable and/or Industrial Water

Interrogatory CR R313-25-8(4)(a)-105/1: Human Use of Groundwater

Interrogatory CR R313-25-8(4)(a)-106/1: Desalination Potential

Interrogatory CR R313-25-8(5)(a)-163/1: Groundwater Compliance for 10,000 Years

Interrogatory CR R313-25-19-182/1: Groundwater Exposure Pathways

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

39. INTERROGATORY CR R313-25-8(5)(A)-39/1: FIGURE 6 CAPTION

Round 1 Interrogatory Response is satisfactory.

40. INTERROGATORY CR R313-25-8(5)(A)-40/1: FIGURES 7, 8, 9, 10, AND 11

Round 1 Interrogatory Response is satisfactory.

41. INTERROGATORY CR R315-101-5.3(6)-41/1: TABLE 7

Round 1 Interrogatory Response is satisfactory.

42. INTERROGATORY CR R315-101-5.3(6)-42/1: HAZARD QUOTIENT IN TABLES 7 AND 8

Round 1 Interrogatory Response is satisfactory.

43. INTERROGATORY CR R313-25-19-43/1: PEAK DOSE IN TABLE 11

Round 1 Interrogatory Response is satisfactory.

44. INTERROGATORY CR R313-25-8(5)(A)-44/2: OCCURRENCE OF INTERMEDIATE LAKES

We are troubled by ES' ongoing statements concerning carbonate sedimentation in lakes: "Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur [at Clive]." Similar statements also appear in ES responses to other interrogatories, such as Interrogatory CR R313-25-8(4)(d)-126/1: Shallow Lake Cycles.

There seems to be a sense in the PA that lacustrine carbonate sedimentation is restricted to the deep, distal (profundal) portions of large lakes. Evidence, however, indicates that this is not correct. Other than the very near shore, fine-grained carbonate sedimentation is a function of water chemistry and can occur in lakes, large or small, at virtually all depths. Provo age (~15.5–13.5 kya) marl in Lake Bonneville is common at paleodepths as shallow as 5 to 10 meters. Modern sediments of the Great Salt Lake have carbonate concentrations as great as 70% (Eardley, 1938; 1966). Preliminary research on a small lake (< 1 km² area, 50 meters maximum depth) in upstate New York found that fine-grained carbonate constitutes approximately 75% of the bottom sediment (Takahashi et al., 1968). Further, calcium carbonate tufa deposits have been mapped in Gilbert-age lake sediments on the Grayback Hills, a short distance northwest of Clive (Doelling et al. 1994, page 13).

Given the importance of sediment characteristics to the mobility and sequestration of radionuclides, more serious consideration needs to be given to this issue. For example, radium is often precipitated with the carbonates, which could significantly impact the concentrations in the lake water.

EnergySolutions' Response: The deep time model is simply a high-level heuristic model designed to assist decision-making with regard to periods of time beyond the compliance period. The defined broad classes of different types of lakes are intended to explore the potential processes and impacts of different elevations of lake. Statements on carbonate sedimentation have been revised in Appendix 13 - the Deep Time. For example, new text includes the following in Section 3.3:

“Carbonate deposition is likely to occur under a wide range of lake conditions but the ratio of carbonate deposition to clastic sedimentation will increase as the lake deepens because of the reduction in sedimentary influx with increased distance from shoreline processes and decreased wave activity.”

And text has been added to state that the model is not dependent on the dynamics of carbonate deposition and that it conservatively assumes all waste is precipitated with and incorporated into local sediments during lake recession:

“The model parameters used in the deep time assessment are sensitive to lake duration and sedimentation rates but are not dependent on the dynamics of carbonate deposition. Radionuclides in sediment will partition between the lake water and solid phase dependent on element-specific solubility and assigned sorption properties. Radionuclides remaining in the pore water can diffuse into the lake water. Some radionuclide species may bind with carbonate ions in the lake water and

precipitate as carbonate. However, the deep time assessment conservatively assumes all waste is precipitated with and incorporated into local sediments during lake recession.”

The last sentence in the preceding text represents a highly conservative (i.e., protective) assumption.

45. INTERROGATORY CR R313-25-7(2)-45/1: INACCURATE CROSS-REFERENCE

Round 1 Interrogatory Response is satisfactory.

46. INTERROGATORY CR R313-25-7(1)-46/1: TORNADOS

Round 1 Interrogatory Response is satisfactory.

47. INTERROGATORY CR R313-25-7(1)-47/1: SELECTION OF BIOME

Round 1 Interrogatory Response is satisfactory.

48. INTERROGATORY CR R313-25-7(9)-48/2: SOURCE AND COMPOSITION OF DU WASTE

We look forward to reviewing the new data demonstrating the sensitivity of the waste composition to PA results. In addition, although it would be ideal to use the actual quantitative method of employing the scaling factors, this seems like an appropriate way to quantify I-129. Given the high dose conversion factor, it is very important to use a conservative approach for I-129. With regard to the statement about a lack of model sensitivity, DEQ will evaluate this after ES completes PA modeling for the groundwater pathway for a time period of at least 10,000 years.

EnergySolutions' Response: See the responses to interrogatories CR R313-25-7(1)-149/2: AMERICIUM SORPTION, CR R313-25-7(1)-147/2: DETERMINATION OF KD VALUE FOR URANIUM, and CR R313-25-7(1)-148/2: INFLUENCE OF CARBONATE ON URANIUM SPECIATION.

49. INTERROGATORY CR R313-25-7(9)-49/1: COMPOSITION OF MATERIAL MASS

Round 1 Interrogatory Response is satisfactory.

50. INTERROGATORY CR R313-25-7(9)-50/1: SAMPLES COLLECTED

Round 1 Interrogatory Response is satisfactory.

51. INTERROGATORY CR R313-25-7(9)-51/1: NATURE OF CONTAMINATION

Round 1 Interrogatory Response is satisfactory.

52. INTERROGATORY CR R313-25-7(9)-52/1: MEASUREMENT TYPES FOR SAMPLING EVENTS

Round 1 Interrogatory Response is satisfactory.

53. INTERROGATORY CR R313-25-7(9)-53/1: SUBSCRIPTS IN EQUATION 1

Round 1 Interrogatory Response is satisfactory.

54. INTERROGATORY CR R313-25-7(9)-54/1: PARTITIONING IN THE SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

55. INTERROGATORY CR R313-25-8(5)(A)-55/2: URANIUM ISOTOPE DISTRIBUTIONS

ES does not appear to have answered the interrogatory. ES stated that the statistical analysis examined how the results varied due to the uranium distributions given in the Waste Inventory report, but it did not state how that distribution (or impacts) would vary if the uranium isotope distribution varies. The uranium isotopic distributions should be revised if any of the literature being reviewed under Interrogatory CR R313-25-7(9)-51/1: Nature of Contamination uncovers relevant new data.

EnergySolutions' Response: As is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Modeling Report, no scenario doses show sensitivity to the uranium isotopic distribution. Therefore, the uranium isotopic distributions were not further revised.

56. INTERROGATORY CR R313-25-7(9)-56/1: INTERPRETATION OF BOX PLOTS

Round 1 Interrogatory Response is satisfactory.

57. INTERROGATORY CR R313-25-7(9)-57/1: DASHED LINES IN FIGURE 4

Round 1 Interrogatory Response is satisfactory.

58. INTERROGATORY CR R313-25-7(9)-58/1: REFERENCE FOR PERSONAL COMMUNICATION

Round 1 Interrogatory Response is satisfactory.

59. INTERROGATORY CR R313-25-7(2)-59/2: BATHTUB EFFECT

The ES response was developed for the rip-rap design and therefore may not be appropriate for the newly proposed ET cover design. In addition, other interrogatories requested examination of the effects of pedogenesis, biointrusion, and other phenomena on the permeability of the radon barrier. We appreciate ES' forthcoming efforts to reexamine the potential for ponding within the waste as part of the ET cover design. We look forward to reviewing the revised report.

EnergySolutions' Response: For version 1.2 of the model, it was assumed that the "top clay liner" referred to in the Interrogatory is the clay liner below the waste zone and not one of the radon barriers in the ET cover system. Net infiltration in version 1.2 of the Model is calculated using stochastic inputs. The implementation in Version 1.2 of the Model is described in detail in Appendix 5 - Unsaturated Zone Modeling from version 1.2 of the Modeling Report. To evaluate the likelihood of the bathtub effect occurring a distribution of net infiltration rates for the ET cover was developed from 10,000 realizations of the net infiltration model. The 99th percentile value of this distribution was 0.43 mm/yr. The design value for the saturated hydraulic conductivity of the clay liner below the waste is $1.0E^{-6}$ cm/s (31.5 mm/yr) (Appendix 5 - Unsaturated Zone Modeling, Section 10.0). At steady state under unit gradient conditions this hydraulic conductivity corresponds to the flux of water through the saturated clay liner. Given the much greater capacity of the clay liner to allow water to flow through it in comparison to the 99th percentile of net infiltration rates, the bathtub effect is not possible. Any increase in saturated hydraulic conductivity of the clay liner below the waste due to naturalization will make the bathtub effect even less likely.

For an examination of the effects of pedogenesis, biointrusion, and other phenomena on the permeability of the radon barrier see the responses to items (1), (2), and (3) for INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

60. INTERROGATORY CR R313-25-7(3)-60/2: MODELED RADON BARRIERS

Refer to the Rebuttals for Interrogatories R313-25-7(2)-05/1; R313-25-8(5)(a)-176/1; and R313-25-8(4)(a)-108/1.

Additional explanation is needed in the sensitivity analysis of infiltration rates to the hydraulic conductivity of the radon barriers underlying the ET cover (EnergySolutions 2014). In particular, it is unclear why a decrease in the hydraulic conductivity of the upper radon barrier leads to an increase in infiltration at the top of the waste. This is counterintuitive and appears to be inconsistent with the results of the earlier Whetstone analyses (presented in the 2014 sensitivity analysis). In that study of infiltration through a rock armor cover, an increase in the hydraulic conductivity by two orders of magnitude increased the infiltration rate from 0.143 to 0.676 inches per year. Furthermore, a more detailed review of the HYDRUS modeling will be performed as part of the revised PA review.

DRC staff members also raised multiple concerns during their review of the Class A West cell ET cover proposal. These concerns must be resolved before such a cover can be considered on the DU embankment.

In addition, the reference to Benson, et al., 2011 in the response does not refer to Benson, et al., 2011 provided in the references in Section 3 of the response document. Rather, it refers to NUREG/CR-7028, which was not included in Section 3.

EnergySolutions' Response: An enhanced assessment of the performance of the Evapotranspiration cover system is described in the response to INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER. A statistical experimental design was developed to provide net infiltration and water content models for version 1.2 of the Model using the variably saturated flow and transport model HYDRUS. One outcome of the statistical analysis was that the net infiltration rate was found to be insensitive to the saturated hydraulic conductivity of the radon barriers.

61. INTERROGATORY CR R313-25-8(4)(A)-61/2: MASS-BALANCE INFORMATION

The fact that mass balance is not externally tracked and reported in GoldSim does not provide a level of confidence that mass is being adequately tracked. Although modeling precision can be made progressively tighter to see if the solution converges to the same values, this does not necessarily indicate good mass balance since this approach will only check over the temporal and spatial discretization internally defined by GoldSim. It is also unknown whether mass is conserved within the mass-flux links of the process-level models (unsaturated to saturated zone) and the external pathway function. The inability to independently verify that mass is conserved is a major limitation of the GoldSim code. Notwithstanding this, ES should provide references to the code developer's test problems that demonstrate that mass is conserved.

DRC notes that it is “strongly recommended” in the GoldSim Containment Transport User’s Guide that the GoldSim user “specifically enforce media flow balances by specifying pathway flow rates and media volumes and masses in a manner that is physically consistent with the mechanics of the system being modeled” (page 229). ES should describe how this has been accomplished in the DU PA model and indicate where it is documented.

DRC also notices that GoldSim “provides a warning message [to the Run Log] if the absolute difference between the inflow and the outflow [of a pathway] exceeds $1\text{E}-10\text{ m}^3/\text{sec}$ AND the ratio of the absolute difference to the inflow exceeds $1\text{E}-6$.” ES should indicate whether it has used this feature to determine whether mass balance is being maintained in the DU PA model. If it has, ES should indicate the results of that determination and where they are reported.

EnergySolutions’ Response:

An extensive explanation of the mass balance of media flows (e.g. water) is provided in the response to part 3 of Interrogatory CR R313-25-8(4)(A)-69/2: LONGITUDINAL DISPERSIVITY. As explained in that response, material mass balance is already verified with independent calculations within version 1.2 of the Model.

GoldSim External Pathway elements are not used in version 1.2 of the Modeling Report.

“Notwithstanding this, ES should provide references to the code developer’s test problems that demonstrate that mass is conserved.”

GoldSim has a 437 page Verification Plan that is generated by its developers for every release. It checks all the fundamental calculations carried out by GoldSim (including mass transport). Note also that GoldSim has been used worldwide for these calculations for over 20 years, and has thereby undergone extensive field testing.

62. INTERROGATORY CR R313-25-7(2)-62/2: NUMERICAL TESTING OF RUNGE-KUTTA METHOD

On May 9, 2014, ES (EnergySolutions 2014) provided a draft revision to the Unsaturated Zone Modeling report (Neptune 2014). We expected that the revised report would provide more extensive documentation of the testing of the Runge-Kutta solution method. Instead, a search of the report found no mention of the term “Runge-Kutta.” DRC anticipates that ES will restore and expand upon the description of the Runge-Kutta solution method in the final version of the revised

Unsaturated Zone Modeling report (Appendix 5 to FRV1), as ES had indicated in its Round 1 response. We look forward to reviewing the revised report.

EnergySolutions' Response: An Appendix has been attached to Appendix 5 - Unsaturated Zone Modeling describing the development and testing of the Runge-Kutta method for estimating volumetric water content of the waste, clay liner, and unsaturated zone below the waste.

63. INTERROGATORY CR R313-25-8(4)(A)-63/2: AIR-PHASE ADVECTION

Since the degree of movement of radon will have a significant impact on dose estimates, ES should investigate transport from all potentially significant processes. We look forward to reviewing the revised report.

EnergySolutions' Response: In version 1.2 of the Modeling Report volatile radionuclides are transported by aqueous advection and aqueous and gaseous diffusion. Fluctuations in barometric pressure at a site with an open ground surface have been shown by Massman and Farrier (1992) to result in the movement of fresh air into the subsurface during a barometric pressure cycle. Velocities simulated at the high point of the pressure cycle and the low point were equal in magnitude and opposite in direction indicating that the fresh air that migrates into the vadose zone moves back out of the vadose zone as the barometric pressure decreases. From a contaminant transport perspective, gas that migrates upward from depth in homogeneous permeable media during a low barometric pressure event will be pushed back down as the barometric pressure increases (Nilson et al., 1991). The presence of fractures, however, has been shown by Nilson et al. (1991) to produce conditions for net outflow of gas from the vadose zone due to barometric pressure fluctuations. The effects on gas transport due to barometric pressure fluctuations shown in numerical simulations by Massman and Farrier (1992), Nilson et al. (1991) and others are considered to be negligible in the field by Weisbrod et al. (2009) who argue that the advective events required to drive these pressure fluctuations are infrequent and depend on local weather variability. The low frequency of atmospheric events required to drive advective transport and the need for fractures to make it effective are reasons that air advection is not considered in performance assessment models.

However, other processes may contribute to significant net transport of gas. Gas migration to the atmosphere due to thermally driven convection has been demonstrated in the field by Weisbrod et al. (2009). The experiment was conducted in the Negev Desert, Israel on a fracture with an aperture that varied from 1 to 5 cm. Temperature gradients due to daily thermal cycles were shown to be sufficient to induce convective venting. The aperture of the fracture tested was larger than any expected in the ET cover and thermal gradients in the Negev Desert are steep. Given the extreme conditions of the field experiment the

influence of this process on radon advection at the Clive site is expected to be much smaller than that observed by Weisbrod et al. (2009).

Remediation of uranium mining legacy sites in Germany conducted by WISMUT GmbH involved developing a strategy to reduce radon releases from waste rock piles. Radon emissions from the waste rock piles resulted in high outdoor concentrations in the vicinity of the waste rock piles of up to $1,500 \text{ Bq/m}^3$ (Regner and Schmidt, 2013). Investigations at the sites determined that radon releases from the rock piles due to convective movement varied spatially and temporally due to changes in buoyancy. The remediation plan implemented was to reduce radon releases by covering the waste rock piles with a mineral soil layer. For the three sites described the covers ranged in thickness from 1.0 meter (m) to 1.9 m (Paul, 2007). The 1.0 m thick design consisted of 0.2 m of topsoil underlain by 0.8 m of mineral sub-soil. The 1.6 m thick design consisted of a 0.4m revegetation layer above a 1.2 m thick loam soil layer to provide storage of soil moisture. The third design was 1.9 m thick and consisted of a 0.4 m low permeability layer on top of the waste rock overlain by a 1.5 m thick soil layer for moisture storage (Paul, 2007). These designs were determined to be protective of human health and the environment and to allow re-utilization of the remediated areas. These designs are similar in thickness and composition to the ET cover design for the Federal DU cell.

64. INTERROGATORY CR R313-25-8(4)(A)-64/2: YUCCA MOUNTAIN STUDIES

These solubility values are based on the assumption that these ions are dissolving from pure solutions. However, it is more likely that the ions are present as solid-solutions within the uranium solid phases. The PA should explain whether the differences between solubility of a pure phase versus that of a solid-solution have been considered in the models.

The phase diagrams in Figures 1–3 below were generated to illustrate the solubility of uranium versus redox potential in the presence and absence of carbonate using Geochemist Workbench with the Lawrence Livermore National Laboratory (LLNL) v8r6+ database. The diagrams were generated using the dissolved ion concentrations from Tables 5 and 6 in the Geochemical Modeling report (Appendix 6 to FRV1), with and without carbonate included and with the pH fixed at 7. The EH and total uranium were varied, and the diagrams are shown in a pourbaix format with the dominant species shown in each region. Under reducing conditions, formation of U(IV) minerals limits the solubility of uranium through formation of uraninite.

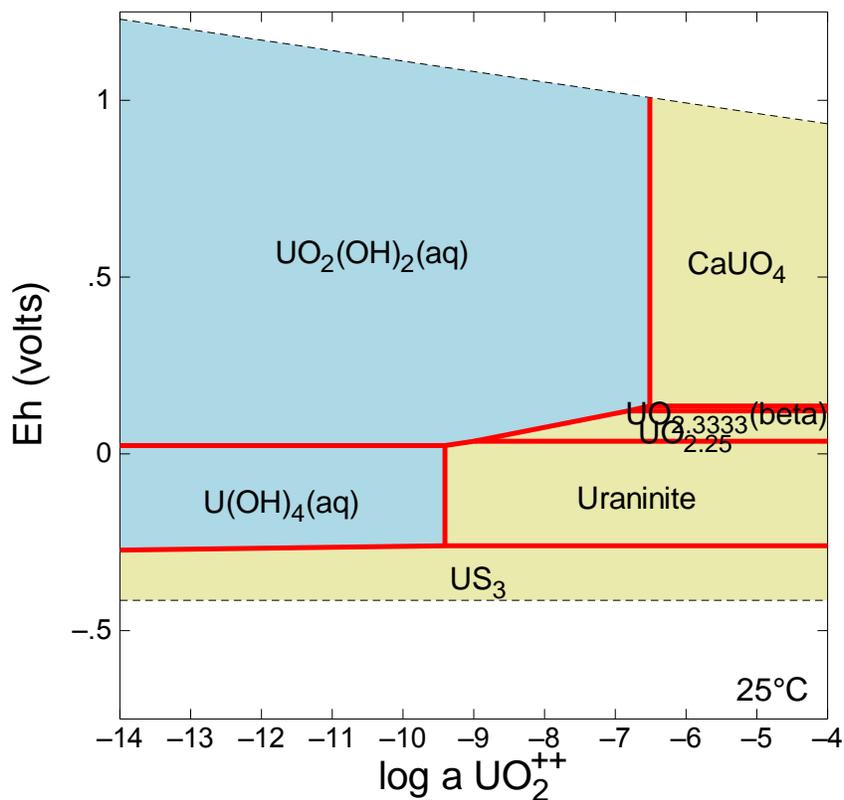


Figure 1. EH-activity diagram demonstrating uranium speciation and solubility in the absence of carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

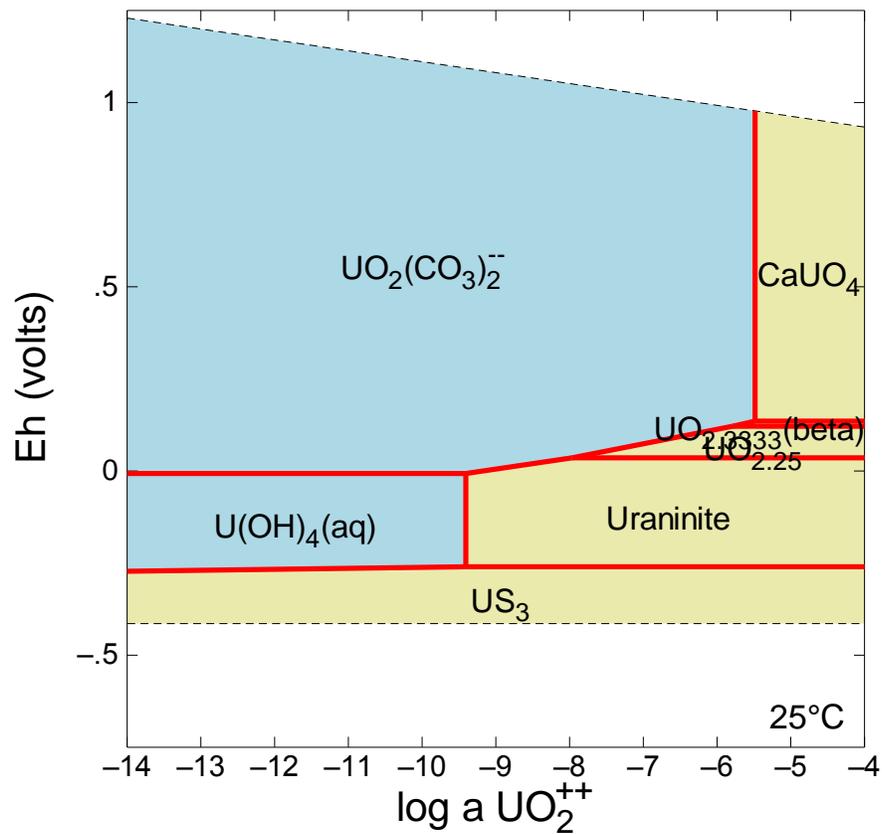


Figure 2. EH-activity diagram demonstrating uranium speciation and solubility in the presence of approximately 100 mg/L carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

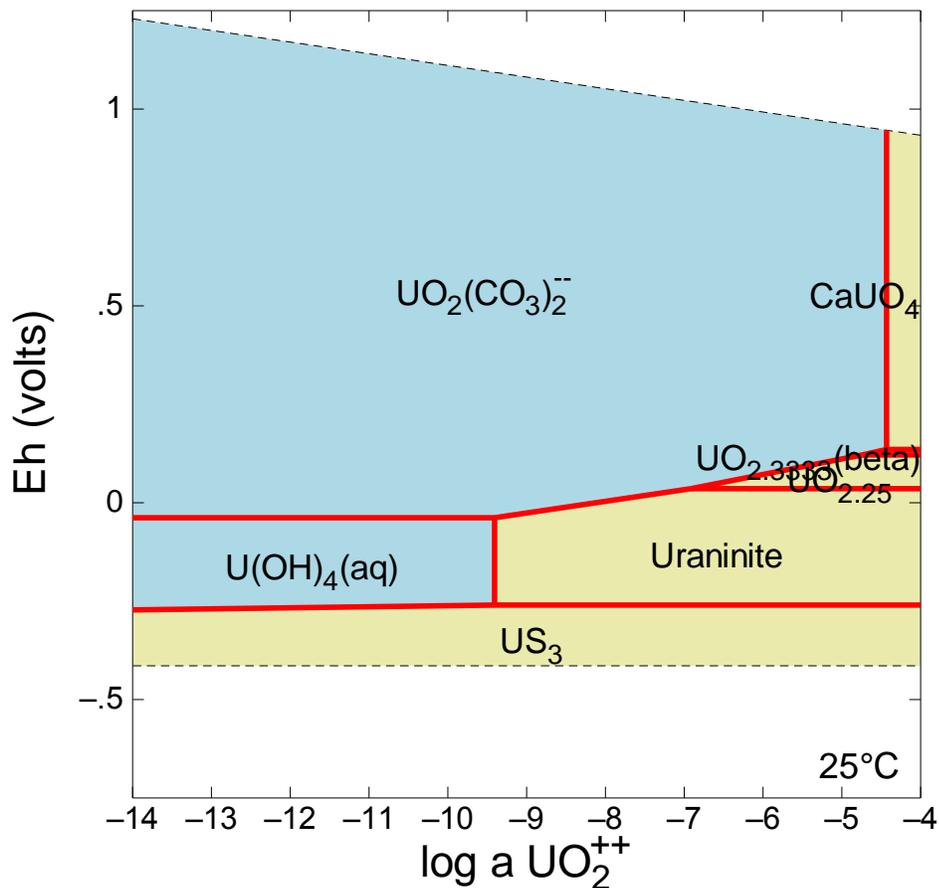
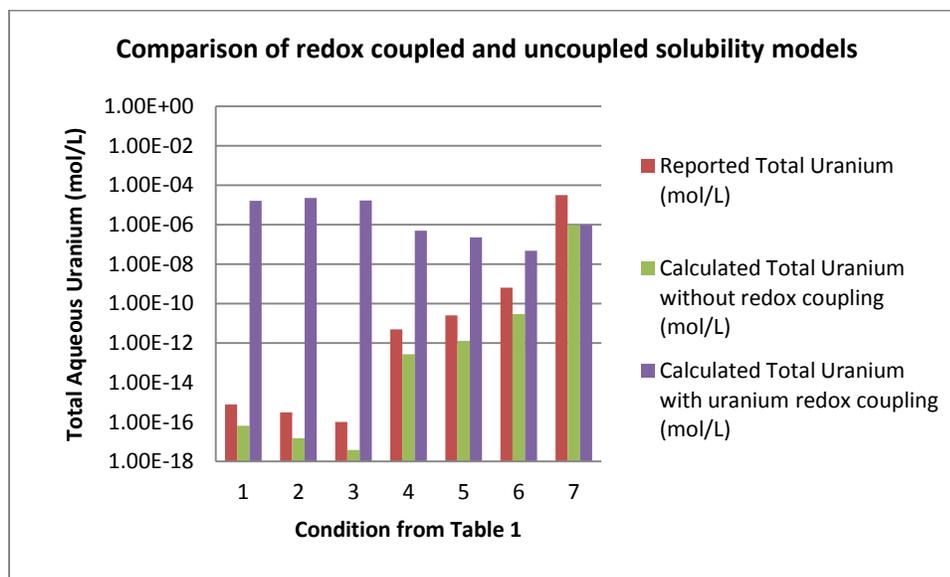


Figure 3. EH-activity diagram demonstrating uranium speciation and solubility in the presence of approximately 350 mg/L carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

The last line of Table 2-64/1 provided in the response presents uranium solubility data from SNL (2007). The uranium concentrations reported in Table 2-64/1 seem to only include the solubility of U(VI) phases and do not consider the potential formation of U(IV) phases, which will have significantly decreased solubility. The PA should indicate whether the geochemical model considers the potential formation of uraninite or other U(IV) phases and the expected redox conditions of the waste. Not considering the U(IV) phases if they are indeed forming will result in a very overly conservative estimate of aqueous uranium concentrations.

Also relevant to the overall prediction of the solubility of uranium is that the solubilities listed in Table 10 of the Geochemical Modeling report (Appendix 6 to FRV1) represent the output of a Visual MINTEQ model of U3O8 solubility. Given the low solubilities of uranium reported in Table 10, it is clear that oxidation of U(IV) to U(VI) was not considered. This must be done by “coupling”

the U(IV)/U(VI) reaction within Visual MINTEQ before running the model. It appears that the intent of the modeling exercises examining schoepite and U₃O₈ solubility in Tables 8–10 was to give boundaries of uranium solubility. However, it is unrealistic to run a model with a relatively high EH/pH condition (such as pH 8, EH 200 mV in Table 10) and not allow for the oxidation of reduced species. Therefore, the reported low solubility values in Table 10 are not reliable for use as the source term in reactive transport models. The table and figure below show the reported values from Table 10 as well as two columns of output from additional Visual MINTEQ runs. In the first column, data from Tables 5, 6, and 10 of the Geochemical Modeling report (Appendix 6 to FRV1) were used as noted in an attempt to reproduce the reported total dissolved uranium concentrations shown in Table 10. This was done by running the model with the U(IV)/U(VI) system “uncoupled,” as was apparently done for the model output shown in Table 10. However, the final column in the table below shows the total uranium concentration in a Visual MINTEQ model with the U(IV)/U(VI) reaction coupled. Oxidation of U(IV) to U(VI) is therefore allowed and the expected total dissolved uranium concentrations are significantly higher. Since the redox chemistry of the waste disposal site in this work is variable, it is recommended that redox coupled solubility calculations be used when defining the source concentrations in reactive transport models. The specific EH and pH ranges expected under the various geologic conditions considered in the reactive transport models must be used in this source term analysis.



EnergySolutions' Response: It is not clear that the solid phases that are modeled in version 1.2 of the Modeling Report are “*likely solid-solutions*” since solid solutions imply a crystalline matrix that is changing internally. The waste form will likely evolve over time so that the expected solid phase in the waste layer is actually a heterogeneous mix of several different solid phases. But these would not likely be solid solutions. According to Sparks 1998 (p. 215), solid solutions “*are thermodynamically unstable at room temperature.*” It is clear in Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report that the solid phase assumptions for uranium (at least) are for equilibrium with pure solids, e.g., when it references modeling shoebite for uranium. It is assumed that the heterogeneity of the system is captured by the uncertainty in the input distribution, or else in the choice for different solid phase solubilities.

The reviewers are correct that the redox equation for U(IV)/U(VI) should be included in solubility calculations for uranium. However, note that changing the U₃O₈ solubility does not make a difference in the 10,000-year quantitative model. For the 10,000-year model, only UO₃ is considered as a solid phase. U₃O₈ solubility is used in the Deep Time portion of version 1.2 of the Model. Therefore, the U₃O₈ solubility input distribution includes appropriate assumptions for the Deep Time portion of version 1.2 of the Model. With the return of a lake, it might be expected that the redox conditions be lower than what would be expected in the range of current groundwater conditions. According to Table 3 of the Rebuttal, uranium solubility, then, would be slightly greater than what is currently being used in version 1.2 of the Modeling Report. Because the Deep Time section already has significant conservatism built-in, a revision of the U₃O₈ solubility distribution will not make a noticeable difference, if that model conservatism is removed.

See the response to interrogatory CR R313-25-7-170/2: DU WASTE FORM RELEASE MECHANISMS AND RATES.

65. INTERROGATORY CR R317-6-6.3(Q)-65/2: COLLOID TRANSPORT

ES described what seems to be an appropriate way of addressing colloids. However, changes in ionic strength can generate mobile colloids. ES should review Cheng and Saiers (2009) and Ryan and Elimelech (1996) and revise the report to discuss potential impacts on the PA model.

EnergySolutions' Response: The discussion of colloidal transport has been expanded in Appendix 6 – Geochemistry Modeling in version 1.2 of the Modeling Report.

66. INTERROGATORY CR R313-25-8(4)(A)-66/2: COLLOID RETENTION

An evaluation of the simulation of colloidal transport will be conducted after the DRC staff reviews the additional references provided by ES in response to this interrogatory. ES should forward the references that are cited in the response as soon as possible.

EnergySolutions' Response: EnergySolutions cannot send the references to the State of Utah directly because of copyright issues. Below are the references and website links to find the references cited in response to this interrogatory.

CRWMS M&O (Civilian Radioactive Waste Management System). 2000. Colloid-Associated Radionuclide Concentration Limits . ANL-EBS-MD-000020 REV 00 ICN 01. This reference can be found at:
<http://pbadupws.nrc.gov/docs/ML0906/ML090690319.pdf>

Degueldre, C., I. Triay, J. Kim, P. Vilks, M. Laaksoharju, N. Mieleley. 2000. "Groundwater colloid properties: a global approach." Applied Geochemistry, vol.15, p. 1043 – 1052. This reference can be found at:
<http://www.sciencedirect.com/science/article/pii/S088329279900102X>

Ryan, J. N., and M. Elimelech, Colloid mobilization and transport in groundwater, Colloids and Surfaces A: Physicochemical and Engineering Aspects, Vol. 107, No. 1, 1996. This reference can be found at:
<http://www.sciencedirect.com/science/article/pii/092777579503384X>

67. INTERROGATORY CR R313-25-8(4)(A)-67/2: SOLUBILITY AND SPECIATION OF RADIONUCLIDES

We look forward to reviewing the revised report.

EnergySolutions' Response: The discussion of solubility and speciation has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

68. INTERROGATORY CR R313-25-8(4)(A)-68/2: DISTRIBUTION OF HYDRAULIC GRADIENTS

The original interrogatory asked ES to consider four possible events or phenomena that could increase local hydraulic gradient. In its response, ES made reference to conditions at Clive between 1999 and 2010. Unfortunately, three of the requested events did not occur during this time period, namely climate change, gully erosion, and biodegradation of the radon barrier. Further, ES' claim that the hydraulic gradient was not a sensitive parameter needs to be revisited after ES increases the modeling time interval from 500 to more than 10,000 years. ES

should provide the missing information; we look forward to reviewing the revised report.

EnergySolutions' Response: The influence of climate change on groundwater levels was addressed by the Intergovernmental Panel on Climate Change (IPCC) in the 5th Assessment Report (IPCC, 2014). In evaluating evidence of climate change influence they observed that changes in groundwater level are often difficult to attribute to climate change as they are also influenced by land use changes and groundwater abstractions (IPCC, 2014, Section 3.2.4). The report notes that a significant number of studies on the relationship between groundwater and climate change have been conducted since 2007. Based on these studies the IPCC report concludes “*The sensitivity of groundwater recharge and levels to climate change is diminished by perennial vegetation, fine-grained soils and aquitards*” (IPCC, 2014, Section 3.4.5). Given the fine grained texture of the Unit 4 soil forming the upper layers of the cover and the surrounding area, the fine-grained texture of Unit 2 forming the shallow aquifer, and the confined nature of the deep aquifer, climate change is not expected to influence hydraulic gradients on the scale of the Clive site.

As is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Modeling Report, hydraulic gradient is not sensitive for all scenarios except groundwater concentration within 500 years. Even then, the sensitivity index of results to changes in K_d of uranium in sand and clay dwarfs that of hydraulic gradient.

Version 1.2 of the Modeling Report includes an enhanced assessment of the influence of radon barriers, surface layer, and evaporative zone layer performance degradation on net infiltration. See item (2) of the response to INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

69. INTERROGATORY CR R313-25-8(4)(A)-69/2: LONGITUDINAL DISPERSIVITY

The ES response generated the following questions:

1. Omission of Horizontal Dispersivity Calculations: Since longitudinal dispersion would decrease the time it takes for the contaminant to reach the compliance point, ES should explain how this omission produces a result that is either conservative (protective of the environment) or is representative of Clive site conditions. We note the offer by ES to perform sensitivity testing of the model to evaluate dispersivities. ES should provide this information in its next report revision and ensure that the model used simulates a time period of 10,000 years or more.

2. Unconfined Aquifer Dimensions: A review of the schematic in Figure 1 of the Saturated Zone Modeling report (Appendix 7 to FRV1) indicates that the saturated horizontal pathway had a constant aquifer thickness (model cell height). ES should explain how this geometry will provide conservative or representative model results given that a large groundwater recharge mound is found along the south and southwest margins of the proposed Federal Cell, thereby increasing the unconfined aquifer thickness there. Conversely, a thinner aquifer on the north side of the disposal cell should increase shallow aquifer velocity. ES should also explain whether instantaneous full vertical mixing, which will dilute the plume, makes sense over a travel distance of 232 feet.
3. Mass Balance: ES should provide evidence to support the statement that the model author (operator) ensured that all flows are properly accounted for. ES should provide the criteria used to determine what magnitude or ratio of mass balance was deemed satisfactory. We appreciate the insight on how DEQ may examine this issue for itself. We are particularly concerned that the model properly accounts for the mass entering the saturated zone from the unsaturated zone.
4. Grid Spacing: Although the grid spacing appears reasonable, ES should calculate and present the Peclet number since that is the more traditional approach to guide space discretization. Ideally, the number should be less than 2.

We look forward to reviewing the revised report.

EnergySolutions' Response: 1) Horizontal dispersion is not calculated because of the geometry of the transport pathway. In the realm of contaminant transport, this is known as a rectangular plane source, as illustrated in Figure 1. As shown in the figure, if a point of interest (in this case the compliance well) is relatively close to the rectangular source (in this case the Federal DU Cell), horizontal dispersion (transverse to the flow direction) becomes negligible.

The width of the disposed waste is the dimension perpendicular to the groundwater flow direction. This distance is 1,429.6 ft ("length overall" in Figure 3 of the Embankment Modeling white paper). The distance from the edge of the embankment (the "toe of the waste", which would be in the side slope section) to the compliance point is 90 ft as required by the groundwater discharge permit. For version 1.2 of the Modeling Report the point of compliance is a virtual well at a fixed location 232 ft from the edge of the DU waste, since the length travelled under the side slope of the embankment, which contains no DU waste (142 ft), is added to the 90 ft. The edge of a plume would be at a distance of $1429.6/2 = 715$ ft perpendicular to the direction for flow from the well. This distance is three times

the distance from the waste to the well. Given the much greater horizontal distance, any horizontal dispersion at the edge of the plume would have an insignificant effect on concentrations at the well.

2) Version 1.2 of the Modeling Report does not attempt to represent the shallow aquifer below the Federal Cell to the level of detail described in the interrogatory. Due to the uncertainty in the aquifer thickness, this parameter is represented in the model as a normal distribution with a mean of 16.2 ft and a standard deviation of 0.25 ft. This distribution for aquifer thickness is considered to be representative. Given the aquifer's small thickness relative to the Federal Cell dimensions the aquifer is assumed to be fully-mixed in the vertical direction. This, along with the approximation of the rectangular source shown in Figure 1, allows the aquifer to be represented by a 1 dimensional column oriented parallel to the flow direction.

A characteristic of all groundwater transport models is the movement of material from the source zone into cells or elements representing the aquifer. For version 1.2 of the Modeling Report the shallow aquifer under the waste is represented by 25 cells that are 16.2 ft thick in the vertical direction. The shortest time-step in the model is the initial time-step of 0.1 yr or 36 days. Time-steps after the first year extend to 1 year length and longer. A time period of 36 days is considered to be adequate for full vertical mixing in the shallow aquifer below the waste.

3) The flow of water from one modeling cell to another in version 1.2 of the Modeling Report is defined by the model developer, and is not subject to numerical approximations. The mass balance of such flows, therefore, is entirely within the control of the modeler. Before examining the details of water flow in version 1.2 of the Modeling Report, however, a bit of background on how GoldSim handles materials flows is in order.

The columns and pathways for water flow in version 1.2 of the Modeling Report are constructed from GoldSim Cell Pathway elements, which are part of the Contaminant Transport module. Each of these elements is mathematically represented as a "continuously-stirred tank reactor" (CSTR), meaning that all materials and contaminants in the Cell are assumed to be instantaneously and thoroughly mixed throughout the Cell. In version 1.2 of the Modeling Report, these Cell elements are arranged in series, making a 1 D column of what is, in effect, a finite difference model. Each Cell contains a mass of a single solid material (a function of its bulk density), as well as some volume of water (a function of the water content) and a volume of air (a function of the air content, which is zero in the saturated zone). The total volume of each Cell is defined by the cross-sectional area of the column times its thickness. Water may be "moved" between Cells by defining advective flux links. An important subtlety in GoldSim is that it does not actually keep track of water that would be moved—that is up to the modeler to define. Rather than actually moving water, GoldSim moves, from

one cell to another, the contamination that would be in the material that is moved. This material could actually be water, soil, or air.

For a given Cell, then, water may flow in and out, depending on the advective flux links for water that the modeler has defined. In general, a modeler would make sure that the volume of water flowing into a Cell is equal to the amount of water flowing out, thereby ensuring mass balance by definition. GoldSim, however, does not require that these values be equal, and manages the difference in flows according to the concept of virtual uncontaminated water. This is best illustrated by an example from version 1.2 of the Modeling Report: The TopSlope container hosts a 1 D column of cells, subdivided into CapLayers, WasteLayers, Liner, and UnsatLayer. These are all connected into a single column, as the subdivision is for other purposes. Water is conceptualized to flow downward through this column as a set flow rate, which can be seen by examining any of the cell definitions (for example, in CapLayers). The rate of water flow from one cell into another cell is defined as an Outflow, on the Outflow tab of the Cell Pathway Properties dialog. Each of the cells in the column has an outflow defined for the Medium Water, with the same volumetric flow rate: WaterFlux. This is defined as the InfiltrationRate times the cross-sectional area of the column, which is the area of the top slope part of the Federal Cell. (Also note that as of version 1.2 of the Modeling Report, this disposal cell is known by its former name, the Class A South Cell). This WaterFlux is the same value for all cells in the column, so by definition the mass balance of water is zero. Each cell in the column is defined to have the same volume of water coming in as going out. A similar setup is used for the side slope cells, though for the purposes of version 1.2 of the Modeling Report, there is no inventory to contaminate the side slope.

At the water table, where the model joins the 1 D vertical unsaturated column to a 1 D horizontal saturated zone column, the allocation of recharge water is a bit more complicated, but again is in the control of the modeler. The saturated zone column has 25 cells that underlie the embankment, and several cells that lie between the embankment and the monitoring well. A conceptual illustration of this arrangement is shown in Figure 2. The allocation of recharge water from the top slope and side slope columns is illustrated in the Waste_to_Footprint and UZ_SZ_Illustration containers. The figures shown in those containers are reproduced in Figures 3 and 4 below. All accounting of flow from the top slope and side slope into the saturated zone is accomplished in the Waste_to_Footprint container, where the relative areas of the top slope and side slope are calculated and the volumetric flux of recharge is allocated to each of the 25 cells comprising the saturated zone beneath the embankment footprint.

Given the complexity of this bookkeeping of water flow, a modeler would like to have assurances that it was performed correctly, and these calculations are provided at the bottom of the Waste_to_Footprint container. To wit: There are

two checksum Summation elements, named Recharge_SS_Checksum and Recharge_TS_Checksum. These add up the fractions applied to the recharge volumes into each of the 25 saturated zone cells. The fractions must sum to 1 for the top slope and for the side slope, and a simple check of the values of these summation elements verifies that indeed they do. The fractions are applied to the WaterFlux coming from the top slope, so that it is subdivided into the 25 saturated zone cells appropriately. The side slope has a similar calculation. Since WaterFlux is allocated by several fractions that all sum to 1, mass balance of recharge water is verified.

Within the horizontal column that represents the saturated zone (in the SZ_ClassASouthFootprint container), a somewhat different approach is used. Here, all saturated zone cells are connected by flow volume, similar to the 1 D unsaturated zone columns, though the volumetric flux from one cell to the next is defined by SZ_WaterFlux. This is the product of the SZ_DarcyVelocity (calculated by application of the Darcy equation in the SatZone_Parameters container) and SZ_CrossSectionalArea, the cross-sectional area of the saturated zone column, perpendicular to the groundwater flow direction. A natural question to ask is how a constant flow through the saturated zone column is indicated given that at each cell within the footprint of the embankment, water is being added to the flow? For each footprint cell in the saturated zone, flow is entering from the upstream cell (SZ_WaterFlux), as well as from recharge from the top slope and side slope, yet flow is leaving to the next cell downstream only at the rate of SZ_WaterFlux. This would seem to cause a mass balance problem, and will generate warnings in the model run log, but in fact these flows are taken into account.

This is where a subtle GoldSim modeling construct comes into play. If a GoldSim Cell Pathway is defined to have more water leaving it than coming in, GoldSim simply makes up the difference, as it were, with clean water. What GoldSim is actually doing is honoring the fundamental definition of how much water is in the cell, as discussed earlier. If there is 1 m³ of water in a cell, then there is always 1 m³ of water in the cell, irrespective of the flows in and out. GoldSim does not actually move water—GoldSim moves contaminants, and moves them in accordance with how much contamination would be transported if a given volume of water were moved. If we have a cell with 1 m³ of water in it, and set up an advective flux link to another cell at a rate of 0.1 m³/y, and have defined no inflow to the upstream cell, GoldSim will move 1/10 of the contamination in water to the downstream cell. The volume of water in the upstream cell remains the same, so in effect 1/10 of the water moved out and was replaced with clean water from some implied source. GoldSim modelers must be keenly aware of this behavior and account for it.

In the case of version 1.2 of the Modeling Report saturated zone, cells are rather overfilled with water. That is, each cell is expelling a water flux of $SZ_WaterFlux$, but is receiving water through $SZ_WaterFlux$ (from the upstream SZ cell) as well as water from its fraction of recharge from the top slope and the side slope. Since the volume of water in the SZ cell never changes (it is set simply to the porosity of the solid medium that is in the cell), the water from the top slope and side slope effectively disappears, but, importantly, the contamination associated with that water remains in the SZ cell. This is a conservative assumption with respect to concentration within the saturated zone. It's as if there were a filter along the bottom of the aquifer that allowed clean water to pass through, but not contamination. As the water flows through the SZ column under the footprint, then, it receives more and more contamination, and the concentration increases since the clean water is implicitly removed from the system.

An alternative way to model the contamination of the saturated zone would be to allow each cell to leak water out the bottom (or the sides) at the same rate that water is entering from recharge. This would explicitly account for water in the system, and would have the effect of removing contamination from the SZ horizontal column and introducing it into the lower groundwater and hence removing it from the Model. This would also reduce concentrations at the monitoring well. Since the deeper groundwater hydraulics are not well understood, the conceptual model for the site is defined to keep all groundwater contamination "in bounds", even if it means erring on the side of increased concentrations at the virtual monitoring well. The 1 D column model, which does not permit flow out the bottom or sides, is conservative in this regard.

4) The Peclet number (Pe) is given by Bear (1972, p. 606) as

$$Pe = \frac{V d}{D_d}$$

where

- V is the velocity (L/T),
- d is the mean grain size or other characteristic length of the medium (L), and
- D_d is the diffusion coefficient (L²/T).

The velocity is calculated as

$$V = \frac{q}{n} = \frac{Ki}{n}$$

where

- q is the volumetric flux (L/T),
- n is the porosity of the medium (—),
- K is the saturated hydraulic conductivity (L/T), and
- i is the hydraulic gradient (—).

The diffusion coefficient of the medium is

$$D_d = D_b n^{4/3}$$

where

- D_b is the bulk diffusion coefficient of ["UO"] $_2^{(2+)}$ in water (L²/T).

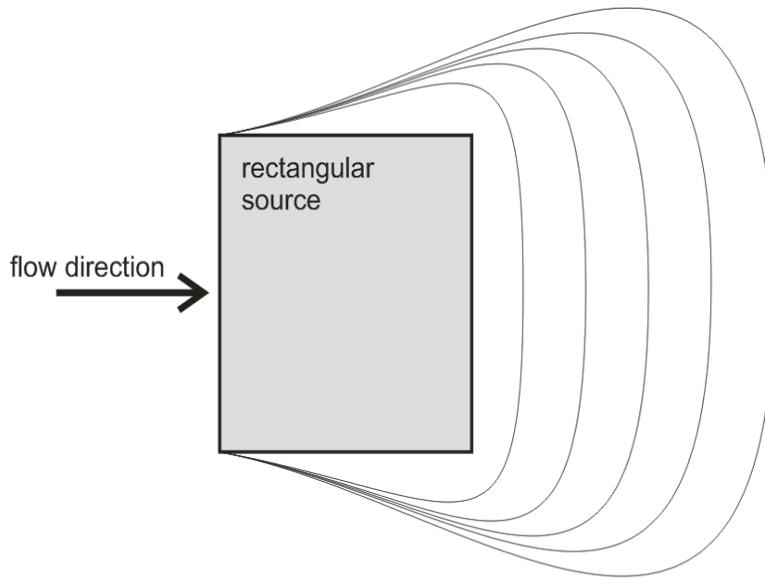
Values used for the Peclet number calculation taken from version 1.2 of the Modeling Report and are listed below. The shallow aquifer occurs in Unit 2 below the Federal DU Cell. Unit 2 is composed primarily of clay so a mean grain size of 2 μm was used.

Parameter	Value	Units
K	9.6×10^{-04}	cm/s
i	6.9×10^{-04}	—
n	0.29	—
d	2.0×10^{-4}	cm
D_b	4.3×10^{-6}	cm ² /s

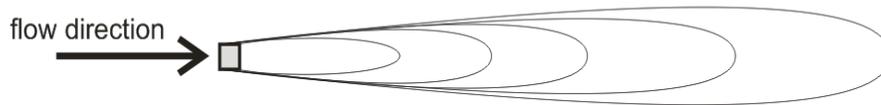
Using these values a Peclet number of 6×10^{-4} is obtained. Comparison with Figure 10.4.1 from Bear (1972, p. 607) indicates that a Peclet number of this magnitude is characteristic of a diffusion-dominated transport system.

Illustration of a rectangular source plume and approximations

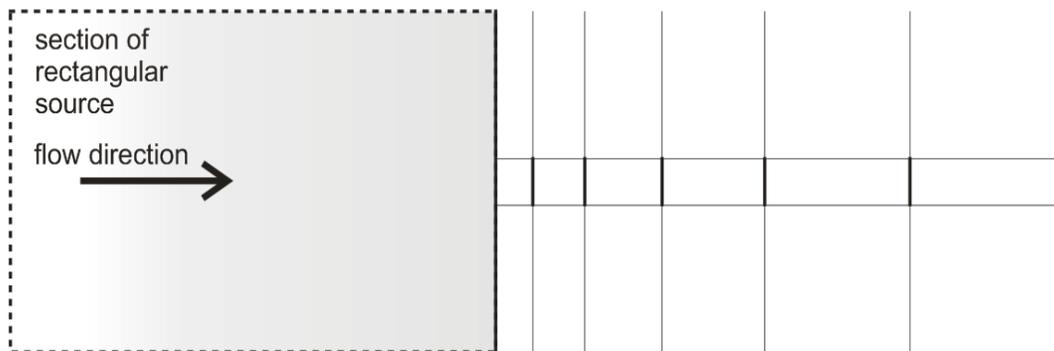
A rectangular source produces a contaminant plume with this generalized shape:



At large distances, the plume is approximated by a point source:



Close to the source, the plume is approximated by an infinite line source, or a 1-dimensional column, where dispersion transverse to flow has no effect:



J Tauxe • June 2014

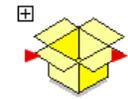
Figure 1. Approximations of a rectangular source plume.

Saturated Zone

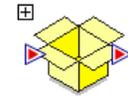
The saturated zone (SZ) underlies the entire site, and receives recharge from all disposal units. Overall, the SZ flow is considered unidirectional, uniform, and steady, meaning that it all flows one direction at a constant rate. The saturated thickness that contributes to flow varies as the water table varies, but is assumed to be completely contained within Unit 2.

Special notes for the DU Class A South Embankment model:

In order to assess concentrations at a given perimeter monitoring well, the disposal units upstream of that well are included. For the purposes of this initial model, which considers only the Class A South embankment, we consider only recharge from that disposal unit to a well at the appropriate distance downgradient.



UZ_SZ_Illustration



[SatZone_Parameters](#)

Saturated Zone modeling

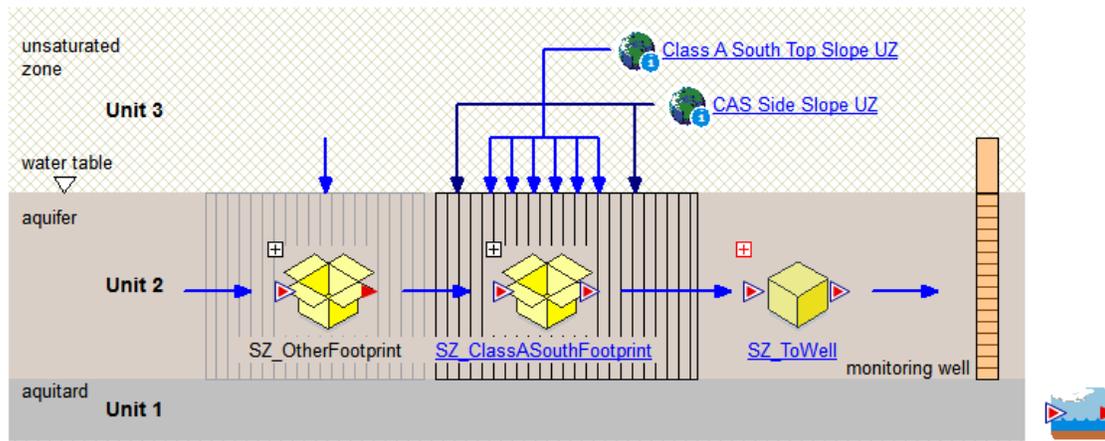


Figure 2. Clive DU PA Model SatZone container.

Mapping of Class A South Waste Cell to the SZ Footprint

Recharge from the TopSlope and SideSlope sections of the embankment is fed into the saturated zone according to the spatial distribution of those parts of the embankment with respect to the footprint.

[Class A South Dimensions](#)

The TopSlope, and SideSlope parts of the embankment are modeled in separate columns, and their contributions to recharge of the footprint are location-dependent. The footprint section of the SZ is subdivided into several cells, and these are set to receive a different amount of the recharge, per the diagram and Expressions below.

There is opportunity for confusion in terminology, since the embankment dimensions, as shown in Class A South Dimensions, has length defined going east/west and width defined going north/south.

In the present situation, the width is defined as being perpendicular to groundwater flow and the length as parallel.

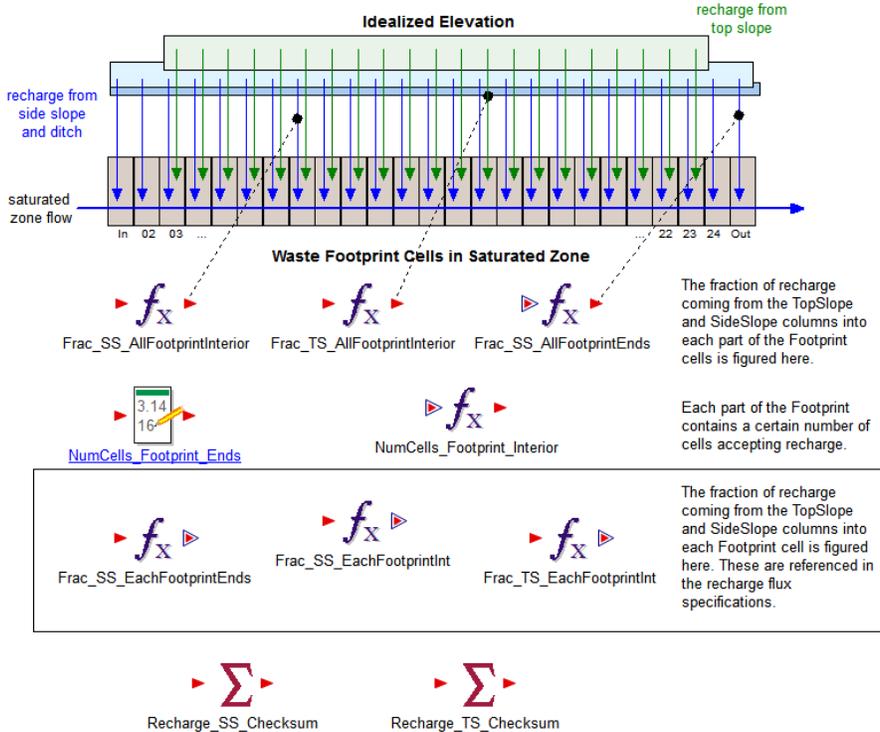
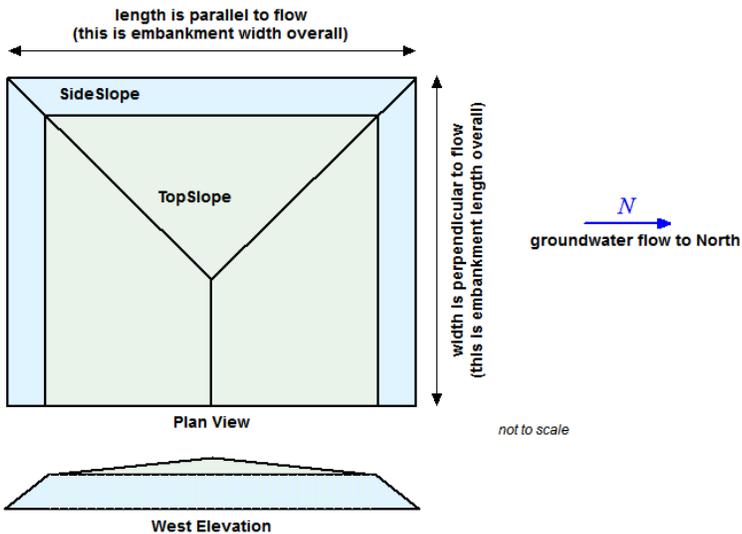


Figure 3. Clive DU PA Model Waste_to_Footprint container.

Saturated Zone Conceptual Model Illustration

The idealized geometry of disposal embankments and their relationship to the saturated zone are illustrated here.

Modeling Water Flow for the Class A South Embankment

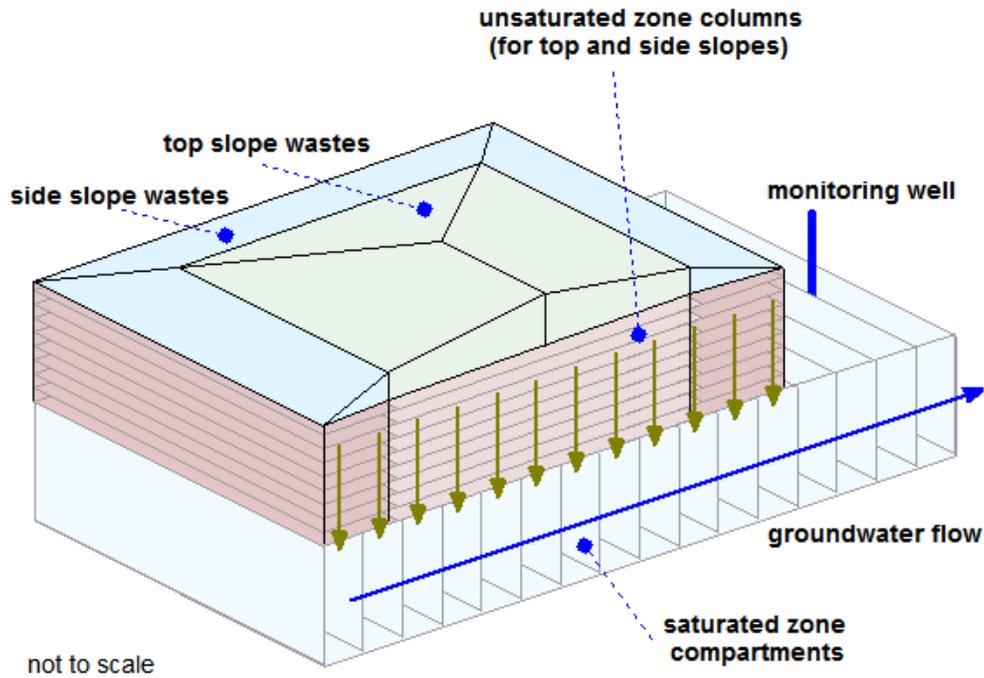


Figure 4. Clive DU PA Model UZ_SZ_Illustration container.

70. INTERROGATORY CR R313-25-7(2)-70/2: GULLY SCREENING MODEL

The PA must consider gully erosion and its effects on infiltration, radon emanation, and groundwater contamination. ES should ensure that the model includes an analysis of the effects of gully formation on cover system infiltration, radon emanation, and groundwater contamination. We look forward to reviewing this response when the revised ET cover report is available.

EnergySolutions' Response: See the response to Interrogatory CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS.

71. INTERROGATORY CR R313-25-8(4)(A)-71/1: BIOTIC PROCESSES IN GULLY FORMATION

Round 1 Interrogatory Response is satisfactory.

72. INTERROGATORY CR R313-25-8(4)(A)-72/1: DE MINIMIS DOSE VALUE

Round 1 Interrogatory Response is satisfactory.

73. INTERROGATORY CR R313-25-19-73/1: ALARA CONCEPT

Round 1 Interrogatory Response is satisfactory.

74. INTERROGATORY CR R313-25-8(5)(A)-74/1: TAILORED DISCUSSION OF SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

75. INTERROGATORY CR R313-25-7(9)-75/1: BRANCHING FRACTIONS

Round 1 Interrogatory Response is satisfactory.

76. INTERROGATORY CR R313-25-7(10)-76/1: QUALITY ASSURANCE PROJECT PLAN SIGNATURE PAGE

Round 1 Interrogatory Response is satisfactory.

77. INTERROGATORY CR R313-25-7(10)-77/1: QUALITY ASSURANCE PROJECT PLAN PAGE NUMBERING

Round 1 Interrogatory Response is satisfactory.

78. INTERROGATORY CR R313-25-7(10)-78/2: GOLDSIM MODEL CALIBRATION

Since we could identify very little of this type of information within the published literature, it would provide some measure of confidence in the GoldSim DU PA model if ES provided DRC with documentation of any of the results of any “global sensitivity analysis” that has been performed on the GoldSim DU PA model. We look forward to reviewing the revised report.

EnergySolutions’ Response: Appendix 15(II) - Sensitivity Analysis Results from version 1.2 of the Modeling Report has been expanded to include more information on methods than previously, and a sensitivity analysis results appendix (Appendix 15(II)) has been added that shows all of the sensitivity analysis results.

79. INTERROGATORY CR R313-25-7(10)-79/1: CRITICAL TASKS AND SCHEDULE

Round 1 Interrogatory Response is satisfactory.

80. INTERROGATORY CR R313-25-7(10)-80/2: TESTING OF GOLDSIM ABSTRACTIONS

Since we could identify very little of this type of information within the published literature, it would provide some measure of confidence in the GoldSim DU PA model if ES provided DRC with documentation of any of the model validation/verification and benchmarking that Neptune has conducted. We look forward to reviewing the revised report.

EnergySolutions’ Response: Section 5 of this interrogatory response document provides “Verification Plan – GoldSim Version 10.50 SP1” published by the GoldSim Technology Group LLC (2011). GoldSim (2011) documents verification completed to demonstrate that the GoldSim software performs its numerical and logical operations correctly.

It is presumed that what is meant by “GoldSim abstractions” is the relationship between a process as modeled in version 1.2 of the Modeling Report and how it is modeled in some external process modeling software, such as HELP or HYDRUS. In the case of HELP, which was referenced in version 1.0 of the Modeling Report, no abstraction was involved. Infiltration values calculated using HELP were used directly to build distributions representative of the model’s behavior. Appendix 5 - Unsaturated Zone from version 1.0 of the Modeling Report of May 2011 states:

“It is important to note that these deterministic (fixed, constant) values from the HELP modeling were calculated external to GoldSim, not directly in the probabilistic Clive DU PA Model itself. They are used in the development of the uncertain stochastic distributions that are used in the GoldSim model, as developed in subsequent sections, and summarized in Section 1.0, Table 1.”

Other than the development of statistical distributions for infiltration rates, no abstraction in version 1.0 of the Modeling Report occurred.

A similar approach was taken in version 1.2 of the Modeling Report, with its revised evapotranspirative (ET) cover that is modeled using HYDRUS. The results from several HYDRUS simulations, which covered variations in saturated hydraulic conductivity, van Genuchten’s α and van Genuchten’s n , are used to develop a statistical regression fit of the infiltration rate. This regression surface is derived directly from the HYDRUS results and is used directly in version 1.2 of the Model, so again no GoldSim abstraction was involved beyond the regression fit. Since the implementation of infiltration rates in version 1.2 of the Model is based directly on the statistical fit to the results of the HYDRUS modeling, and no separate modeling is performed, no verification is indicated other than a quality assurance check to assure that the values were properly transferred.

These approaches are described in the Clive DU PA Model container \Disposal\ClassASouthCell\TopSlope\Column_Transport\WaterTransport as well as in Appendix 5 - Unsaturated Zone Modeling from version 1.2 of the Modeling Report.

81. INTERROGATORY CR R313-25-7(2) AND 7(6)-81/2: COMPARISON OF DISPOSAL CELL DESIGNS

None of the ES responses provided the requested comparison between the Class A West Cell and the Federal Cell cover designs. It is our belief that such a comparison of the structural design and expected performance of the cells with rock-armor and/or ET cover systems is needed to enable DRC to compare proposed and existing designs and ensure that the proposed designs comply with R313-25-7(2) and (6).

At present, only a rock-armor cover system has been approved for the Class A West cell, and the proposed ET cover system for that cell is undergoing DRC review and has not yet been approved. ES should compare the proposed Federal Cell with all alternative cover systems that have been proposed for the Class A West cell, or with an approved cover system only.

The proposed Federal Cell that contains the DU waste must have an approved design such that its cover system is fully integrated with, or completely isolated from, the existing 11e.(2) cover system, as appropriate, based on applicable federal and state laws and regulations. ES should show how the proposed ET cover system, based on soil, will be integrated with, or isolated from, the existing 11e.(2) rock-armor cover system. ES should describe how the design of that part of the Federal Cell containing DU waste will meet all potentially applicable DOE and NRC regulations, including types of wastes disposed of and connection, or lack of connection, with nearby waste cells, and also types of influence, or lack of influence, on or by other nearby waste cells, including the existing 11e.(2) cell.

At this time, DRC does not expect ES to provide a “stand-alone engineering design report,” as was requested in the original interrogatory. However, a more complete description of structural design and performance is requested, particularly in the design of features of the proposed cell contrasting with features of existing cells. We look forward to reviewing the revised information.

EnergySolutions’ Response: See the response to interrogatory CR R313-25-7(2)-160/2: COMPARISON OF CLASS A WEST AND FEDERAL CELL DESIGNS.

82. INTERROGATORY CR R313-25-20-82/2: LIMITATION ON INADVERTENT INTRUDER SCENARIOS

As described in the discussion of Interrogatory CR R313-25-8(4)(b)-07/2: Applicability of NRC Human Intrusion Scenarios and Interrogatory CR R313-25-20-12/2: Selection of Intrusion Scenarios, we do not accept that position. ES must provide arguments as to why the proposed inadvertent intruder scenarios should not be included, or else include them in the DU PA. We look forward to reviewing the revised report.

EnergySolutions’ Response: See the response to Interrogatory CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

83. INTERROGATORY CR R313-25-20-83/2: INTRUDER-DRILLER AND NATURAL RESOURCE EXPLORATION SCENARIOS

ES did not explain why drilling to explore for water had been included in a previous PA (EnergySolutions, 2012) based on “a very remote but finite chance that someone in the future might drill a well to determine whether potable groundwater exists at the Clive, UT site,” but was excluded here. ES also did not address the possibility of mineral exploration. Additional findings relevant to this topic are found in the discussion of Interrogatory CR R313-25-8(5)(a)-29/2: Limitation to Current Conditions of Society and the Environment. ES needs to address these issues as well as those found in Interrogatory CR313-25-8(4)(b)-

07/2 before this interrogatory can be closed. We look forward to reviewing the revised report.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

84. INTERROGATORY CR R313-25-7(6)-84/2: BELOW-GRADE DISPOSAL OF DU

We look forward to reviewing the new material on the cover system discussing its potential impacts on infiltration and groundwater, and the potential effects of erosion on below-grade disposal and on the effects of Aeolian deposition on near-term and deep time modeling. ES should ensure that these revisions are consistent with and resolve other related DEQ concerns in Interrogatories CR R313-25-8(5)(a)-18/2: Sediment Accumulation and CR R313-25-8(4)(d)-159/2: Embankment Damage by Lake Formation.

In response to the request under this interrogatory to “describe the types, forms, and locations of intruder barriers,” ES responded that “there is no requirement for an intruder barrier,...” and did not provide additional information. However, in response to a similar question in Interrogatory CR R313-25-8(4)(b)-07/1: Applicability of NRC Human Intrusion Scenarios, ES responded that the “intruder barriers of EnergySolutions’ Federal Cell are the same as its licensed Low Level Radioactive Waste Disposal facility, which are those defined in UAC R313-25-2....” ES should clarify these apparent conflicting statements. We look forward to reviewing the revised report.

EnergySolutions' Response: The Condition 35 Compliance Report has been revised to reflect the response to interrogatory CR R313-25-8(4)(b)-07/2: Applicability of NRC Human Intrusion Scenarios.

85. INTERROGATORY CR R313-25-8(4)(A)-85/1: UNCERTAINTY DISTRIBUTIONS ASSIGNED TO DOSE CONVERSION FACTORS

Round 1 Interrogatory Response is satisfactory.

86. INTERROGATORY CR R313-25-8(5)(A)-86/2: CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL

ES did not address expanding the current limited deep time model to address “other” exposure pathways. Such pathways include wave-cutting increasing access to waste, which could occur if waves were to remove the top portion of the embankment, followed by retreat of the lake, leaving non-dispersed DU exposed.

ES should construct a PA analysis scenario to simulate possible dose effects for this situation.

EnergySolutions' Response: Additional features, events, and processes have been added to Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report. However, these additions expressly do not constitute “exposure pathways”. As noted by NRC,

“Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]” [emphasis added] (NUREG-1573, pg. 3-10)

The Rebuttal requests that the effects of other pathways such as wave-cutting of the embankment be addressed. With the current disposal configuration placing all depleted uranium waste below grade, the dispersal mechanisms previously considered in the Deep Time component of version 1.0 of the Model are no longer applicable.

87. INTERROGATORY CR R315-101-5.3(6)-87/2: ORAL TOXICITY PARAMETERS

The discussion of RfD for uranium toxicity provided by ES is adequate. However, we do not agree that ingestion of groundwater is not a pathway. See, inter alia, Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

88. INTERROGATORY CR R313-25-19-88/2: COLLECTIVE DOSE AND ALARA

The ES response commits to resolve this issue in the next report revision. We look forward to reviewing the revised text.

EnergySolutions' Response: Collective doses and ALARA have been corrected in Version 1.2 of the Modeling Report.

89. INTERROGATORY CR R313-25-7(9)-89/2: CONTAMINATION LEVELS IN DUF6

We note that the correct regulatory citation should actually be UAC R313-25-8(5)(c). However, we do not understand why that regulation addresses the main point of the interrogatory. R313-25-8(5)(a) specifies concentrated DU and other wastes as separate materials. The question remains as to why the PA did not include “other wastes” as required by R313-25-8(5)(a). This issue needs to be resolved if ES is to demonstrate compliance with R313-25-8(5)(a). We look forward to reviewing the revised text.

EnergySolutions’ Response: See the response to interrogatory CR R313-25-8(5)(A)-157/2: INCLUSION OF DU AND OTHER WASTES IN PA.

90. INTERROGATORY CR R313-25-7(1–2)-90/2: CALIBRATION OF INFILTRATION RATES

We look forward to reviewing the new ET cover design for the Federal Cell and the related PA model results. Some of the information we expect to see regarding the new ET cover for the Federal Cell includes the following:

- Cover layer characteristics: Characteristics include thickness, types of soil texture, particle gradation specifications, moisture retention characteristics, slope angle, slope length, upgradient drainage areas, slope runoff coefficients, leaf area index, and soil porosity and saturated permeability.
- Effects of aging on hydraulic conductivities of cover materials.
- Duration of model simulations: ES should ensure that all infiltration and contaminant transport models simulate cover performance for at least 10,000 years or more, as called for in Interrogatory CR R313-25-8(4)(d)-155/1: Cover Performance for 10,000 Years.

- Coordination of interrogatory resolution: When describing the ET cover design, ES should coordinate responses to other related interrogatories, including the following:
 - CR R313-25-7(2)-05/1: Radon Barrier
 - CR R313-25-7(3)-60/1: Modeled Radon Barriers
 - CR R313-25-7(1)-100/1: Groundwater Recharge from Precipitation
 - CR R313-25-8(4)(a)-112/1: Hydraulic Conductivity
 - CR R313-25-8(4)(d)-153/1: Impact of Pedogenic Process on the Radon Barrier
 - CR R313-25-8(5)(a)-176/1: Representative Hydraulic Conductivity Rates

We look forward to reviewing the revised report. Additional information related to this topic and the ET cover system will be presented in an upcoming interrogatory on the promised ES ET cover system report.

EnergySolutions' Response: See the responses to interrogatories CR R313-25-7(2)-91/2: DESIGN CRITERIA FOR INFILTRATION, CR R313-25-7(2)-05/2: RADON BARRIER, CR R313-25-8(4)(d)-155/2: COVER PERFORMANCE FOR 10,000 YEARS, CR R313-25-7(3)-60/2: MODELED RADON BARRIERS, CR R313-25-7(1)-100/2: GROUNDWATER RECHARGE FROM PRECIPITATION, CR R313-25-8(4)(A)-112/2: HYDRAULIC CONDUCTIVITY, CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER, and CR R313-25-8(5)(A)-176/2: REPRESENTATIVE HYDRAULIC CONDUCTIVITY RATES.

91. INTERROGATORY CR R313-25-7(2)-91/1: DESIGN CRITERIA FOR INFILTRATION

Information related to this topic and the ET cover system will be presented in an upcoming interrogatory related to the ES ET cover system report.

EnergySolutions' Response: Appendices 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site and 3 – Embankment Modeling from version 1.2 of the Modeling Report have been revised to address the design of the proposed Federal Cell evapotranspirative Cover.

92. INTERROGATORY CR R313-25-20-92/2: INADVERTENT INTRUDER DOSE STANDARD AND SCENARIOS

It is our understanding that the Utah DEQ Director has determined that the acceptable level is a policy decision of DEQ/DRC.

EnergySolutions’ Response: In its “Basis of Interrogatory,” the Division acknowledges that NRC precedent establishes a dose limit of 500 mrem/yr for the inadvertent intruder. Similarly, Utah law prohibits the Radiation Control Board from adopting rules,

“for the purpose of assuming responsibilities from the United States Nuclear Regulatory Commission with respect to regulation of sources of ionizing radiation, that are more stringent than the corresponding federal regulations which address the same circumstances” unless the board “makes a written finding after public comment and hearing and based on evidence in the record that corresponding federal regulations are not adequate to protect public health and the environment of the state,” and such findings are “accompanied by an opinion referring to and evaluating the public health and environmental information and studies contained in the record which form the basis for the board’s conclusion” Utah Code Ann. § 19-3-104(8) and (9) –

Use of a “policy decision” by the Division for application of an intruder dose limit other than 500 mrem/year is expressly prohibited.

93. INTERROGATORY CR R313-25-22-93/2: STABILITY OF DISPOSAL SITE AFTER CLOSURE

See DEQ comments on the ES responses to the following interrogatories:

CR R313-25-8(5)(a)-03/1: Deep Time – Sediment and Lake Concentrations

CR R313-25-8(5)(a)-86/1: Consequences of Sedimentation on Disposal Cell

CR R313-25-8(4)(d)-129/1: Lake Erosion

CR R313-25-8(4)(d)-131/1: Potential Wave Energy

We look forward to reviewing the revised report.

EnergySolutions’ Response: The discussion of lake cycles in Appendix 13 – Deep time Assessment has been revised. Additionally, see the responses to interrogatories CR R313-25-8(5)(a)-03/2: DEEP TIME – SEDIMENT AND LAKE CONCENTRATIONS, CR R313-25-8(5)(A)-86/2: CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL, CR R313-25-8(4)(D)-129/2: LAKE EROSION, and CR R313-25-8(4)(D)-131/1: POTENTIAL WAVE ENERGY.

94. INTERROGATORY CR R313-25-3(8)-94/1: ULTIMATE SITE OWNER

Round 1 Interrogatory Response is satisfactory.

95. INTERROGATORY CR R313-25-8(4)(A)-95/2: ESTIMATION OF I-129 CONCENTRATIONS

We look forward to reviewing the revised report.

EnergySolutions' Response: The discussion of I-129 concentrations has been expanded in Appendix 4 – Waste Inventory from version 1.2 of the Modeling Report.

96. INTERROGATORY CR R313-25-8(4)(A)-96/2: CURRENT AND FUTURE POTABILITY OF WATER

We find the position on limited yield to be reasonable with regard to the shallow unconfined aquifer. However, groundwater is being extracted for beneficial uses in the Clive area presumably from the deeper confined aquifer. For example, ES uses or has used groundwater from a local well to suppress dust and decontaminate equipment and waste containers.

Several deep wells have been drilled near Clive, Utah. A log for one well just west of the Clive turnoff from Interstate 80 was drilled in 1969 to a depth of 350 feet for the Cox Construction Company. The intended use was for highway construction sprinkling and compaction (see <http://waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-545>). The location is said to have been S 2100 ft E 1100 ft from NW cor, Sec 18, T 1S, R 11W, SLBM. The well is reported to have produced groundwater during a pumping test in 1969 at a rate of 600 gpm over 10 hours of testing (click on Well Log link at <http://waterrights.utah.gov/cgi-bin/docview.exe?Folder=welllog427264>). The well is now associated with Utah water right 16-722, with a well whose location is said to be at S 1900 ft W 1400 ft from NE cor, Sec 18, T 1S, R 11W, SLBM. The well log shown on the Utah Water Rights website is the same as that for the well previously described for water right 16-545. Groundwater pumped from the well is reported to be used for dust suppression and control and truck washdown (<http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-772>). The well reportedly had produced about 15,313,800 gallons of groundwater by 2008. Another well, located about 3 miles east of the Clive low-level waste disposal facility, is related to Utah groundwater right 16-190 by Skull Valley Company for water for livestock (see <http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-190>). The depth is 293 feet, with water down at 263 feet. The flow is given as only 0.0377 cfs. Another reference shows a map for the Grassy Mountain Facility, northwest of Clive, with wells called the North USPCI Water Supply Well and the South USPCI Water Supply Well (Hansen, Allen and Luce, Inc., 2010). USPCI also drilled a well west of the Clive facility (<http://www.waterrights.utah.gov/cblapps/wrprint.exe?wrnum=16-796>). That well was drilled in 1992, and a well test was conducted then with an air lift yield of

0.134 cfs. Repairs were attempted in 1997, along with pumping at 350 gpm, before the well was abandoned.

The ES response has not addressed the possibility that drawdown associated from these or similar wells located just off site at Clive could pull contamination from the Federal Cell through the underlying unsaturated zone and water table via discontinuities in the confining layer into the confined aquifer, from where it could be pumped to the surface and put to beneficial use. Although water from the deeper aquifer would probably be too saline for direct domestic use without treatment, it could be used for dust suppression and similar industrial purposes.

It is also possible that this deep groundwater could be treated by techniques such as reverse osmosis and be used as drinking water, as is currently happening at the nearby Delle Auto Truck Stop. This is also the case at Aragonite, a commercial hazardous waste incinerator owned by Clean Harbors, located about 4 miles east of Clive, where two deep wells exist (between 700 and 800 feet bgs) (Earthfax 1999). Both of these deep wells, located directly to the northeast of the Aragonite facility, are currently being pumped to supply drinking water to approximately 100 employees through a reverse osmosis system. Therefore, a drinking water scenario in an industrial setting from a deep well in the confined aquifer outside the facility's boundaries should be considered.

It is our understanding that local health organizations regulate small sources that do not meet the test of a public water system as described in R309-100-4. In the case of Tooele County, the county health department requires that for any culinary water use, the water user needs to pay for what the department refers to as the "full chemical test" based on EPA standards. These EPA standards do not include "radiologicals". Thus, the water user would not necessarily know about potential exposure to radioactive contaminants. In the case of reverse osmosis treatment, the contaminants would partition between the treated water and the wastewater byproduct, creating multiple exposure pathways.

Another pathway that should be examined is the flow of contaminants from the unconfined aquifer to the confined aquifer through the annulus between borehole and the well casing. We recognize that drilling regulations require boreholes to be sealed. In Tooele County, borehole sealing inspections are performed by the county health department. However, failure to properly seal the annular space is not unusual in well drilling.

Both of these groundwater exposure pathways need to be examined and the results compared to the R313-25-19 groundwater dose limit.

EnergySolutions' Response: EnergySolutions has assessed the possible inadvertent exposure to an intruder constructing and industrially using water from the deeper confined strata that has become cross-contaminated by gradient-driven communication with depleted uranium-related wastes that have migrated into the upper unconfined aquifer, (see the response to Interrogatory CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS for the projected industrial intruder results). Because of the high saline and total dissolved solid content of the confined aquifer (similar to that found in the unconfined aquifer), groundwater pumped from the deep aquifer is classified as Category IV and therefore unpotable.

However, important hydrogeologic differences exist between a possible inadvertent industrial intruder well and the other examples cited by in the Division's Interrogatory. For example, the bore logs of both the Skull Valley Company and Aragonite wells located several miles east of the Federal Cell proposed location reveals they are primarily an extended gravel zone within the recharge zone of the foothills of the Cedar Mountains (extremely dissimilar to that immediately adjacent to the proposed Federal Cell).

EnergySolutions further recognizes that while not producing water within similar geohydrological conditions, NRC suggests the awareness demonstrated by Aragonite well owners for the need to treat the Class IV groundwater prior to ingestion,

“that current local well-drilling techniques and/or water use practices will be followed at all times in the future.” (NUREG-1573).

Therefore, since current local practices for the area surrounding Clive that share similar groundwater characteristics and yields do not include groundwater drinking wells without known treatment, consideration of a groundwater ingestion exposure pathway is inappropriate and counter to NRC guidance.

See also the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

97. INTERROGATORY CR R313-25-8(4)(A)-97/2: NEED FOR POTABLE AND/OR INDUSTRIAL WATER

As discussed under Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, ES fails to mention a nearby well that has been used for dust suppression and equipment decontamination. Assuming that this water is obtained from the deeper confined aquifer, it could become contaminated from pollution in the overlying water table aquifer and cause exposure to surface workers. Likewise, future treatment of the deep confined aquifer could render this water

beneficial for other industrial applications and drinking water. These possibilities need to be examined.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

98. INTERROGATORY CR R313-25-7(1)-98/1: MONTHLY TEMPERATURES

Round 1 Interrogatory Response is satisfactory.

99. INTERROGATORY CR R313-25-7(1)-99/1: EVAPORATION

Round 1 Interrogatory Response is satisfactory.

100. INTERROGATORY CR R313-25-7(1)-100/2: GROUNDWATER RECHARGE FROM PRECIPITATION

In the process of modifying the text for the revised report, ES should provide a reference for the quoted text in its response to this interrogatory (EnergySolutions 2014, pages 102–103). ES should also document the presence or absence of rip rap on part of the side slopes; if rip rap is present anywhere, the model should be amended to account for reduced evaporation in these areas of rip rap. We look forward to reviewing the revised report.

EnergySolutions' Response: The statement from Section 3.2.3 of Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site has been referenced. Note that the last few sentences in the quoted text in the Round 1 Interrogatory Response document were not included in Appendix 2, because they were considered unnecessary to fulfill the request of the Interrogatory.

Riprap is not used in the cover design. SWCA (2013, p.5) describe the design as “the cover designs ... include riprap-lined diversion ditches to direct water away from the ET cover, but the top and sides of the ET cover do not include riprap as part of the cover materials.” See the response to interrogatory CR R313-25-7(2)-179/1: RIP RAP as to continued Division-authorized use of riprap for Clive’s surface water management ditch network.

101. INTERROGATORY CR R313-25-7(1)-101/2: NATURE OF UNITS 1 AND 2

The ES response is largely satisfactory, providing that DRC finds the promised description in the revised report to be adequate. However, ES should include in the revised report all of the additional text and description provided in its response to this interrogatory. Furthermore, ES should document and explain the cause of

the shallow groundwater mounding in the vicinity of Wells MW-60 and MW-63 in the southern part of Section 32 (see *EnergySolutions*, 2014) and discuss quantitatively its impact throughout time on vertical components of hydraulic gradient. We look forward to reviewing the revised report.

EnergySolutions' Response: The descriptions of units 1 and 2 materials in Section 3.3.1 of Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site from version 1.2 of the Modeling Report has been revised. The shallow groundwater mounding in the vicinity of wells MW-60 and MW-63 has been also added to Appendix 2.

102. INTERROGATORY CR R313-25-7-102/1: SEISMIC ACTIVITY

Round 1 Interrogatory Response is satisfactory.

103. INTERROGATORY CR R313-25-7-103/2: HISTORICAL FLOODING

ES does not discuss historical non-chronic flooding at the site, as was requested in the interrogatory. After times of heavy precipitation, water at the site may collect in depressions along the surface in various places. ES should provide details about locations and depths and how the water management system operates to remove the water. Reference to Clive's exterior berm system, as found in the ES LLRW license renewal application dated March 6, 2013, is not appropriate, in that (1) that berm is designed for the active operational life of the facility, and (2) that berm will not persist after facility closure. If it were to, the need for active, ongoing maintenance would be evident; however, such maintenance does not comply the requirements of several state regulations for LLRW, including, but not limited to, R313-25-8(4)(d), R313-25-22, and R313-25-24(1). Consequently, ES should revise its response to address and resolve this interrogatory. We look forward to reviewing the revised report.

EnergySolutions' Response: As noted in the Rebuttal quoted above, reference to operational procedures and conditions is not appropriate, since post-closure conditions should assume no active management. Similarly, historical non-chronic flooding due to site topography during operations is not relevant to the PA. Should localized depressions near the closed embankment accumulate water for short periods of time, their impact is expected to be minimal since evaporation far exceeds precipitation at Clive. See also the response to Interrogatory CR R313-25-8(4)(A)-68/2: DISTRIBUTION OF HYDRAULIC GRADIENTS.

104. INTERROGATORY CR R313-25-7(2)-104/2: INFILTRATION IN THE PRESENCE OF RIP RAP OR NATURAL ROCK

Upcoming report revisions will add new text and better describe the model use. Therefore, the ES response will be evaluated as part of the more detailed review of the HYDRUS modeling during the review of the forthcoming revised PA. With reference to the proposed text for Section 7.2.1.6 of the Conceptual Site Model report, ES should clarify which disposal cell design is being referred to (the rip rap or an ET design). Any rip rap on side slopes of an ET cover system should be described. ES should also explain and justify how this design will mitigate future pluvial lake flooding at Clive. We look forward to reviewing the revised report.

EnergySolutions' Response: Section 7.2.1.6 of Appendix 2 - Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site has been revised to address the Federal Cell's disposal design and evapotranspirative cover system. The design's performance regarding pluvial lake flooding has also been addressed. The currently-approved use of riprap to line Clive's drainage ditch network will not require revision as a result of the construction of the Federal Cell.

105. INTERROGATORY CR R313-25-8(4)(A)-105/2: HUMAN USE OF GROUNDWATER

Based on the discussion provided under Interrogatory CR R313-25-8(4)(A)-96/2: Current and Future Potability of Water, a member of the general population could drill a well into the confined aquifer and treat the water for domestic and industrial uses. Under current Tooele County regulations, if the domestic uses do not qualify as a public water system, there are no requirements for testing for radioactive contamination. It is also possible that future demand for municipal and industrial water in Utah, combined with currently available treatment technology, could render the deep aquifer useable for drinking water and many other industrial uses. These types of exposure scenarios need to be evaluated.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

106. INTERROGATORY CR R313-25-8(4)(A)-106/2: DESALINATION POTENTIAL

ES stated that the Conceptual Site Model report (Appendix 2 to FRV1) was being revised to acknowledge the technical feasibility and practical improbability of groundwater desalination at Clive. However, contrary to what ES indicated the

proposed revision would acknowledge, the actual ES language does not comment on the technical feasibility of desalination, nor does it recognize that desalination is accomplished in the vicinity of Clive to produce potable water. This needs to be corrected. Further, the probability that Clive groundwater will someday be extracted, treated, and put to beneficial use as drinking and/or industrial water will be a function of economics. Like most Western States, Utah, with a finite quantity of water resources and a growing population, will someday be forced to draw on West Desert groundwater to service future generations. To help DEQ assess groundwater conditions in the deep aquifer in the well near I-80 at the south end of the Grayback Hills, ES should provide comprehensive well completion details, groundwater elevation, and water quality sampling and analysis results for this deep well.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

Note also that the interrogatory statement “Like most Western States, Utah, with a finite quantity of water resources and a growing population, will someday be forced to draw on West Desert groundwater to service future generations” is exceedingly speculative, contrary to NRC guidance for performance assessment. While one could speculate on the perceived inevitability of groundwater treatment in the West Desert, one could as easily speculate on the “inevitability” of overpopulation resulting in war over resources or pandemic illnesses resulting in a population crash. NRC correctly cautions against such speculation. See the response to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

107. INTERROGATORY CR R313-25-7(1)-107/2: PREDOMINANT VEGETATION AT THE CLIVE SITE

It is clear that this area has experienced substantial historic disturbance from grazing. This, in combination with stressful climatic and substrate conditions, has left a vascular plant cover that is weedy and ephemeral. This cryptobiotic crust cover, while not comprised of vascular plants, is still a biotic component that likely has substantial importance in the stability of the soil surface.

The PA still needs to address a number of questions pertaining to the plant cover, including the kind of plant community that can be expected beyond 500 years on the ET cover, whether it will be robust and self-sustaining, whether any of the plants will set deep roots, and if so, how deep, and how effective the plant community will be in reducing infiltration.

EnergySolutions' Response: As is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Modeling Report, biomass % cover and productivity is not sensitive for all scenarios. Furthermore, to help discourage unbounded speculation regarding the impact of long-term environmental changes on a site's plant community, NRC has stated,

“Given the uncertainty in projecting the site's biological environment beyond relatively short periods of a few hundred years, it is sufficient to assume that current biological trends remain unchanged throughout the period of analyzed performance.” (NUREG-1573, pg 3-11).

Accordingly, Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site and Appendix 9 – Biological Modeling from version 1.2 of the Modeling Report have been expanded to explain that the projected vegetation community expected to become established on the evapotranspirative cover well prior to the completion of any institutional control period will be equivalent to the vascular plant cover and the associated crust observable at Clive today.

108. INTERROGATORY CR R313-25-8(4)(A)-108/2: BIOINTRUSION

We await the results of that evaluation.

EnergySolutions' Response: Section 3.5.2 of Appendix 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site and Appendix 9 – Biological modeling from version 1.2 of the Modeling Report have been revised to incorporate and reference analysis conducted by SWCA (2011).

109. INTERROGATORY CR R313-25-7(2)-109/1: GEOCHEMICAL DEGRADATION OF RIP RAP

ES notes that this interrogatory is no longer relevant for the top slope of the Federal Cell since the Federal Cell will largely use an ET cover. However, this interrogatory should be addressed in regard to rip rap that will be used on portions of the side slope and on ditches.

EnergySolutions' Response: In the basis for Interrogatory CR R313-25-7(2)-109/1: GEOCHEMICAL DEGRADATION OF RIP RAP, the Division states,

“DRC and EnergySolutions have paid attention to a small but significant portion of the rock at the nearby Vitro site that has degraded geochemically at a substantial rate within the past several decades.”

In a Notice of Confirmatory Action received from the Division on May 30, 2012, direction was included regarding the inclusion of surety funds to account for the analysis of the impact on the Class A and Class A North embankments' final cover performance integrity of the rapid weathering apparently observed by U.S. Department of Energy (DOE) and Division representatives on the Vitro and LARW Embankments. As a means of qualitatively assessing the rate of aggregate degradation, EnergySolutions commissioned Wiss, Janney, Elstner Associates, Inc. (WJE) to conduct a Rock Fragment Petrographic Study (WJE, 2013).

In their Study, WJE studied subjectively selected aggregate rock samples from the LARW embankment cover and current Clive stockpiles that displayed cracking and degradation similar to those Vitro areas under continued observation by DOE staff, as well as samples that appeared to be the same rock type but did not have visible cracking or degradation. For the eleven rock fragments specifically chosen as representative of the Vitro degradation, WJE concluded that *“severe distress suggests that these particles were in a weak and highly weathered condition at the time the fill was installed.”* WJE further observed that the most weathered rocks were *“most likely in a weakened condition at the time it was placed as fill.”* As a result of these observations, WJE noted that *“This type of normal degradation takes place relatively slowly (over geologic time) [not at a substantial rate within the past several decades],”* and as such is not indicative of Division's inaccurate concerns of *“rapid weathering.”*

Additionally, the current LLRW and 11e.(2) CQA/QC Manual - Rock Erosion Barrier Work Element includes Quality of Rock controls that mirror WJE's recommendation for selection of material that *“would be less prone to relatively rapid deterioration that has reportedly occurred relatively soon after the material was installed.”* Finally, the results of the DOE and WJE studies further demonstrate that the weathered rock observed on the Vitro and LARW covers is limited to a small percentage of the overall rock covering (less than 1%) and are not expected to increase in the geologic short term. The currently-approved use of riprap to line Clive's precipitation management network will not require revision as a result of the construction of the Federal Cell.

110. INTERROGATORY CR R313-25-8(4)(A)-110/1: RADON TRANSFER FROM WATER

Round 1 Interrogatory Response is satisfactory.

111. INTERROGATORY CR R313-25-7-111/2: LIKELIHOOD OF LAVA DAM FORMATION

The cited documents were not included in the reference list in Section 3 of the response document. ES should provide full reference information so that we can review these sources.

EnergySolutions' Response: The complete list of references for the Round 1 response for this interrogatory are listed below. Note that the citation for (Nash, 1989) in the text of the response should have been (Nash, 1990).

- Link, P.K., D. S. Kaufman, and G. D. Thackray, 1998, Field Guide to Pleistocene Lakes Thatcher and Bonneville and the Bonneville Flood, Southeastern Idaho, in Hughes, S.S. and Thackray, G.D. eds., Guidebook to the Geology of Eastern Idaho, Idaho Museum of Natural History, p. 251-266.
- Nash, W.P., 1990, Black Rock Desert, Utah, in C.A Woods and J. Kienle, eds. Volcanoes of North America, Cambridge University Press, Cambridge p. 271-273.
- Oviatt, C.G. and W. P. Nash, 1989, Late Pleistocene Basaltic Ash and Volcanic Eruptions in the Bonneville Basin, Utah, Bulletin Geological Society of America, V. 101, p. 292-303.
- Oviatt, C.G., and B. P. Nash, 2014a, The Pony Express Basaltic Ash: A Stratigraphic Marker in Lake Bonneville Sediments, Utah, Miscellaneous Publication 14-1, Utah Geological Survey 10 p.

112. INTERROGATORY CR R313-25-8(4)(A)-112/1: HYDRAULIC CONDUCTIVITY

The ES response is not adequate, in that the analysis mentioned does not account for changes in hydraulic conductivity of the surface layer and the evaporative zone. Currently, with presently modeled hydraulic conductivities, the PA model indicates that water does not infiltrate down to the radon barriers at significant rates. As a result, the model currently shows the radon barriers to be insensitive to changes in hydraulic conductivity. However, that may very well change once the PA modeling accounts for changes in hydraulic conductivity of the surface layer and the evaporative zone. Increases in hydraulic conductivity may permit greater rates of infiltration and lesser fractional removal of water via evaporation. Furthermore, a strong correlation exists between van Genuchten alpha values and hydraulic conductivity, as shown by Guarracino (2007). Therefore, the correlated values of alpha should be made also when changes in hydraulic conductivity are made for the surface layer and the evaporative zone in the model.

Also, the interrogatories referenced are in need of additional information and resolution. Therefore, resolution of this interrogatory will also require resolution of several others, including those listed in Interrogatory CR R313-25-7(1-2)-90/1: Calibration of Infiltration Rates.

EnergySolutions' Response: See the responses to interrogatories CR R313-25-7(2)-05/2: RADON BARRIER and CR R313-25-7(3)-60/2: MODELED RADON BARRIERS.

113. INTERROGATORY CR R313-25-8(5)(A)-113/2: PLACEMENT OF BULK LOW-LEVEL WASTE AMONG DU CANISTERS

It is not clear how the ES response satisfies the UAC R313-25-8(5)(a) requirement that the PA include “total quantities of concentrated depleted uranium and other wastes.” Doses from DU and other wastes (including bulk waste) will sum and must be accounted for in the model quantitatively for 10,000 years and qualitatively (after concentrations are modeled quantitatively) until peak dose is attained. Neither of these requirements is satisfied currently in the PA model. Among other open questions is (1) how the source term for DU and other wastes will be developed and (2) how relevant engineering requirements related to R313-25-7(2) and (10) will be satisfied, including structural stability of backfill and quality assurance for waste emplacement, respectively. Alternatively, ES could commit not to use bulk low-level radioactive waste as in-fill for DU container disposal. We look forward to reviewing the revised text.

EnergySolutions' Response: See the response to interrogatories CR R313-25-8(5)(A)-157/2: INCLUSION OF DU AND OTHER WASTES IN PA and CR R313-25-7(2)-173/2: STABILITY OF EMBANKMENT.

114. INTERROGATORY CR R313-25-19-114/2: ELEVATED CONCENTRATIONS OF TC-99

We look forward to reviewing the results of the new ET cover design and how it may affect Tc-99 concentrations in the groundwater over 10,000 years or more. These results would need to be integrated in the groundwater exposure scenarios discussed in Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water.

With regard to general strategies for addressing Tc-99, the possibility of locating Tc-99 contaminated waste higher in the embankment is inconsistent with the current approach of burying the DU waste below native grade levels. However, the second strategy has merit, especially since there appears to be inadequate volume below grade to bury all of the DU waste.

EnergySolutions' Response: Appendix 3 – Waste Inventory, Appendix 11 – Dose Assessment and version 1.2 of the Modeling Report have been revised to project the fate and transport of Tc-99 in groundwater from water percolating through an evapotranspirative cover over the Federal Cell. Since EnergySolutions has already committed to only dispose of depleted uranium wastes below ground surface, the Division's proposed second strategy is inapplicable. Additionally, see responses prepared for Interrogatories CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

115. INTERROGATORY CR R315-101-5.3(6)-115/1: URANIUM TOXICITY REFERENCE DOSES

Round 1 Interrogatory Response is satisfactory.

116. INTERROGATORY CR R313-25-8(4)(A)-116/1: CS-137 DECAY

Round 1 Interrogatory Response is satisfactory.

117. INTERROGATORY CR R313-25-8(5)(A)-117/2: GROUNDWATER PROTECTION LIMIT FOR TC-99

Limitations on exposures to the general public are established in R313-25-19. Pursuant to R313-25-8(5)(a), these standards must be met for 10,000 years or more for any viable groundwater or other pathway. See our comments on Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water. We note that ES did not provide a response to our query regarding Tc-99 concentrations in the embankment side slopes. The requested explanation should be provided.

EnergySolutions' Response: Since EnergySolutions' commitment to limit disposal of depleted uranium to below grade regions beneath the Federal Cell top slope, the Division's inquiries as to Tc-99 concentrations in the embankment side slopes is inapplicable. Furthermore, see responses prepared for Interrogatories CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS regarding the unreasonableness of further groundwater ingestion analysis.

118. INTERROGATORY CR R313-25-7(10)-118/1: GOLDSIM RESULTS

Round 1 Interrogatory Response is satisfactory.

119. INTERROGATORY CR R313-25-8(4)(A)-119/1: RESUSPENSION AND AIRBORNE PATHWAYS

Round 1 Interrogatory Response is satisfactory.

120. INTERROGATORY CR R313-25-8(4)(A)-120/2: GULLIES AND RADON

We assume that this “further...modeling” will include the impact of erosion on the radon flux, and we look forward to receiving and reviewing these further erosion modeling efforts.

EnergySolutions’ Response: See the response prepare for Interrogatory CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS

121. INTERROGATORY CR R313-25-19-121/2: GULLIES AND RECEPTOR LOCATION

First, this interrogatory has more to do with the OHV enthusiast dose model than with the gully/erosion model. Thus, this interrogatory applies equally well to the existing and revised gully/erosion models.

The gist of this interrogatory is that OHV riders would spend proportionally more of their time in gullies than on the top surface of the embankment. ES argued that the steep walls of the gullies would preclude OHV enthusiasts from riding in the gullies. However, the steep gully walls would offer a challenge to the OHV enthusiasts and encourage them to ride there to demonstrate the capabilities of their machine and/or to demonstrate their driving skills. A cursory review of results to a Google search on “dunes gullies ATVs” demonstrates that gullies are some of the favorite places for ATV enthusiasts to ride.

Furthermore, a gully in the side of the embankment would provide a preferential path to the top for the OHV enthusiasts, so that they would not have to go up the steeper sides of the un-eroded embankment.

In brief, DRC does not agree with the ES response and believes that further investigation into this issue is warranted. We look forward to reviewing the revised report.

EnergySolutions’ Response: The lack of result sensitivity to the Division’s proposed variations in the time and ultimate impact of OHV in and around dune gullies is contemplated as part of the comprehensive parameter sensitivity documented in Appendices 15 (I and II) – Sensitivity Analysis Methods and Results from version 1.2 of the Modeling Report.

Additionally, while the formation of some of the gullies may actually erode through significant depths of the evapotranspirative cover, the ratio of gully footprint to total evapotranspirative cover surface area remains minimal. As such, the overall evapotranspirative cover surface continues to perform and limit infiltration, as designed. The gullies' influences are further tempered when including the effects of the extreme depth between the bases of the deepest probable gullies to the below-grade depleted uranium waste, resulting in insignificant increases in resulting groundwater concentrations.

Under the conditions of inadvertent intruder-created gullies, NRC warns that,

“Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite [that may result in subsequent exposure to members of the general public].” (NUREG-1573, pg. 3-11).

Therefore, NRC considers it inappropriate to model doses or further impacts to the general public that result from the actions of an inadvertent intruder. See also the response to Interrogatory CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS.

122. INTERROGATORY CR R313-25-8(4)(D)-122/2: SIZE OF PLUVIAL LAKES

The ES response is satisfactory; ES should correct the text accordingly in the revised report. We look forward to reviewing the revised report.

EnergySolutions' Response: Section 3.1 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address the size of pluvial lake formation.

123. INTERROGATORY CR R313-25-8(4)(D)-123/2: TIMING OF LAKE CYCLES

We continue to believe the descriptions of the Clive exposure are not relatable to the Burmester core, and that the Knoll section documentation of the Deep Time Assessment report (Appendix 13 to FRV1) is inadequate. ES should revise its report to resolve this finding.

EnergySolutions' Response: Appendix 13 - Deep Time from version 1.2 of the Modeling Report has been substantially revised. Please refer to new text revisions for additional context on the discussions of the Clive exposure and Burmester core. See also the response prepared for Interrogatory CR R313-25-8(4)(D)-14/2: SEDIMENT MIXING.

124. INTERROGATORY CR R313-25-8(4)(D)-124/2: MECHANISMS FOR PLUVIAL LAKE FORMATION

ES should correct the text accordingly in the revised report. We look forward to reviewing the revised text.

EnergySolutions' Response: Section 3.2 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address the mechanisms for pluvial lake formation.

125. INTERROGATORY CR R313-25-8(4)(D)-125/2: DEEP LAKE CYCLES

ES should correct the text accordingly in the revised report. We look forward to reviewing the revised text.

EnergySolutions' Response: Section 3.2 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address deep lake cycles.

126. INTERROGATORY CR R313-25-8(4)(D)-126/2: SHALLOW LAKE CYCLES

ES stated that: “Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur.” We believe that this assumption is incorrect, as explained in the comments on the ES response to Interrogatory CR R313-25-8(5)(a)-44/1: Occurrence of Intermediate Lakes. ES should revise the report accordingly.

EnergySolutions' Response: Please refer to the response to Interrogatory CR R313-25-8(5)(a)-44/2: Occurrence of Intermediate Lakes.

127. INTERROGATORY CR R313-25-8(4)(D)-127/2: CARBONATE SEDIMENTATION

The ES response is satisfactory; ES should correct the text accordingly in the revised report. We look forward to reviewing the revised report.

EnergySolutions' Response: Section 3.3 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised to address carbonate sedimentation.

128. INTERROGATORY CR R313-25-8(4)(D)-128/2: LAKE SEDIMENTATION

We agree with the ES response but recommend that the final report discuss a deep time sensitivity analysis, similar to that provided for doses, which expands on the information provided in the ES response. ES should revise the report accordingly.

EnergySolutions’ Response: Additional features, events, and processes regarding deep time sensitivity have been added to Appendices 13 – Deep Time Assessment, 15(I) Sensitivity Analysis Methods, and 15(II) Sensitivity Analysis Results from version 1.2 of the Modeling Report. However, these additions expressly do not constitute “doses”. As noted by NRC,

“Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]” [emphasis added] (NUREG-1573, pg. 3-10)

129. INTERROGATORY CR R313-25-8(4)(D)-129/2: LAKE EROSION

We agree with the ES response but recommend that the final report discuss a deep time sensitivity analysis, similar to that provided for doses, which expands on the information provided in the ES response. ES should revise the report accordingly.

EnergySolutions’ Response: Additional features, events, and processes regarding deep time lake erosion have been added to Appendices 13 – Deep Time Assessment, 15(I) Sensitivity Analysis Methods, and 15(II) Sensitivity Analysis Results from version 1.2 of the Modeling Report. However, these additions expressly do not constitute “doses”. As noted by NRC,

“Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]” [emphasis added] (NUREG-1573, pg. 3-10)

130. INTERROGATORY CR R313-25-8(4)(D)-130/1: LAKE GEOCHEMISTRY

Round 1 Interrogatory Response is satisfactory.

131. INTERROGATORY CR R313-25-8(4)(D)-131/2: POTENTIAL WAVE ENERGY

This position appears to be the opposite of that taken in the Deep Time Assessment report (Appendix 13 to FRV1), as indicated by the text from Section 4.0 quoted above. ES should clarify its position on the effects of wave action from small lakes, provide appropriate references for this conclusion, and ensure that its position is consistent throughout the report.

EnergySolutions' Response: The text has been changed in Appendix 13 – Deep Time from version 1.2 of the Modeling Report. The text in v1.2 (Section 4.1) currently states:

*“It should be noted that a Gilbert-sized lake would not reach the Clive elevation (Oviatt, 2014a). The size of a lake in the PA model that is needed to obliterate the waste embankment can be as shallow as 1 m, which may or may not have sufficient wave power to [actually] obliterate the site.”
[Brackets added to point out PA model assumption versus reality.]*

EnergySolutions assumes, for purposes of deep time modeling, that any lake that reaches the Federal Cell, with a depth as shallow as 1 m at the embankment, will obliterate the embankment. All text is now consistent on this issue.

The assumption of complete erosion of the embankment during the first lake return to the Clive site is a simplifying and conservative assumption.

132. INTERROGATORY CR R313-25-8(4)(D)-132/2: SEDIMENTATION MODEL

We look forward to reviewing the revised report, including a description of how wind-blown sediments, sediments moved by lake action, and sediments resulting from oolitic precipitation affect the overall lake sedimentation.

EnergySolutions' Response: Section 3.4 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised.

133. INTERROGATORY CR R313-25-8(4)(D)-133/2: CALCULATIONS OF RADIOACTIVITY IN WATER AND SEDIMENT

The ES response is adequate, assuming that ES will add to the revised PA report the information provided in the response. We look forward to reviewing the revised report.

EnergySolutions' Response: Section 6.5.2 of Appendix 13 – Deep Time Assessment from version 1.2 of the Modeling Report has been revised.

134. INTERROGATORY CR R313-25-8(4)(D)-134/1: FUTURE LAKE LEVEL ELEVATIONS

Round 1 Interrogatory Response is satisfactory, with the exception of the statement that “Intermediate lakes are assumed to be smaller lakes that reach and exceed the altitude of Clive, but are not large enough that carbonate sedimentation can occur.” ES should revise this statement to be consistent with corrections needed in response to Interrogatories CR R313-25-8(5)(a)-44/2: Occurrence of Intermediate Lakes and CR R313-25-8(4)(d)-126/2: Shallow Lake Cycles. We look forward to reviewing the revised report.

EnergySolutions' Response: Please refer to the response to Interrogatory CR R313-25-8(5)(a)-44/2: Occurrence of Intermediate Lakes.

135. INTERROGATORY CR R313-25-19-135/2: EXPOSURE TO GROUNDWATER

As discussed elsewhere (see, for example, Interrogatory CR 313-25-8(4)(a)-96/2: Current and Future Potability of Water, and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water), SC&A believes that additional information must be provided to demonstrate the groundwater at Clive is not a potential dose pathway. Under Interrogatory CR 313-25-8(4)(a)-96/2, SC&A indicates that ES needs to examine the possibility that the lower confined aquifer at Clive could become contaminated and thus become a source of exposure. If the water from this deep aquifer were used for domestic and/or industrial uses but did not meet the test of a public water system, regulation would be left to the Tooele County. It is our understanding that the County does not require testing for uranium or other radioactive contaminants. It does, however, require that the TDS for an individual water system be less than 2,000 mg/L. As noted in the table above, for Tc-99 Pathway Maximum Dose, when treating Clive groundwater, exposures exceeding the limits of R313-25-19 are possible, depending on the initial concentration of Tc-99 in the groundwater.

ES needs to explain why there are no viable groundwater pathways such as those discussed in Interrogatory CR 313-25-8(4)(a)-96/2 or include them in the DU PA.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS, and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

136. INTERROGATORY CR R313-25-7(1)-136/2: IRON (HYDRO)OXIDE FORMATION

ES provided an approach that seems appropriate, although overly conservative. In addition to revising the Geochemical Modeling report to state that no credit was taken for adsorption onto the steel drums, ES should also state that no credit was taken for iron (oxyhydr)oxide phases formed during canister degradation. Based on the concerns raised in the discussion for Interrogatory CR R313-25-8(4)(a)-64/1: Yucca Mountain Studies, the modeling of the source term will be reevaluated with regard to the estimation of uranium solubilities. We look forward to reviewing the revised report.

EnergySolutions' Response: No credit in version 1.2 of the Modeling Report was taken for iron (oxyhydr)oxide phases formed during canister degradation.

137. INTERROGATORY CR R313-25-7(1)-137/2: TOTAL DISSOLVED CARBONATE CONCENTRATIONS AND OTHER GEOCHEMICAL DATA

We look forward to reviewing the revised report.

EnergySolutions' Response: 1. The carbonate concentrations are higher than that with atmospheric pressure of CO₂. Reviewing Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report, though, it is of minimal significance in the development of input distributions. The distributions are sufficiently wide to incorporate higher carbonate content.

2. and 4. Recent groundwater data (EnergySolutions, 2012) shows that data from the 76 monitoring wells agree with the values in (previously numbered) Tables 5 and 6. The ranges of the newer data are within the ranges in those tables, with only a few exceptions. For Table 5, for example, there were 3 pH values greater than the max pH presented in (previously numbered) Table 5; there was one Eh value less than the minimum Eh; there was 1 bicarbonate value slightly less than the lowest bicarbonate. Only the TDS values were quite a bit different with a range of the 76 groundwater well data from 3300 to 23,500 mg/L (as compared to 26,000 to 75,000 mg/L in Table 5). With similar data values to Table 5 for key chemical parameters like pH, Eh and bicarbonate, changes in solubilities and K_{ds} do not need to be made due to the newer data.

For Table 6, most of the newer groundwater wells have ranges that are lower than those from the initial groundwater wells. The only exception is sulfate, for which the range widened with 12 values greater than the maximum sulfate concentration in Table 6.

Note as well, that variability in these geochemical parameters is expected between the groundwater and the unsaturated zone, waste layers and cap.

3. Addressed in Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report.

138. INTERROGATORY CR R313-25-26(1)-138/2: MONITORING WELL COMPLETION ZONES

The ES response is adequate. ES should complete the clarification to the report as described. We look forward to reviewing the revised report.

EnergySolutions' Response: Section 2.2 of Appendix 6 – Geochemical Modeling from version 1.2 of the Modeling Report has been revised.

139. INTERROGATORY CR R313-25-7(1)-139/2: ION CHARGE BALANCE

The ES response appears adequate, but it may need to be modified depending on the reassessment of total dissolved carbonate concentration and the justification for the representativeness and range of TDS data described in Interrogatory CR R313-25-7(1)-137/2: Total Dissolved Carbonate Concentrations and Other Geochemical Data. We look forward to reviewing the revised report.

EnergySolutions' Response: The discussion of ion charge balance has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

140. INTERROGATORY CR R313-25-7(1)-140/2: DETERMINATION OF KD VALUES

We look forward to reviewing the associated text changes described in the response.

EnergySolutions' Response: The discussion of K_D determination has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

141. INTERROGATORY CR R313-25-7(1)-141/2: PH AND KD VALUES AND SERNE (2007)

The clarification of the chemical speciation of the element will be vitally important text since it provides justifications for the selected K_d ranges. We look forward to reviewing the revised Geochemical Modeling report (Appendix 6 to FRV1).

It is indeed likely that pH and carbonate are more important than the specific sorbing phases. However, since the model is based on empirical K_d values, it is unclear how variable clay and iron content will be used. ES should discuss the manner by which all factors (pH, dissolved ions (competing ion effect), and solid phase composition) are used to determine the appropriate K_d range.

EnergySolutions' Response: The second paragraph of the rebuttal actually applies to Interrogatory CR R313-25-7(1)-142/2: REFERENCES FOR KD DISCUSSION, not this interrogatory. See the response to Interrogatory CR R313-25-7(1)-142/2: REFERENCES FOR KD DISCUSSION.

142. INTERROGATORY CR R313-25-7(1)-142/2: REFERENCES FOR KD DISCUSSION

The text modification described will be vitally important text since it provides justifications for the selected K_d ranges. We look forward to reviewing the revised report.

Regarding the second statement, it is indeed likely that pH and carbonate are more important than the specific sorbing phases. However, since the model is based on empirical K_d values, it is unclear how variable clay and iron content will be used. ES should discuss the manner by which all factors (pH, dissolved ions (competing ion effect), and solid phase composition) are used to determine the appropriate K_d range. The use of empirical K_d values for Clive soils and groundwater is imperative in the PA analysis process.

EnergySolutions' Response: As stated in Section 3.0 of Appendix 6 - Geochemistry Modeling from version 1.2 of the Modeling Report, literature studies were screened for those that applied to the different hydrostratigraphic units of the waste disposal site. Once the appropriate literature sources were identified, these studies were all considered to be equally viable for geochemical input parameter values, such that the minimum and maximum literature values were identified and a log-normal distribution was developed. As described in subsections of Section 4, adsorption onto clays is considered for the K_d input distribution for clay in the model (used in the unsaturated zone). Iron oxide adsorption was considered for neptunium and uranium.

The intention of the distribution development is to include a wide range for parameter input distributions, considering site conditions. If any of these input parameters is shown to be a sensitive parameter, the input distribution can be refined to reduce the uncertainty in the results, if that uncertainty of results is unacceptable. Except for the K_d distributions for technetium and iodine, which are described in Section 3, only ranges of values for both K_d and solubility were considered, since a log-normal distribution was used. Note that central values for

solubility are presented in the Table 4, but these central values are not used in the distribution development.

143. INTERROGATORY CR R313-25-7(1)-143/2: NEPTUNIUM SPECIATION

With regard to the first statement, we note that EPA 2004 was not included in the references in Section 3 of the ES response document and so could not be reviewed. ES is correct that both EH-pH and activity-pH diagrams need to be considered. However, the EH-pH diagrams provided do show the dominance of the carbonate complexes discussed here. At carbonate concentrations higher than 57 mg/L, mono-, di-, and tri-carbonate species can dominate Np(V) speciation. Therefore, while the point made by ES using the activity-pH diagram is well taken, it should be noted that the speciation is highly sensitive to the total carbonate concentration and should be considered in establishing solubility ranges. The sensitivity of neptunium solubility to high salinities should also be considered, in particular whether the Visual MINTEQ thermodynamic database is as robust as the Pitzer database used for PHREEQC.

With regard to the second statement, we encourage ES to review Bidoglio et al. (1985), Kohler et al. (1999), Turner et al. (1998), and Yu et al. (2007) and incorporate some consideration of the influence of Np-carbonate complexes. ES should revise the report to address these issues and concerns.

EnergySolutions' Response: The discussion of neptunium speciation has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

144. INTERROGATORY CR R313-25-7(1)-144/2: PLUTONIUM SPECIATION

ES should delete the following sentence of its response, since it would also not be correct for Pu(VI): “It is assumed that discussion of neptunium in the Interrogatory text is a typo and should have been plutonium.” The DEQ error with reference to Np(VI) has been corrected and there is no need for further explanation.

Regarding the statement about EPA (1999), there is considerable debate regarding the appropriate Pu(IV) hydroxycarbonate species and the associated stability constants. Therefore, if this speciation information is used for Kd determination, it has a potential for introducing a high degree of uncertainty. ES should review Clark et al. (1995) for a discussion of the Pu(IV) hydroxycarbonate species. Additional discussion and justification are needed to incorporate findings from this literature reference. We look forward to reviewing the revised report.

EnergySolutions' Response: The discussion of plutonium speciation has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

145. INTERROGATORY CR R313-25-7(1)-145/2: SORPTION REVERSIBILITY AND GLOVER ET AL. (1976) DATASET

ES should explain why the higher K_d values for plutonium used in the Geochemical Modeling report (Appendix 6 to FRV1), rather than those in Glover et al. (1976), are more current or applicable to Clive soil and groundwater conditions. We look forward to reviewing the revised report.

EnergySolutions' Response: The discussion of sorption reversibility has been expanded in Appendix 6 – Geochemistry Modeling from version 1.2 of the Modeling Report.

146. INTERROGATORY CR R313-25-7(1)-146/2: DETERMINATION OF K_D VALUES

We look forward to reviewing the revised report.

EnergySolutions' Response: Table 3 of Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report has been revised to include a table of the ranges of K_d values for the three soil textures (sand, silt, clay) for each element in the model, and relate them to the literature references as described in the subsections of the Modeling Report. Providing these ranges clarifies the values chosen from the literature and how they were used to develop probability distributions as described in Section 3.0 of Appendix 6.

147. INTERROGATORY CR R313-25-7(1)-147/2: DETERMINATION OF K_D VALUE FOR URANIUM

We look forward to reviewing the revised report.

EnergySolutions' Response: The reference to EPA (1999) in Appendix 6 – Geochemical Modeling from version 1.2 of the Modeling Report has been revised to reflect conclusions from EPA (1999) that some of these high K_d values correspond to experiments where precipitation of U occurred in addition to adsorption. As such, Appendix 6 has been modified to clarify assumptions and derivations of geochemical parameters.

148. INTERROGATORY CR R313-25-7(1)-148/2: INFLUENCE OF CARBONATE ON URANIUM SPECIATION

We look forward to reviewing the revised report.

EnergySolutions' Response: Section 4.1.13 of Appendix 6 from version 1.2 of the Modeling Report has been revised to focus on the effects of carbonate and p_H on U sorption. Additionally, the carbonate assumptions included in version 1.2 of the Modeling Report have been clarified as to the applicability of the references used for K_d distribution development to the Clive site, with respect to the high carbonates expected at Clive. More detail of how these distributions were developed has also been provided in Appendix 6 - Geochemical Modeling from version 1.2 of the Modeling Report.

149. INTERROGATORY CR R313-25-7(1)-149/2: AMERICIUM SORPTION

As ES extends its groundwater infiltration and transport modeling from 500 to more than 10,000 years, additional model inputs could be found to be “sensitive.” We look forward to reviewing the revised report. Furthermore, several of the exponents are missing negative signs in the paragraph of the response that begins “Given these assumptions....”

EnergySolutions' Response: Analysis of the sensitivity of groundwater migration to various model input parameters is reported in Appendix 15(II) – Sensitivity Analysis Results from version 1.2 of the Model Report. Additionally, typographical errors have been corrected in Appendices 15(I and II) – Sensitivity Analysis Methods and Results from version 1.2 of the Modeling Report.

See also the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

150. INTERROGATORY CR R313-25-7(2)-150/2: PLANT GROWTH AND COVER PERFORMANCE

The PA indicates that greasewood size and rooting depth on the site is likely limited by the presence of a shallow, compressed, thin clay layer currently located 2 feet below the ground surface that apparently traps water and maintains roots at shallow depth. However, there is no evidence that, subsequent to this shallow, compressed, thin clay layer being locally homogenized with other soil and lost as a distinct layer as a result of mining and processing of portions of the on-site near-surface silty clay layer prior to emplacement in the Federal Cell, and with the shallow perching layer that this thin layer once created therefore being locally destroyed, conditions will exist at the site that will inhibit or prevent deeper rooting by shrubs such as greasewood. Changes will occur. Moreover, the size of greasewood plants at the surface is not a sure indicator of the length of their taproots. One expert, whose views are presented by the U.S. Forest Service in an article on SPECIES: *Sarcobatus vermiculatus*, indicates that greasewood typically sends taproots down to the water table and states that there is an inverse

relationship between above-ground greasewood height, canopy coverage and total leaf surface area and the associated depth to groundwater (Anderson, 2004): “Black greasewood height, canopy coverage, and total leaf surface area are inversely related to depth to water.” In other words, when groundwater is deep, and taproots must extend down to a great depth to acquire pore water from the capillary fringe, greasewood plant size at the surface tends to be small, just as is seen at the Clive site. Excavations of root systems of only two greasewood plants on the site by one of the licensee’s consultants do not make for a comprehensive study that can be fully relied on, when numerous other studies claim that greasewood taproots in arid or semi-arid environments can grow down to depths of 12.7 meters (42 feet) below ground surface or more (Chimner and Cooper, 2004; Harr and Price, 1972; Nichols, 1993; Meinzer, 1927; Waugh and Smith, 1998; White, 1932; WSDNR, 2011). We understand that the ET cover system is currently being modeled and that a report will soon be presented that deals with deep plant rooting. We look forward to reviewing this response when the ET cover report is available.

EnergySolutions’ Response: Although the limited field excavations of shrubs at the Clive site noted relatively shallowly rooted individuals, the model extends black greasewood roots to 5.7 m. As noted in the previous response, the use of 5.7 m in the PA model as the maximum greasewood rooting depth is considered conservative for two reasons. The first reason is that the roots are not expected to penetrate (nor would they need to penetrate) the radon barriers (thick clay layers) in the ET cover, which start at a depth of 3 ft. This assumption is supported by the limited root profile excavations performed at the Clive site, which found that tap roots and fine roots tend to spread laterally on top of the compact clay layer that occurs naturally at the site approximately 60 cm below ground surface (SWCA 2013). Though the naturally occurring compact clay layer will be removed/disrupted during construction activities, with regard to plant rooting it can be considered analogous to the compact clay radon barriers in the constructed cover. As noted a number of times throughout the round 2 interrogatories, the constructed cover is likely to evolve from an as-built condition toward one more closely resembling native soils. Thus, the compacted radon barrier, built to a specification of no less than 95% compaction, can reasonably be expected to exceed or approximate the native compacted clay layer approximately 2 feet below the surface.

Though root penetration of the radon barriers is not expected to occur, the PA model conservatively assumes a maximum rooting depth well beyond the depth of the barriers. The second reason that 5.7 m was selected as the maximum rooting depth is that 5.7 m represents an estimate of what Groeneveld (1989) terms "maximum effective root depth" for greasewood. Isolated roots may grow well below this depth under special circumstances of water availability and aeration. The maximum root depth of 19 m cited by Robertson (1983) and others is an

example of such special circumstances, as Groeneveld suggests that this maximum depth for greasewood is an artifact of preferential pathways created by mining activities. These preferential pathways are not expected to occur in the constructed cover, especially with the compacted clay radon barrier occurring 3 ft below ground surface. Also, as previously noted, when the constructed cover is in place, depth to groundwater at the site will be in excess of 23 m, beyond even the most conservative report of maximum root depth, meaning that black greasewood and other shrubs would not be able to exploit the current aquifer.

Version 1.2 of the Model currently assesses shrubs in two different categories – deeply rooted shrubs, as represented by black greasewood, and more shallowly rooted shrubs, as represented by shadscale and gray molly. We concur with the reviewer’s comment that four-winged saltbush roots more deeply than shadscale. However, four-winged saltbush is much less common at the site than either shadscale or black greasewood, and we believe the growth attributes of four-winged saltbush are adequately captured in the model by the input parameters for the black greasewood category.

The reviewer notes that there is an inverse relationship between above-ground greasewood height, canopy coverage and total leaf surface area and the associated depth to groundwater (Anderson, 2004): “Black greasewood height, canopy coverage, and total leaf surface area are inversely related to depth to water.” The reviewer implies that this is because the plant must sink more of its resources into tap root development to reach the groundwater, and also implies that the small plants sizes noted at the Clive site would suggest a large taproot development. We disagree with this interpretation. A review of the primary study (Harr and Price, 1972) cited by Anderson (2004) shows that the smaller plants associated with deeper groundwater used only half as much groundwater as the plants associated with shallow groundwater. This may be attributed to reduced capability of roots to reach groundwater. Indeed, Anderson (2004) states in the sentence immediately following the one quoted by the reviewer that there is a reduction in root growth associated with increasing soil depth, not the other way around. Therefore, for all of the reasons stated above, we feel that a maximum shrub rooting depth of 5.7 m adequately represents maximum rooting depths of black greasewood and four-winged saltbush at the Clive site.

To help discourage unbounded speculation regarding a site’s plant community, it is important to recognize that NRC has stated,

“Given the uncertainty in projecting the site’s biological environment beyond relatively short periods of a few hundred years, it is sufficient to assume that current biological trends remain unchanged throughout the period of analyzed performance.” (NUREG-1573, pg 3-11).

Accordingly, NRC considers that the current biological trends and Clive conditions reported in SWCA (2011) are preferential to the non-site specific general studies cited by the Division. See also the response prepared to Interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.

151. INTERROGATORY CR R313-25-8(4)(A)-151/2: RADON BARRIER ATTENUATION

We look forward to reviewing the results of the ET cover radon modeling effort, and we anticipate that these results will be consistent with previous results for the Clive site.

EnergySolutions' Response: Radon modeling is documented in Appendix 18 – Radon Diffusion Modeling from version 1.2 of the Modeling Report. Section 4 of Appendix 18 documents the methodology for diffusion calculations performed by GoldSim. Calibration is documented in Section 6 of Appendix 18. Doses resulting from the inhalation of radon that manages to escape into the atmosphere are reported in Section 6 of version 1.2 of the Modeling Report. Additionally, Table 10 of Appendix 15 – Sensitivity Analysis Results from version 1.2 of the Modeling Report illustrates parameters to which ground surface radon flux is sensitive.

152. INTERROGATORY CR R313-25-8(5)(A)-152/2: GOLDSIM INPUT PARAMETERS

ES described how to run the GoldSim model to gain the answer to the question. However, we do not agree with this approach. A reader of the report should not be forced to run the GoldSim model to “gain an appreciation of where [the radon correction factors] come from.” It is the report’s function to provide this information to its readers, particularly those without access to GoldSim.

In addition, while the radon correction factors are calculated by GoldSim, for the purposes of the PA they are treated like input parameters. As such, they should be described in the documentation, just as any other input parameter. We look forward to reviewing the revised report.

EnergySolutions' Response: Appendix 18 - Radon Modeling from version 1.2 of the Modeling Report explains the behavior of radon in the model, as well as the need for calibration of the diffusivity of radon (in order to counteract numerical dispersion) and the methodology employed to do so. The calibration factors are not input variables, as they change as other inputs in the model change, such as material properties, cell dimensions, or burial depths. That said, a recent calibration done with the top of the DU waste at a depth of 3 m below the clay radon barrier resulted in the following values:

Waste	0.349
Radon barrier clay	0.894
ET cover materials	0.974

Version 1.2 of the Model contains documentation within it that helps one to understand processes and interrelationships. While these are also discussed in the appendices from version 1.2 of the Modeling Report, the Model itself is the best manifestation of the Performance Assessment, and serves the role of a supplemental comprehensive document.

153. INTERROGATORY CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER

ES' response focused on infiltration; it should also address radon diffusion:

1. The ES response began by referring to *EnergySolutions* 2014, which obviously was not included in FRV1. ES needs to integrate the information from this document into the revised report. Then DRC can review and comment on how that information is being used in the DU PA.
 2. The ES response indicates that the ET cover would reduce infiltration by two orders of magnitude compared with the rock armor mulch cover. The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers 2014) does not support this statement. The original mean infiltration rate (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas with the ET cover the rate is about 0.04 cm/yr—reduced by only a factor of three.
 3. The ES response indicates that the ET cover design will limit infiltration down to the radon barrier. However, the response does not address what impact pedogenesis, burrowing animals (if any), plant roots, gullies, and similar mechanisms would have on the radon diffusion upwards to the surface.
 4. Finally, in its response ES described the cover performance modeling that is required. DRC looks forward to receiving and reviewing this refined modeling effort.
1. **EnergySolutions' Response:** The *EnergySolutions*, (2014a) reference was provided DRC in hardcopy of March 31, 2014 and electronically on April 10, 2014. See also the response to Interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.
 2. While *EnergySolutions* does not understand why the Division considers an infiltration “reduced by only a factor of three” for the evapotranspirative cover compared to the traditional rock armor as a criticism of the revised Federal

Cell cover design, the presentation of infiltration rates has been revised in Appendices 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site, 3 – Embankment Modeling, 5 – Unsaturated Zone Modeling, 11 – Dose Assessment, and the main report from version 1.2 of the Modeling Report.

3. See the responses for INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.
4. The evapotranspirative cover performance has been added to Appendices 2 – Conceptual Site Model for Disposal of Depleted Uranium at the Clive Site, 3 – Embankment Modeling, 5 – Unsaturated Zone Modeling, 11 – Dose Assessment, and the main report from version 1.2 of the Modeling Report.

154. INTERROGATORY CR R313-25-8(4)(D)-154/2: USE OF FIELD DATA TO VALIDATE DISPOSAL CELL COVER PERFORMANCE

ES did not address the fact that the Monticello Disposal Facility in Utah uses an ET cover, but the measured percolation rate is substantially higher than that proposed for the Federal Cell. ES should address the possible causes of this discrepancy.

With regard to ES’ responses related to Cover Test Cell (CTC) data collected to date, DEQ has determined that only cover soil temperature data are reliable from that facility. Hence, ES reference to other water balance-related data collected at the CTC facility may be suspect. Further, the CTC facility was constructed to simulate the riprap cover design of the Low-Activity Radioactive Waste Cell, and not any ET cover now proposed for the DU disposal cell.

Also see Interrogatory CR R313-25-7(3)-60/2: Modeled Radon Barriers.

We look forward to completing our review of this response when the revised ET cover report is available.

EnergySolutions’ Response: The cover system employed at the Monticello, Utah Mill Tailings Site Disposal Facility is described as:

“The cover system consists of multiple layers (from top to bottom): blended top soil with vegetation that limits erosion, a layer of fine-grained soil that provides frost protection, 12 inches of sand that limit the buildup of water, a high-density polyethylene geomembrane that protects the underlying radon barrier, and a 2-foot compacted clay layer that serves as the radon barrier.” (DOE, 1995, pg. 1).

There are a number of differences that may contribute to Monticello's higher projected infiltration. For example, Monticello reports an average precipitation of 353.8 mm/year, 1.6 times higher than Clive's 19-year average of 215.9 mm/year. Monticello's blended surface layer includes no gravel admixture and consists of materials with higher hydraulic conductivities than that proposed for the Federal Cell. Additionally, Monticello's overall thickness is less than that proposed for the Federal Cell.

EnergySolutions recognizes that the Cover Test Cell facility was constructed to simulate the riprap cover design of the Low-Activity Radioactive Waste Cell, and not the evapotranspirative Federal Cell cover. Even so, the Cover Test Cell confirms that models developed in support of the rock armor cover have over-predicted infiltration; this result is not unexpected for an above-grade embankment in an arid climate.

Also see the response to Interrogatory CR R313-25-7(3)-5/2: RADON BARRIER.

155. INTERROGATORY CR R313-25-8(4)(D)-155/2: COVER PERFORMANCE FOR 10,000 YEARS

It is not clear that a naturalized radon barrier has no effect on radon releases. Affirmative evidence is needed to support this claim. ES should also indicate when the compromised radon-barrier report mentioned in its response will be available. It is not clear why this modeling should not be part of the DU PA. The claim that "the ET Cover design will limit infiltration down to the radon barrier" is not substantiated when considering that the PA model to date has not accounted for or implemented NRC guidance indicating that, based on a vast amount of experimental and field data, shallow soil layers (<10 feet deep) in a cover system undergo dramatic degradation over time; that is, with increases of hydraulic conductivity values generally ranging from one to three orders of magnitude (see Benson et al., 2011, in NUREG/CR-7028). Moreover, the same study shows that the use of small-diameter soil samples in laboratory testing of soil hydraulic conductivity values generally underestimates these values compared to actual field-scale hydraulic conductivities by one or more orders of magnitude. The PA uses small-diameter soil sample values instead of field-scale values. Both of these factors suggest that the current, unmodified PA modeling does not properly account for increased rates of infiltration down to the radon barrier. ES should modify the PA model to account for these factors.

The ES response also mentioned possibility of a new study of "volcanic landforms in the Black Rock Desert." If that study has been completed, ES should provide the results/data for DEQ review. If not, ES should provide a schedule for completion of the new study, or the reason it is not being undertaken.

In addition, the interrogatory requested a discussion of historical analogs of similar structures and how they have functioned over long periods of time. ES did not provide such a discussion.

The ES response also stated that: “It is not considered necessary at this time because the ET Cover design will limit infiltration down to the radon barrier. With no infiltration down to that level....” The revised GoldSim DU PA model (v1.199) provided by ES on May 5, 2014 (Rogers 2014), does not support this statement. The original mean infiltration rate at the waste level (VerticalFlow_BelowCap) was about 0.12 cm/yr, whereas the rate with the ET cover is about 0.04 cm/yr—reduced by only a factor of three, instead of being eliminated as claimed in the ES response. ES should clarify. Moreover, that calculated infiltration rate reflects modeling without ES having made adjustments in hydraulic conductivity values as requested above, which would likely increase modeled rates of infiltration down to the waste.

We look forward to evaluating other issues (such as erosion) when the ET cover report is available.

Also see Interrogatory CR R313-25-7(3)-60/2: Modeled Radon Barriers.

EnergySolutions’ Response: It is important to note that while an informative analysis, the covers examined by Benson, 2011 are not equivalent to that proposed for the Federal Cell. Even so, the effects of equivalent cover parameter ranges on cover performance are addressed in the response to Interrogatory CR R313-25-7(2)-05/2: RADON BARRIER.

156. INTERROGATORY CR R313-25-26(2-3)-156/2: SEPARATION OF WASTES IN FEDERAL CELL

The ES response is satisfactory assuming that the appropriate written agreements as to long-term stewardship are obtained from DOE on a timely basis.

EnergySolutions’ Response: Noted without comment.

157. INTERROGATORY CR R313-25-8(5)(A)-157/2: INCLUSION OF DU AND OTHER WASTES IN PA

It is not clear how the ES response satisfies the UAC R313-25-8(5)(a) requirement that the PA include “total quantities of concentrated depleted uranium and other wastes.” Among other open questions is how the source term for total quantities of DU and other wastes will be developed. ES should coordinate resolution of this interrogatory with Interrogatory CR R313-25-7(9)-89/2: Contamination Levels in DUF6. We look forward to reviewing the revised report.

EnergySolutions’ Response: As is reported in the Condition 35 Compliance Report and version 1.2 of the Modeling Report, EnergySolutions has committed not to dispose of any “other wastes” in the Federal Cell until a Performance Assessment can be compiled that includes both DU and other Class A wastes. Until that time, EnergySolutions will only dispose of depleted uranium waste below grade in the Federal Cell. As such, the waste inventory included in version 1.2 of the Modeling Report is representative of all wastes currently projected to be disposed of in the Federal Cell.

158. INTERROGATORY CR R313-15-1009(2)(B)(I)-158/2: WASTE PACKAGING

It is our understanding that that ES has experienced some problems in the past with shipments from Terranear (DOE subcontractor) in soft sided packaging. ES should provide a discussion of these problems and indicate the relevance of the Terranear experience to handling of DU3O8 in soft-sided packaging.

EnergySolutions’ Response: The Division is fully aware of the issues with shipments from Terranear in soft-sided packaging, having cited them under the GSAP program for a shipment in October 2011 that had unexpected tritium contamination on the exterior of the package when it arrived at Clive.

In the context of version 1.2 of the Model, shipment packaging issues are irrelevant, since no credit is taken for the package in enhancing containment of the waste once disposed. Furthermore, the issues alluded to in the interrogatory relate to tritium containment. Tritium is not a contaminant in the depleted uranium wastes being considered; thus, the concern is irrelevant.

159. INTERROGATORY CR R313-25-8(4)(D)-159/2: EMBANKMENT DAMAGE BY LAKE FORMATION

We believe that this assumption regarding aeolian deposition is incorrect, as explained in the comments on the ES response to Interrogatory CR R313-25-8(5)(a)-18/1: Sediment Accumulation. In addition, with regard to the period beyond 10,000 years, see comments on Interrogatory CR R313-25-8(5)(a)-86/2: Consequences of Sedimentation on Disposal Cell.

EnergySolutions' Response: The Rebuttal text quoting an *EnergySolutions* response with aeolian sedimentation rates of > 0.1 mm/year are not included in Appendix 13 - Deep Time from version 1.2 of the Modeling Report. Sedimentation rates for aeolian deposition were not used in the model prior to the formation of the first intermediate or deep lake; instead an assumption was made that the next lake would destroy the disposal mound. No credit is taken for potential mitigating effects of aeolian deposition.

160. INTERROGATORY CR R313-25-7(2)-160/2: COMPARISON OF CLASS A WEST AND FEDERAL CELL DESIGNS

It is our understanding that an ET cover is now being considered for the Class A West cell as well as for the Federal Cell. Comparisons of the structural design and expected performance of the two cells are needed. The following issues still need to be addressed in the PA:

The geometry, slopes, and boundary shapes and sizes would differ between the two different cells.

The distance to a monitoring well from the central portion of the cell would differ between the two cells.

The current PA proposes that the DU waste disposal cell be conjoined with the 11e.(2) cell, with no isolation barrier between them, whereas the Class A West cell would not be conjoined with an 11e.(2) cell.

DU waste components in the Federal Cell would ingrow, thereby becoming more hazardous instead of less hazardous with time, contrary to what would be the case for most of the waste in the Class A West cell.

Over a sufficiently long time, Ra-226, which would be present at relatively high concentrations in the Federal Cell, would increase in activity until it exceeds Class C limits, unlike the bulk of the waste disposed of in the Class A West cell.

Some of the containers from the Paducah and Portsmouth GDPs that would be disposed of in the Federal Cell would contain heels having relatively high

concentrations of highly mobile Tc-99, unlike the bulk of the waste disposed of in the Class A West cell.

The heels in these cylinders would also contain transuranics, unlike the bulk of the waste deposited in the Class A West cell.

The Federal Cell design must meet performance standards for a minimum of 10,000 years.

As previously discussed, any proposed Federal Cell that contains DU waste must have an approved design such that its cover system is fully integrated with, or completely isolated from, the existing 11e.(2) cover system, as required by applicable federal and state laws, regulations, and rules. Pertinent DOE and NRC guidance should be followed as well. A more complete description of structural design and performance of the proposed Federal Cell, one that incorporates and accounts for all of the factors mentioned above, is requested.

EnergySolutions' Response: Version 1.2 of the Modeling Report has been revised to reflect the construction of an evapotranspirative cover over the proposed Federal Cell. While EnergySolutions recognizes that it is seeking separate approval for construction of a similar cover system over its Class A West (CAW) embankment from the Division, demonstration of the CAW cover's ability to satisfy low-level radioactive waste disposal performance objectives unique to Class A-type waste are unrelated to the requirements imposed on the Federal Cell evapotranspirative cover's ability to satisfy the unique depleted uranium performance criteria addressed in version 1.2 of the Modeling Report.

161. INTERROGATORY CR R313-25-7(2-3)-161/2: INCONSISTENT INFORMATION ON WASTE EMPLACEMENT

We look forward to confirming the disposition plan by reviewing the revised Figure 1.2 and note that, regardless of the depth of disposal, the revised report should not contain discrepancies, including but not limited to inconsistencies regarding available below-grade DU disposal volume and DU container dimensions. ES should include in its response information on the number of containers (cylinders and drums) of DU waste that can be placed in the designed disposal space, including the volume of backfill materials and any protective earthen blanket layers required. ES should also indicate how this number of DU containers and waste volume compares with the total DOE inventory needing disposal.

EnergySolutions' Response: As was reported in the Round 1 responses of March 2014, Figure 1.2 has been clarified to reflect EnergySolutions' commitment that only a volume of depleted uranium that can be disposed of below grade in the

Federal Cell will be managed. Because EnergySolutions has committed to only dispose of significant quantities of depleted uranium below grade in the Federal Cell, neither the total volume of DOE inventory, third-party inventory, or DOD inventory available for management need be revised.

162. INTERROGATORY CR R313-25-22-162/2: DISPOSAL CELL STABILITY

We look forward to judging the adequacy of parts of the response once we have the results of the SIBERIA modeling.

EnergySolutions' Response: Appendix 10 – Erosion Modeling from version 1.2 of the Modeling Report has been revised to include results of incorporation of the SIBERIA model into version 1.2 of the Model.

163. INTERROGATORY CR R313-25-8(5)(A)-163/2: GROUNDWATER COMPLIANCE FOR 10,000 YEARS

As discussed elsewhere (see, for example, Interrogatory CR R313-25-8(4)(a)-96/2: Current and Future Potability of Water, and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water), SC&A believes that additional information must be provided to demonstrate the groundwater at Clive is not a potential dose pathway. Under Interrogatory CR R313-25-8(4)(a)-96/2, SC&A indicates that ES needs to examine the possibility of that the lower confined aquifer at Clive could become contaminated and thus become a source of exposure. If the water from this aquifer were used for domestic uses but did not meet the test of a public water system, regulation would be left to Tooele County. It is our understanding that the County does not require testing for uranium or other radioactive contaminants.

EnergySolutions' Response: See the responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

164. INTERROGATORY CR R313-15-1009-164/1: INCORRECT RULE CITATION

Round 1 Interrogatory Response is satisfactory.

165. INTERROGATORY CR R313-15-1009(1)(C)(I)-165/1: INCORRECT CITATION OF RA 226 LIMIT

Round 1 Interrogatory Response is satisfactory.

166. INTERROGATORY CR R313-25-22-166/2: STABILITY OF WASTE

ES should indicate what revisions to the quality assurance/quality control procedures will be needed to handle the DU oxide shipments in canisters from the GDPs or explain how canisters are covered under current quality assurance/quality control procedures. Examples of some of the topics that need to be addressed include, but are not limited to, the following:

Details on how headspace will be eliminated from the DUF6 containers after arrival at Clive, including methods and equipment necessary for detecting headspace, access of the container to insert CLSM fill material, and re-sealing or closure of the DUF6 container

Discussion of potential interactions between CLSM material and DU waste materials, including any possible effects on the ability of the CLSM material to harden sufficiently to sustain needed stresses without deformation of the cover system

DUF6 container spacing and geometry on a waste lift and details about any co-location of DUF6 cylinders with DU waste drums

Placement of fill material between individual containers on a waste lift.

EnergySolutions' Response: No revisions will be needed to the LLRW and 11e.(2) Construction Quality Assurance/Quality Control Manual. DUF6 container headspace mitigation will not require revision to these procedures; field methods such as opening ports or valves will be used to gain access for CLSM. If ports or valves are not available in suitable size or location, the drums and cylinders will be penetrated. A large variety of tools are available for this task and have been used successfully at Clive for containers and waste forms ranging from steel liners to steam generators formerly used at nuclear power plants. There is no need to re-seal or close the DUF6 canister; and this is not typically done for other waste forms placed in CLSM. These procedures have successfully been used in the disposal of approximately 40,000 tons of depleted uranium, with no adverse interactions between the Controlled Low Strength Material (CLSM) and depleted uranium. CLSM will be the fill material used in DU disposal. See also revised drawing 14004-L1.

167. INTERROGATORY CR R313-15-1009(2)(A)(VII)-167/1: PYROPHORICITY OF DUO2

Round 1 Interrogatory Response is generally satisfactory, but a license condition may be needed to set an upper limit on particle sizes and quantities of DUO2 in any given container. Such conditions will be coordinated with the resolution of

Interrogatories CR R313-15-1009(2)(b)(i)-158/2: Waste Packaging, CR R313-25-22-162/2: Disposal Cell Stability, and CR R313-25-22-166/2: Stability of Waste.

EnergySolutions' Response: Condition 16.B of EnergySolutions' Radioactive Material License UT2300249 already prohibits receipt of waste “*readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or of explosive reaction with water.*” Similarly, Condition 16.D prohibits receipt of waste that is “*pyrophoric.*” These conditions would continue to be sufficient without the addition of a duplicative License Condition.

168. INTERROGATORY CR R313-25-7(2)-168/1: RIP RAP SIZING

ES notes that this interrogatory is no longer relevant since the Federal Cell will use an ET cover and rip rap is not used in the ET cover. However, ES should describe any use of rip rap on the lower parts of side slopes and on adjacent ditches and discuss the issues associated with this interrogatory that are pertinent to this use.

EnergySolutions' Response: As is reflected in Section 3.1.2 of Appendix 3 – Embankment Modeling to version 1.2 of the Modeling Report (attached as Appendix A to the Compliance Report), there is no riprap material included in the construction of the proposed evapotranspirative cover. No changes in the Division-approved riprap specifications for EnergySolutions' current drainage ditch network is required as a result of approval of the Federal Cell. Approved riprap specifications are summarized in Figure 6 of Appendix 3.

169. INTERROGATORY CR R313-25-7(9)-169/1: CLARIFICATION OF STATISTICAL TREATMENT OF CHEMICAL AND ISOTOPIC ASSAYS

Round 1 Interrogatory Response is satisfactory.

170. INTERROGATORY CR R313-25-7-170/2: DU WASTE FORM RELEASE MECHANISMS AND RATES

However, UO₃ is a mineral and will not be “mobile,” although the ions dissolving from UO₃ may be mobile. The major distinction between U₃O₈ and UO₃ is the uranium oxidation state. U₃O₈ is less soluble because the U(IV) present in the mineral is less soluble. Therefore, the discussion of the potential release rates and the likely solid phases present in the facility need to be tied to the redox conditions of the site. In addition, the clarifications noted in the ES response regarding release of waste should be added to the PA documentation. We look forward to reviewing the revised report.

EnergySolutions' Response: It is recognized that ions dissolving from any mineral phase are generally “mobile,” whereas the mineral form itself is not assumed to move.

Redox conditions were considered in the development of solubility and K_d input distributions, which control the release rate of the radionuclides in the waste. The discussion of the relationship between the redox conditions and the potential release rates of UO₃ and U₃O₈ and the solid phases likely to be present has been expanded in Section 4, 5, and 6 of Appendix 6 of version 1.2 of the Modeling Report and in the response prepared to Interrogatory CR R313-25-8(4)(A)-64/2: YUCCA MOUNTAIN STUDIES.

171. INTERROGATORY CR R313-25-7-171/2: ADEQUACY OF DU CELL BUFFER ZONE

The ES position is contingent upon DOE accepting stewardship of the combined cell and DEQ receipt of a written/executed agreement between ES and DOE. On page 1-3 of the Compliance Report, Revision 1, ES indicated that this policy issue must be resolved before disposing of concentrated DU in the Federal Cell. We note that ES did not include a reference for the approval of the License Amendment Request on November 26, 2012. This should be provided to ensure completeness of the review record.

EnergySolutions' Response: Reference to the requested approval letter of November 26, 2012 will be added to the Compliance Report.

172. INTERROGATORY CR R313-25-20-172/2: INADVERTENT INTRUDER PROTECTION

ES did not address one of the concerns stated in the interrogatory, namely that the failure to demolish and reclaim existing ES buildings in Section 29 (currently not accounted for in the ES LLRW or 11e.(2) sureties) could attract people in the future to occupy this adjoining land. The presence of these buildings could encourage human activities of many kinds on the margin of the buffer zone, thus increasing the chance of intrusion into the buffer zone or embankment at a later date. This concern needs to be addressed.

EnergySolutions' Response: Results of bounding scenarios considering inadvertent intrusion demonstrate the protection of the inadvertent intruder to applicable regulatory limits. The Division lacks jurisdiction to apply requirements outside the boundaries of the licensed facility, particularly since inadvertent intrusion, by definition, occurs within the facility buffer zone. Considering that the potential for inadvertent intrusion to occur is considered to be 1; i.e., credit is not taken for any probability associated with this intrusion; the presence or absence of structures on adjacent land is irrelevant to the analysis.

The numerous unlicensed and unregulated buildings, structures, and equipment EnergySolutions owns and uses to support its day-to-day business operations (such as the Administration Building located on Clive’s Section 29, EnergySolutions’ Corporate Offices in Salt Lake City – Utah, or EnergySolutions offices in Tooele – Utah) do not fall within the area subject to the License at the Clive “disposal site” and are not subject to the Division’s regulation.

These buildings and facilities are instead governed by various municipal zoning and business regulations. Their purpose is solely administrative, as they do not house or handle any low-level radioactive waste. There is no legal or regulatory justification for the Division’s application of regulatory required performance objectives to buildings, equipment and facilities that are entirely outside the area defined in the License. Even if demolition were included as a license condition or in the Performance Assessment, the Division lacks legal authority to enforce a demolition requirement.

In fact, in the highly unexpected event that EnergySolutions were to file for bankruptcy or otherwise become defunct, a bankruptcy receiver or other entity would assume ownership of these facilities and would have the legal authority to dispose of them. Any attempt by the Division to require demolition of such facilities under a bankruptcy scenario would represent a significant infringement on private property rights.

173. INTERROGATORY CR R313-25-7(2)-173/2: STABILITY OF EMBANKMENT

ES should provide additional information in response to the following comments on this calculation:

- The calculation appears to have included the weight of only one cylindrical shell rather than two. The currently proposed design involves stacking an additional cylindrical shell over each cylindrical shell at the base of the embankment for at least a portion of the embankment.
- The shell weight was assumed to be 2,500 lb, whereas the B&W Conversion Services website (<http://www.bwconversionservices.com/our-process/>) indicates that some shells weigh 4,500 lb.
- The density of the U3O8 is assumed to be 8.3 g/cc. Presumably, this is the particle density. The bulk density, as noted in the ES response to Interrogatory CR R313-25-22-162/1: Disposal Cell Stability, is 2.4 to 2.7 g/cc. Using the value of 2.7 g/cc and assuming that the shell is completely filled with U3O8, the mass of the contents would be about 25,000 lb. This

mass is similar to the range of DUF6 masses of 20,000 lb to 28,000 lb, depending on container wall thickness, quoted by B&W Conversion Services.

- ES engineering drawing 14004-L1 provided in the response to Round 1 Interrogatories, dated March 31, 2014, shows the DU disposal zone to be between 7.0 to 7.8 feet thick. Since UF6 cylinders have a nominal diameter of 4 feet, it is apparent that ES may place drummed waste immediately above or below a cylinder. If this is the case, the calculations also need to account for this added weight.

In addition, the loading calculation does not include the contribution of materials in the embankment above the DU layers. We look forward to reviewing the revised report.

EnergySolutions' Response: The bearing calculations have been revised, as follow, to include the comments provided by the DRC.

- The previously submitted calculations did include the weight of two (2) cylinders for the double stack scenario. The proposed double stacking configuration requires the overlying (2nd layer) cylinders to be offset as shown on the "Conceptual Double Stack Configuration" detail on Drawing 14004-L1 (Revision 1), attached. A cylinder on the 1st layer supports 2 overlying cylinders but it shares the load with the cylinders on either side of it. Therefore, it would bear only ½ the weight of each cylinder on top of it. The calculations were not revised per this comment.
- The calculations have been revised to assume the analyzed cylinder shells weigh 4500 lbs each.
- EnergySolutions opted for the most conservative weight in the original calculation by using the particle density of 8.3 g/cc. However, we agree that it is more accurate (while still conservative) to use a bulk density of 2.7 g/cc. The calculations have been revised accordingly. Please note that the revision (along with using a shell weight of 4500 lbs) results in a maximum weight of 29,901 lbs, which is slightly higher than the reported cylinder weight range of 20,000 to 28,000 lbs.

The calculations were revised to incorporate the first 3 comments and the results are as follow. Please also note that in addition the revised calculations now include the weight of sand fill between the cylinders. The calculations are attached.

Single Layer Bearing on the Clay Liner Surface = 653 psf

Double Layer Bearing on the Clay Liner Surface = 1,208 psf

- *EnergySolutions* agrees that there is the potential to place a single layer of drums over a single layer of the cylinders. Two placement configurations, as show in the “Conceptual Cylinder-Drum Stack Configuration” detail on the attached Drawing 14004-L1 (Revision 1), were analyzed. As seen in the figure, there is the potential for a cylinder to support the weight of up to fourteen (14) 55 gallon drums. Please note that the placement configuration shows the drums positioned horizontally rather than vertically. This is because although a 55 gallon drum is slightly less than 3 ft tall, on a pallet it is closer to 3.5 ft tall, which combined with a 4 ft diameter cylinder would exceed 7 ft in combined height. A horizontal placement of the drums would assure that the combined height does not exceed 7 ft. The bearing calculations (attached) at the surface of the clay liner were performed and resulted in a bearing of 1,010 psf.

As requested, *EnergySolutions* has performed and attached loading calculations at the foundation surface (bottom of the clay liner) that accounts for all overlying materials (liner, DU, fill, waste, radon barrier, and erosion barrier layers). The layer unit weights for liner, waste, radon barrier, filter rock and rock cover were obtained from the “Mixed Waste Design Engineering Report (DER)”, dated May 7, 2003.

The total loading on the in-situ soils (foundation) is calculated to be just over 7,528 psf.

174. INTERROGATORY CR R313-25-7(6)-174/1: WASTE EMPLACEMENT IN CLASS A SOUTH DISPOSAL CELL

Round 1 Interrogatory Response is satisfactory.

175. INTERROGATORY CR R313-25-7(2)-175/1: INFILTRATION RATES FOR THE FEDERAL CELL VERSUS THE CLASS A WEST CELL

ES notes that this interrogatory is no longer relevant since the Federal Cell will use an ET cover. We agree with this position. However, a thorough discussion of the modeling of infiltration rates, with soil hydraulic conductivity values as provided in NUREG/CR-7028 (Benson et al., 2011), is expected in the report on the ET cover system.

EnergySolutions' Response: A methodology for assessment of the full range of initial Federal Cell cover geophysical properties and sensitivity of the projected infiltration on their degradation over time is included in Appendix 15(I) of version 1.2 of the Modeling Report. As is reported in the sensitivity results included in Appendix 15(II), the Federal Cell cover characteristic for which infiltration is most sensitive are Biomass % cover, Clay K_d for Pu, Clay K_d for Cs, Silt K_d for Ra, tortuosity of water content exponent, and cover layer gravel admixture density (all of which exhibit a sensitivity index of < 0.01 , meaning the results are not sensitive to their variations). Variations in geophysical characteristics suggested by Benson et al., 2011 were not demonstrated sensitive. See also the response for INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER.

176. INTERROGATORY CR R313-25-8(5)(A)-176/1: REPRESENTATIVE HYDRAULIC CONDUCTIVITY RATES

Claims made regarding PA modeling for the Class A West Cell ET cover design require review and verification by DEQ. Until such time, this interrogatory will remain open. We recognize that this interrogatory spans two topics: (1) alternative assignments of initial cover properties and (2) alternative approaches to degradation models for changes in cover properties over time.

EnergySolutions' Response: See the responses to interrogatory CR R313-25-7(2)-05/2: RADON BARRIER for additional detail on the sensitivity of cover geophysical characteristics.

While *EnergySolutions* recognizes that it is seeking separate approval for construction of a similar cover system over its Class A West (CAW) embankment from the Division, demonstration of the CAW cover's ability to satisfy low-level radioactive waste disposal performance objectives unique to Class A-type waste are unrelated to the requirements imposed on the Federal Cell evapotranspirative cover's ability to satisfy the unique depleted uranium performance criteria addressed in version 1.2 of the Modeling Report. Similarly, neither the already closed LARW embankment, nor the ongoing cover construction projects for *EnergySolutions*' Mixed Waste embankment have impact on version 1.2 of the Modeling Reports demonstration that the Federal Cell meets the necessary performance objectives. The Mixed Waste and Class A West embankments are

independent physically and hydraulically separate from the proposed Federal Cell. Therefore, there are no outstanding claims regarding the unrelated Class A West cell cover design that require review and verification before closure of this Interrogatory.

177. INTERROGATORY CR R313-25-8(5)(A)-177/2: DOSE FROM PLANT UPTAKE

This statement is correct in that the currently approved cover at Clive has a capillary break in it above the radon barrier, which would discourage deep rooting. However, ES has proposed an ET cover for the DU waste. This ET cover has no effective capillary break layer in it. The grain size distribution has not been engineered thus far to provide for one. Therefore, ES needs to address potential doses from plant uptake assuming that the ET cover system is used. Furthermore, ES needs to consider the potential for plant uptake and potential doses beyond 500 years.

EnergySolutions' Response: It is recognized that the evapotranspirative cover proposed for the Federal Cell does not include a capillary break layer. The evapotranspirative cover does include two radon barriers, which are comparable to the natural 60-cm deep compacted clay layer observed at the Clive area surrounding the Federal Cell, upon which plant roots appear to extend laterally and to not penetrate (SWCA 2013, Figure 6). However, in version 1.2 of the Model, plant roots have maximum rooting depths of 5.7 m, 4.5 m, 1.5 m, 1.1 m, and 0.5 m below ground surface for greasewood, trees, grasses, shrubs, and forbs, respectively. Therefore, plant roots are assumed to penetrate through the entire cover in version 1.2 of the Model (but not all the way to the depleted uranium waste – due to its depth of disposal), and can transport radionuclides to the ground surface where plant litter gets mixed instantaneously with the top layer of soil (1-cm thick) and is subject to transport by downward water advection, diffusion in air and water, burrow collapse, and resuspension in air. Therefore, plant roots are a pathway in version 1.2 of the Model. However, doses from the plant uptake of depleted uranium pathway are very small (e.g. < 0.01 mrem/year mean dose to rancher within 10,000 years).

178. INTERROGATORY CR R313-25-8(5)(A)-178/2: SURFACE WATER PATHWAY

Although limited potential exposure pathways could be the case for the next 500 years, the site has to be modeled at least 10,000 years quantitatively and 1,000,000 years qualitatively. Furthermore, ES needs to address potential surface water pathways associated with the ET cover as opposed to the rip rap.

EnergySolutions' Response: There are differences between the expected performance of the ET cover system and the rock armor system with respect to runoff. First, the rock armor system has filter layers designed to route water out of the cover system to a retention pond. The ET cover system has no designed lateral flow layers. While the upper layer of the rock armor cover consisted of rip-rap with a low water holding capacity, the upper two layers of the ET cover system are designed to function as store-and-release layers. These layers reduce runoff by providing storage for water accumulating from precipitation events and enhancing losses by evaporation. As described previously, the Clive facility is sited in an area of extremely low topographic relief, and surface water features such as stream channels are non-existent on site and in the immediate vicinity. The ancestral lake bed is quite flat, so there is little in the way of land surface gradients which might drive surface water flow. Any runoff and associated sediment transport will be local, and is likely to remain in the vicinity of the site.

Furthermore, the purpose of the qualitative exploration beyond 10,000 years is informative and specifically NOT to assess or determine “exposure pathways.” While arbitrarily assigning exposure pathways to the qualitative assessment may be academically interesting, such exercises are directly opposing NRC guidance,

“Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]”
[emphasis added] (NUREG-1573, pg. 3-10)

As such, exposure and dose should NOT be converted from resulting concentrations as a result of any qualitative assessment of the fate and transport of depleted uranium resulting from “changes in climate”, “glaciations”, or “interglacial rise in sea level that occur in response to changes in global climate.” By doing so, the Division invalidates the express purpose for the qualitative deep time evaluation.

179. INTERROGATORY CR R313-25-7(2)-179/1: RIP RAP

ES notes that this interrogatory is no longer relevant for the top slope of the Federal Cell since the Federal Cell will largely use an ET cover. However, this

interrogatory should be addressed in regard to any rip rap that will be used on portions of the side slope and on ditches.

EnergySolutions' Response: As is reflected in Section 3.1.2 of Appendix 3 – Embankment Modeling to version 1.2 of the Modeling Report (attached as Appendix A to the Compliance Report), there is no riprap material included in the construction of the proposed evapotranspirative cover. No changes in the Division-approved riprap specifications for EnergySolutions' current drainage ditch network is required as a result of approval of the Federal Cell. Approved riprap specifications are summarized in Figure 6 of Appendix 3.

While there are several sources for this material, EnergySolutions has typically secured riprap for other similar construction needs via long-term contract with the U.S. Bureau of Land Management for their rock pits in the nearby Central Grayback 62744 Community Pit. As part of the Division's review of EnergySolutions' annual LLRW surety revision, the availability of sufficient rock to complete cover construction for the 11e.(2), LLRW, and Mixed Waste embankments and associated ditch network has already been successfully demonstrated.

180. INTERROGATORY CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD

However, it is still necessary for ES to demonstrate that exposures to groundwater will remain below the R313-25-19 dose limit (4 mrem/yr) during the entire R313-25-8(5)(a) defined compliance period (10,000 years or more). No additional response to this interrogatory is required from ES.

181. ENERGYSOLUTIONS' RESPONSE: THE 4 MREM/YEAR LIMIT PROMULGATED IN UAC R313-25-20 STRICTLY APPLIES TO DOSES INCURRED TO ANY MEMBER OF THE GENERAL PUBLIC FROM THE INGESTION OF GROUNDWATER. SEE THE RESPONSE TO INTERROGATORY CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS FOR FURTHER DEMONSTRATION THAT GROUNDWATER INGESTION IS NOT A REASONABLE PATHWAY FOR ANALYSIS. INTERROGATORY CR R313-25-19-181/2: GROUNDWATER MORTALITY

The issue with the untraceability of the data ES used remains, and the response also did not address the use of incorrect statistical analysis performed by ES. Both of these facts severely weaken the arguments presented in the response and limit our ability to agree with ES' conclusions.

EnergySolutions' Response: Responses to the Division's insistence of reaching beyond NRC guidance regarding bounding analyses to current water uses by forcing a groundwater ingestion dose pathway are found in responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

182. INTERROGATORY CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS

As discussed elsewhere (see, for example, Interrogatory CR R313-25-8(4)(a)-96/2 and Interrogatory CR R313-25-8(4)(a)-97/2: Need for Potable and/or Industrial Water), SC&A believes that additional information must be provided to demonstrate the groundwater at Clive is not a potential dose pathway. Under Interrogatory CR R313-25-8(4)(a)-96/2, SC&A indicates that ES needs to examine the possibility that the lower confined aquifer at Clive could become contaminated and thus become a source of exposure, either to an inadvertent intruder or to a member of the public. If the water from this aquifer were used for domestic uses but did not meet the test of a public water system, regulation would be left to Tooele County. It is our understanding that the County does not require testing for uranium or other radioactive contaminants.

EnergySolutions' Response: As is reflected in *EnergySolutions* (2013), both the upper unconfined and lower confined aquifers have been classified as Class IV, "non-potable, saline ground water" due to total dissolved solids and other naturally-present constituents. As such, consideration of a groundwater ingestion scenario as an exposure or dose pathway is not representative of "current local well-drilling techniques and/or water use practices," (NRC, 2000). Even so, *EnergySolutions* recognizes current local groundwater practices involve pumping of water as a limited source of non-ingestible industrial water (such as for dust suppression). While of comparably poor water quality, similar local wells installed for the production of industrial water have been screened into the deeper confined aquifer as production sources for industrial water (due to the relatively low yield of the upper, unconfined aquifer).

In fact, *EnergySolutions* requested permission from the Division to install such a well in Section 29 (immediately north of the area licensed for radioactive waste management), (Envirocare, 2005; included as Section 6 to this Response Report). Analyses and representative well characteristics from Envirocare (2005) have been used to model potential doses for an inadvertent industrial intruder well scenario in support of the response to this Interrogatory. Since a cost-benefit/business analysis is implied in Envirocare's 2005 decision to seek approval to install a well in the northwest corner of Section 29 (as opposed to continuing to truck water), repeating such an activity as part of this response is

unnecessary. Envirocare deemed pumping water from a local well financially feasible and commissioned the study (attached as Section 6 to the Round 2 Response Report). Envirocare abandoned its pursuit of the Section 29 well when it became apparent that burdensome regulatory requirements would make it more expensive than continuing to truck water from another source. It is assumed that these same regulatory hurdles will not be present in the Inadvertent Industrial Well scenario considered below.

However, it is important to note that Envirocare's 2005 petition to install the well was that of an "*informed*" or "*advertent*" intruder. Envirocare knew what quality of water was being sought and, as such, the limited uses to which it could be applied. Conversely, if someone were to explore for water in the valley in the future, after the loss of institutional control, without knowledge of water quality, they would most likely install a well nearer to the foothills – where water quantity is more abundant and of higher quality. Water quality continues to degrade as it migrates to the center of the valley – this is the conceptual model for the entire Basin and Range Province. It is extremely unlikely that an industrial user without any knowledge of the valley would select the middle of the valley as their well installation site of primary interest. Additionally, for any industrial use other than dust suppression, the inadvertent intruder will quickly realize the poor quality of the groundwater – when their associated pumps and other industrial equipment become corroded and unusable. This poor quality water naturally contains high concentrations of Uranium and other NORM isotopes. Once an industrial user becomes aware that the water (even in its natural form) must be treated before its possible uses can be expanded – that individual no longer is "*inadvertent*" in its knowledge or intended groundwater uses.

As for the Division's insistence on including a groundwater ingestion dose pathway in the model, the quality of water from the deeper aquifer is of similar classification to that from the shallow aquifer (very high TDS, brackish, and of extremely poor taste and smell). An assumption that there is any possible or reasonable chance to drink it is as unlikely as an assumption that the shallow aquifer is ingested. Therefore, no ingestion was considered credible or representative of current practice.

While highly improbable, it is assumed that an inadvertent industrial intruder driller uses a mud rotary system (which is common in the Clive area) to drill a well (similar in physical characteristics to that proposed in 2005) 90 feet from the design toe of the DU waste within the Federal Cell. For the purposes of this analysis, it is assumed that this occurs sometime after site closure/ institutional control. As is justified in the response to Interrogatory CR R313-25-20-92/2: Inadvertent Intruder Dose Standard and Scenarios, all exposure scenarios (whether acute or chronic) are subject to a dose limit of 500 mrem/year.

These are the known uses of groundwater in the valley. Since this scenario considers direct application of contaminated water onto a broad industrial land surface as dust suppression, any resulting external exposure pathway bounds that of a volumetrically-limited imaginary R/O brine impoundment (as included in the Division's interrogatory basis). In fact, the current users use R/O to treat groundwater pulled from the mountain front, which has much lower TDS (yet, still requires R/O treatment) and a higher yield. These current users are also several miles upgradient of EnergySolutions' proposed Federal Cell and will not be impacted by its construction and operation. Envirocare's 2005 analysis modeled what Envirocare intended to do, which was to install a deep well near the licensed area (also upgradient) for direct use in dust control.

Finally, it is important to note that EnergySolutions (even in support of its 2005 analysis) has never considered the use of an R/O system down-gradient of its licensed areas. This is because the poor native groundwater condition (i.e., extremely high TDS) downgradient of EnergySolutions' licensed areas prevents effective use of R/O systems. In fact, the reason the only R/O system currently in use in that valley is located at the foothills – is that the TDS for the groundwater from that foothill location is approximately half that naturally beneath EnergySolutions' embankments. R/O systems will not work effectively on groundwater with TDS levels significantly higher than those at Aragonite.

ACUTE INADVERTENT WELL DRILLER INTRUDER SCENARIO

DEFINITION: A distinct acute exposure scenario to an inadvertent intruder considered in this analysis is referred to as the “*acute well drilling scenario*”. The acute well drilling scenario is based on the assumption that after active institutional control ceases, an intruder drills a well within the licensed buffer zone (90 feet from the toe of the disposed depleted uranium). The acute well drilling scenario considers exposures during the short period of time required for drilling and construction of the well. During well drilling, the following relevant exposure pathways are assumed:

- External exposure photon-emitting radionuclides in the unshielded cuttings pile containing waste, and
- Inhalation of radionuclides suspended in air from the uncovered cuttings pile containing waste.

The importance of the acute well drilling scenario arises primarily from the assumption that an inadvertent intruder could be located near an unshielded cutting pile for a substantial period of time. Probabilistic isotopic concentrations in the unconfined aquifer (as projected in version 1.2 of the Modeling Report) are used to calculate the associated acute well drilling scenario isotopic dose $[D_{wd}(i,t)]$

for each isotope, i , at the unique time, t , corresponding to that isotopic concentration in the unconfined aquifer.

$$D_{wd}(i,t) = DC_{wd}(i) \times C_{pit}(i,t)$$

where

- $D_{wd}(i,t)$ = The acute dose to the well driller for isotope, i , at the time of its peak shallow aquifer concentration (as projected in version 1.2 of the Modeling Report), (mrem/year).
- $DC_{wd}(i)$ = Acute well drilling scenario dose coefficient for radionuclide, i , (mrem/year per uCi/m³).
- $C_{shallow}(i,t)$ = Isotopic, i , concentration of the waste in the shallow aquifer, (uCi/m³).

The acute well drilling scenario dose coefficient for isotope, i , [$DC_{wd}(i)$] is estimated by summing the exposure pathway dose coefficients:

$$DC_{wd}(i) = DC_{ext}(i) + DC_{inh}(i)$$

where

- $DC_{ext}(i)$ = Acute well drilling scenario external exposure dose coefficient for radionuclide, i , (mrem/year per uCi/m³).
- $DC_{inh}(i)$ = Acute well drilling scenario inhalation exposure dose coefficient for radionuclide, i , (mrem/year per uCi/m³).

The acute well drilling external exposure dose coefficient for isotope, i , [$DC_{ext}(i)$] is estimated by:

$$DC_{ext}(i) = f_c \times U_y(wd) \times DCF_{ie15}$$

where

- f_c = Dilution factor for mixture of upper aquifer waste water, deep aquifer clean water, geologic cuttings, and well drilling mud, (unitless).

$U_y(wd)$	=	Fraction of a year well driller is exposed to cuttings and mud management pit while drilling the well, (unitless).
DCF_{ie15}	=	Dose conversion factor for external exposure to 15 cm of soil and mud uniformly contaminated with radionuclide, i , (mrem/year per uCi/m ³).

The acute well drilling inhalation exposure dose coefficient for isotope, i , [$DC_{inh}(i)$] is estimated by:

$$DC_{inh}(i) = \left(\frac{f_c \times U_y(wd) \times I_{aw} \times L_a(wd) \times DCF_{inh}}{\rho_{mud}} \right)$$

where

I_{aw}	=	Annual air intake for driller (m ³ /year)
$L_a(wd)$	=	Air mass loading during drilling (kg/m ³)
DCF_{inh}	=	Dose conversion factor for inhalation of radionuclide, i , (mrem per uCi).
ρ_{mud}	=	Average bulk density of geologic cuttings (kg/m ³)

The dilution factor, f_c , that accounts for the mixture of upper aquifer waste water, deep aquifer clean water, geologic cuttings, and well drilling mud is computed as:

$$f_c = \left(\frac{V_{shallow}}{V_{shallow} + V_{deep} + V_{mud} + V_{cuttings}} \right)$$

where

$V_{shallow}$	=	Volume of contaminated water from the shallow aquifer brought up as part of the well excavation process, (m ³).
V_{deep}	=	Volume of clean water from the deep aquifer brought up as part of the well excavation process, (m ³).

V_{mud} = Volume of drill mud used up as part of the well excavation process, (m³).

$V_{cuttings}$ = Volume of drill cuttings excavated from the well drilling process, (m³).

The volume of drill cuttings, $V_{cuttings}$, brought up as part of the excavation process is computed as:

$$V_{cuttings} = \pi z_{excavation} \left(\frac{DIA_{excavation}}{2} \right)^2$$

where

$z_{excavation}$ = Total depth of excavation, (m).

$DIA_{excavation}$ = Total diameter of excavation, (m).

The volume of water from the confined aquifer, V_{deep} , brought up as part of the excavation process (assumed to be from the region of 2 times the excavation diameter) is computed as:

$$V_{deep} = \pi n_{deep} z_{deep} (DIA_{excavation})^2$$

where

z_{deep} = Depth of excavation in unit 1 (deep aquifer hosting zone), (m).

n_{deep} = Effective porosity of unit 1 (deep aquifer hosting zone), (unitless).

The volume of water from the unconfined aquifer, $V_{shallow}$, brought up as part of the excavation process (assumed to be from the region of 2 times the excavation diameter) is computed as:

$$V_{shallow} = \pi (n_{uncon} z_4 + n_{uncon} z_3) (DIA_{excavation})^2$$

where

z_4	=	Thickness of excavation in unit 4 between water table and lower layer boundary (unconfined aquifer hosting zone), (m).
z_3	=	Thickness of unit 3, (m).
n_{uncon}	=	Effective porosity of unconfined aquifer, (unitless).

CHRONIC INADVERTENT INDUSTRIAL INTRUDER SCENARIO

DEFINITION: A distinct chronic exposure scenario to an inadvertent intruder considered in this analysis is referred to as the chronic post- drilling scenario. The chronic post- drilling scenario is based on the assumption that after active institutional control ceases, an inadvertent intruder who works near the Federal Cell, uses water produced from the intruder well for industrial purposes (such as dust suppression). While it is recognized that this industrial individual did not conduct activities that actually intruded into the waste, it is assumed that any associated industrial activities are conducted within the buffer area. Additionally, it is assumed that the industrial intruder is unaware of any possible depleted uranium-related contaminants that may have leached into the unconfined aquifer. Under this condition, NRC still characterizes the inadvertent industrial user as an inadvertent intruder, since:

“Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite [that may result in subsequent exposure to members of the general public].”
(NUREG-1573, pg. 3-11).

The following relevant exposure pathways involving the contaminated material sprayed onto the surface are then assumed to occur:

- External exposure photon-emitting radionuclides in the unshielded surface-sprayed wastewater, and
- Inhalation of radionuclides suspended in air from the unshielded surface-sprayed wastewater.

The importance of the chronic post-drilling scenario arises primarily from the assumption that an intruder could inadvertently use contaminated water for dust suppression for a substantial period of time. It is assumed that water extracted from the production well consists of contaminated wastewater from the unconfined aquifer (not within the well screen depth) that has leaked down into

the uncontaminated deep aquifer (where the well casing is screened). The chronic post-drilling scenario isotopic dose [$D_{pd}(i,t)$] is estimated for each isotope, i , at its unique time of peak concentration, t , in the unconfined aquifer.

$$D_{pd}(i,t) = DC_{pd}(i) \times C_{shallow}(i,t)$$

where

$D_{pd}(i,t)$ = The chronic dose to the post driller for isotope, i , at the time of its peak shallow aquifer concentration (as projected in version 1.2 of the Modeling Report), (mrem/year).

$DC_{pd}(i)$ = Chronic post-drilling scenario dose coefficient for radionuclide, i , (mrem/year per uCi/m³).

The chronic post-drilling scenario dose coefficient for isotope, i , [$DC_{pd}(i)$] is estimated by summing the exposure pathway dose coefficients:

$$DC_{pd}(i) = DC_{pd-ext}(i) + DC_{pd-inh}(i)$$

where

$DC_{pd-ext}(i)$ = Chronic post-drilling scenario external exposure dose coefficient for radionuclide, i , (mrem/year per uCi/m³).

$DC_{pd-inh}(i)$ = Chronic post-drilling scenario inhalation exposure dose coefficient for radionuclide, i , (mrem/year per uCi/m³).

The chronic post-drilling scenario external exposure dose coefficient for isotope, i , [$DC_{pd-ext}(i)$] is estimated by:

$$DC_{pd-ext}(i) = f_{pdc} \times U_y(pd) \times DCF_{ie15}$$

where

f_{pdc} = Dilution factor for mixture of upper aquifer waste water and deep aquifer clean water, (unitless).

$U_y(pd)$ = Fraction of a year inadvertent industrial worker is exposed to ground surface contaminated by dust suppression spray, (unitless).

The chronic post-drilling inhalation exposure dose coefficient for isotope, i , $[DC_{pd-inh}(i)]$ is estimated by:

$$DC_{pd-inh}(i) = \left(\frac{f_{pdc} \times U_y(pd) \times I_{aw} \times L_a(wd) \times DCF_{inh}}{\rho_s} \right)$$

where

$$\rho_s = \text{Average bulk density of surface soils (kg/m}^3\text{)}$$

The well water dilution factor, f_{pdc} , that accounts for the mixture of upper aquifer waste water that has been allowed to leak downward into the confined aquifer and the deep aquifer clean water is computed as:

$$f_{pdc} = \left(\frac{Q_{shallow}}{Q_{produced}} \right)$$

where

$$Q_{shallow} = \text{Shallow aquifer water downward leakage rate, (m}^3\text{/year).}$$

$$Q_{produced} = \text{Total rate of water produced from the well (including from the deep, confined aquifer and any water leaked from the upper confined aquifer) for industrial uses, (m}^3\text{/year).}$$

The volume of contaminated wastewater transported from the upper unconfined aquifer, through the leaking well casing, and downward to the deep, confined aquifer, $Q_{shallow}$, is computed using the Thiem-Dupuit's method (Freeze, R.A. and J.A. Cherry, 1979) as the volume of water producible from the unconfined aquifer, under steady-state pumping, that would result in the localized waste table drop (i.e., cone of depression), projected in Envirocare (2005), as:

$$Q_{shallow} = 2\pi K_{shallow} D \left(\frac{s'_{m1} - s'_{m2}}{\ln(r_2/r_1)} \right)$$

where the parameters are illustrated in the following:

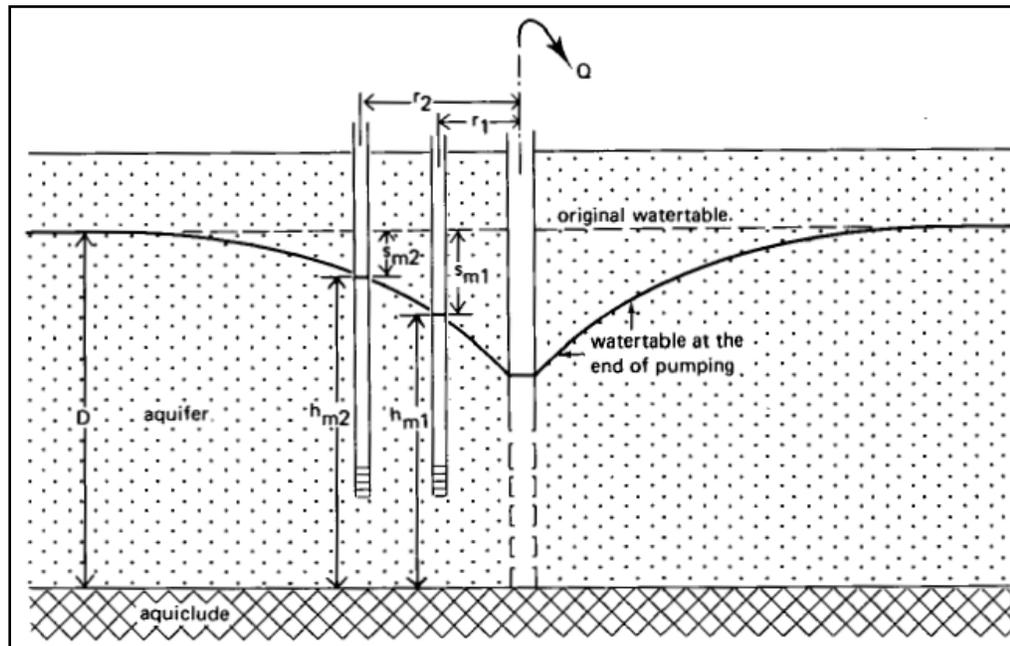


Figure - Thiem-Dupuit's method scenario parameter layout

INADVERTENT INTRUDER WELL DOSE CALCULATIONS:

Doses in the inadvertent intruder groundwater analysis were estimated by using the isotopic concentrations projected in the upper unconfined aquifer in version 1.2 of the Modeling Report and well characteristics similar to that proposed in Envirocare (2005). For each exposure pathway in a scenario of interest, an effective dose equivalent (EDE) in mrem/year for each isotope of interest is calculated.

TABLE – Inadvertent Intruder Well Model Input Parameters

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
$Q_{produced}$	Total rate of water produced from the well (including from the deep, confined aquifer and any water leaked from the upper confined aquifer) for industrial uses	1.33E+05	m ³ /year	Envirocare, 2005
Z_{deep}	Depth of excavation in unit 1 (deep aquifer hosting zone)	1.71E+02	m	Envirocare, 2005
n_{deep}	Effective porosity of unit 1 (deep aquifer hosting zone)	1.30E-01	unitless	Envirocare, 2005
$U_y(wd)$	Fraction of a year well driller is exposed to cuttings and mud management pit while drilling the well	4.57E-03	unitless	EPA, 2011
I_{aw}	Annual air intake for driller	2.19E+04	m ³ /year	EPA, 2011
$L_a(wd)$	Air mass loading during drilling	1.00E-06	kg/m ³	EPA, 2011
ρ_{mud}	Average bulk density of geologic cuttings	1.00E+03	kg/m ³	Envirocare, 2005
$Z_{excavation}$	Total depth of excavation	1.83E+02	m	Envirocare, 2005
$DIA_{excavation}$	Total diameter of excavation	2.41E-01	m	Envirocare, 2005
Z_4	Average thickness of unit 4	3.05E+00	m	Envirocare, 2005
Z_3	Average thickness of unit 3	4.57E+00	m	Envirocare, 2005
n_{uncon}	Effective porosity of saturated regions of units 4 and 3	2.90E-01	unitless	Envirocare, 2005
$U_y(pd)$	Fraction of a year inadvertent industrial worker is exposed to ground surface contaminated by dust suppression spray	2.28E-01	unitless	EPA, 2011
ρ_s	Average bulk density of surface soils	1.60E+03	kg/m ³	Envirocare, 2005
D_{wt}	Average depth from ground surface to unconfined aquifer (water table)	5.18E+00	m	Envirocare, 2005
D	Average thickness of unconfined aquifer	6.10E+00	m	Envirocare, 2005
$K_{shallow}$	Effective hydraulic Conductivity of saturated regions of units 4 and 3	1.06E+02	m/yr	Envirocare, 2005
r_1	Radial distance to 1st unconfined aquifer drawdown reading	9.14E+02	m	Envirocare, 2005
r_2	Radial distance to 2nd unconfined aquifer drawdown reading	2.13E+03	m	Envirocare, 2005
s'_1	Steady-state draw down in unconfined aquifer at 1st location	2.13E-01	m	Envirocare, 2005
s'_2	Steady-state draw down in unconfined aquifer at 2nd location	1.22E-01	m	Envirocare, 2005

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
V_{mud}	Volume of drilling mud	1.69E+02	m ³	Fleming, et. al 2012
Sr-90	Peak unconfined shallow aquifer concentration - mean	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
Tc-99	Peak unconfined shallow aquifer concentration - mean	7.40E-01	uCi/m ³	Table 2 Modeling Report (v1.2)
I-129	Peak unconfined shallow aquifer concentration - mean	4.82E-04	uCi/m ³	Table 2 Modeling Report (v1.2)
Th-230	Peak unconfined shallow aquifer concentration - mean	1.85E-29	uCi/m ³	Table 2 Modeling Report (v1.2)
Th-232	Peak unconfined shallow aquifer concentration - mean	1.44E-35	uCi/m ³	Table 2 Modeling Report (v1.2)
Np-237	Peak unconfined shallow aquifer concentration - mean	9.75E-21	uCi/m ³	Table 2 Modeling Report (v1.2)
U-233	Peak unconfined shallow aquifer concentration - mean	3.86E-25	uCi/m ³	Table 2 Modeling Report (v1.2)
U-234	Peak unconfined shallow aquifer concentration - mean	1.51E-24	uCi/m ³	Table 2 Modeling Report (v1.2)
U-235	Peak unconfined shallow aquifer concentration - mean	1.10E-25	uCi/m ³	Table 2 Modeling Report (v1.2)
U-236	Peak unconfined shallow aquifer concentration - mean	2.24E-25	uCi/m ³	Table 2 Modeling Report (v1.2)
U-238	Peak unconfined shallow aquifer concentration - mean	1.12E-23	uCi/m ³	Table 2 Modeling Report (v1.2)
Sr-90	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
Tc-99	Peak unconfined shallow aquifer concentration - median	1.95E-02	uCi/m ³	Table 2 Modeling Report (v1.2)
I-129	Peak unconfined shallow aquifer concentration - median	6.76E-10	uCi/m ³	Table 2 Modeling Report (v1.2)
Th-230	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
Th-232	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
Np-237	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
U-233	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
U-234	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
U-235	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
U-236	Peak unconfined shallow aquifer concentration - median	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
U-238	Peak unconfined shallow aquifer concentration - median	2.21E-39	uCi/m ³	Table 2 Modeling Report (v1.2)
Sr-90	Peak unconfined shallow aquifer concentration - 95th %ile	0.00E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
Tc-99	Peak unconfined shallow aquifer concentration - 95th %ile	4.46E+00	uCi/m ³	Table 2 Modeling Report (v1.2)
I-129	Peak unconfined shallow aquifer concentration - 95th %ile	3.39E-03	uCi/m ³	Table 2 Modeling Report (v1.2)
Th-230	Peak unconfined shallow aquifer concentration - 95th %ile	3.35E-34	uCi/m ³	Table 2 Modeling Report (v1.2)
Th-232	Peak unconfined shallow aquifer concentration - 95th %ile	2.09E-40	uCi/m ³	Table 2 Modeling Report (v1.2)
Np-237	Peak unconfined shallow aquifer concentration - 95th %ile	1.32E-27	uCi/m ³	Table 2 Modeling Report (v1.2)
U-233	Peak unconfined shallow aquifer concentration - 95th %ile	1.00E-28	uCi/m ³	Table 2 Modeling Report (v1.2)
U-234	Peak unconfined shallow aquifer concentration - 95th %ile	8.10E-29	uCi/m ³	Table 2 Modeling Report (v1.2)
U-235	Peak unconfined shallow aquifer concentration - 95th %ile	6.77E-30	uCi/m ³	Table 2 Modeling Report (v1.2)
U-236	Peak unconfined shallow aquifer concentration - 95th %ile	1.08E-29	uCi/m ³	Table 2 Modeling Report (v1.2)
U-238	Peak unconfined shallow aquifer concentration - 95th %ile	6.35E-28	uCi/m ³	Table 2 Modeling Report (v1.2)

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
				Report (v1.2)
Sr-90	Mean Dose Conversion Factor (inhalation)	5.92E+02	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Tc-99	Mean Dose Conversion Factor (inhalation)	4.81E+01	mrem per uCi	Appendix 11, Modeling Report (v1.2)
I-129	Mean Dose Conversion Factor (inhalation)	3.55E+02	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Th-230	Mean Dose Conversion Factor (inhalation)	3.70E+05	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Th-232	Mean Dose Conversion Factor (inhalation)	4.07E+05	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Np-237	Mean Dose Conversion Factor (inhalation)	1.85E+05	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-233	Mean Dose Conversion Factor (inhalation)	3.55E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-234	Mean Dose Conversion Factor (inhalation)	3.48E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-235	Mean Dose Conversion Factor (inhalation)	3.15E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-236	Mean Dose Conversion Factor (inhalation)	3.22E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
U-238	Mean Dose Conversion Factor (inhalation)	2.96E+04	mrem per uCi	Appendix 11, Modeling Report (v1.2)
Sr-90	Mean Dose Conversion Factor ext - 15cm)	4.40E-04	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
Tc-99	Mean Dose Conversion Factor ext - 15cm)	7.84E-05	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
I-129	Mean Dose Conversion Factor ext - 15cm)	8.09E-03	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
Th-230	Mean Dose Conversion Factor ext - 15cm)	7.56E-04	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
Th-232	Mean Dose Conversion Factor ext - 15cm)	3.26E-04	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)

INPUT PARAMETER	DESCRIPTION	VALUE	UNIT	REFERENCE
Np-237	Mean Dose Conversion Factor ext - 15cm)	4.87E-02	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
U-233	Mean Dose Conversion Factor ext - 15cm)	8.73E-04	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
U-234	Mean Dose Conversion Factor ext - 15cm)	2.51E-04	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
U-235	Mean Dose Conversion Factor ext - 15cm)	4.51E-01	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
U-236	Mean Dose Conversion Factor ext - 15cm)	1.34E-04	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)
U-238	Mean Dose Conversion Factor ext - 15cm)	6.44E-05	mrem/year per uCi/m ³	Appendix 11, Modeling Report (v1.2)

Using these input parameters, there are several factors (independent of isotope) that are calculated according to the approach summarized above.

TABLE – Inadvertent Intruder Well Model Calculated Parameters

CALCULATED PARAMETER	DESCRIPTION	VALUE	UNIT
$Q_{shallow}$	Shallow aquifer water downward leakage rate	4.37E+02	m ³ /year
f_{pdc}	Dilution factor for mixture of upper aquifer waste water and deep aquifer clean water	3.28E-03	unitless
$V_{shallow}$	Volume of contaminated water from the shallow aquifer brought up as part of the well excavation process	4.04E-01	m ³
V_{deep}	Volume of clean water from the deep aquifer brought up as part of the well excavation process	4.06E+00	m ³
$V_{cuttings}$	Volume of drill cuttings excavated from the well drilling process	8.36E+00	m ³
f_c	Mud driller dilution factor	2.22E-03	unitless
$DC_{inh(i)} / DCF_{inh}$	Intermittent ratio (isotope independent)	2.22E-10	m ³ /year
$DC_{ext(i)} / DCF_{ie15}$	Intermittent ratio (isotope independent)	1.02E-05	m ³ /year
$DC_{pd-inh(i)} / DCF_{inh}$	Intermittent ratio (isotope independent)	1.03E-08	m ³ /year
$DC_{pd-ext(i)} / DCF_{ie15}$	Intermittent ratio (isotope independent)	7.50E-04	m ³ /year

These calculated factors can then be used to estimate inadvertent intruder well doses from isotopic unconfined aquifer concentrations projected in version 1.2 of the Modeling Report. As such, isotopic doses are to the acute Intruder Driller from unconfined shallow aquifer concentrations output from version 1.2 of the Modeling Report as calculated below.

TABLE – Acute Well Driller Isotopic Doses

ISOTOPE	ACUTE DOSE FROM MEAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	ACUTE DOSE FROM MEDIAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	ACUTE DOSE FROM 95% ILE SHALLOW AQUIFER CONCENTRATION (mrem/year)
Sr-90	0.00E+00	0.00E+00	0.00E+00
Tc-99	8.51E-09	2.24E-10	5.13E-08
I-129	7.77E-11	1.09E-16	5.47E-10
Th-230	1.52E-33	0.00E+00	2.76E-38
Th-232	1.30E-39	0.00E+00	1.89E-44
Np-237	4.06E-25	0.00E+00	5.50E-32
U-233	3.05E-30	0.00E+00	7.91E-34
U-234	1.17E-29	0.00E+00	6.27E-34
U-235	1.27E-30	0.00E+00	7.84E-35
U-236	1.60E-30	0.00E+00	7.74E-35
U-238	7.38E-29	1.46E-44	4.18E-33

Since the version 1.2 Model Report-projected isotopic mean, median, and 95-percentile concentrations do not occur at the same point in time, it is inappropriate to estimate a total effective dose equivalent by summing over all isotopes. However, doing so does create a bounding estimate, above which the total dose estimated to the acute well driller will not exceed (upper dose limit from mean shallow aquifer concentrations = 8.6E-09 mrem/year, upper dose limit from median shallow aquifer concentrations = 2.2e-10 mrem/year, and upper dose limit from 95-percentile shallow aquifer concentrations = 5.2E-08 mrem/year), all of which are significantly lower than the 500 mrem/year intruder limit.

Application of the calculated factors can also be used to estimate isotopic doses to the chronic Industrial Intruder from isotopic unconfined aquifer concentrations projected in version 1.2 of the Modeling Report.

TABLE – Chronic Well User Isotopic Doses

ISOTOPE	CHRONIC DOSE FROM MEAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	CHRONIC DOSE FROM MEDIAN SHALLOW AQUIFER CONCENTRATION (mrem/year)	CHRONIC DOSE FROM 95% ILE SHALLOW AQUIFER CONCENTRATION (mrem/year)
Sr-90	0.00E+00	0.00E+00	0.00E+00
Tc-99	4.09E-07	1.08E-08	2.46E-06
I-129	4.68E-09	6.56E-15	3.29E-08
Th-230	7.02E-32	0.00E+00	1.27E-36
Th-232	6.01E-38	0.00E+00	8.73E-43
Np-237	1.89E-23	0.00E+00	2.55E-30
U-233	1.41E-28	0.00E+00	3.65E-32
U-234	5.39E-28	0.00E+00	2.89E-32
U-235	7.26E-29	0.00E+00	4.47E-33
U-236	7.40E-29	0.00E+00	3.57E-33
U-238	3.40E-27	6.71E-43	1.93E-31

Since the version 1.2 Model Report-projected isotopic mean, median, and 95-percentile concentrations do not occur at the same point in time, it is inappropriate to estimate a total effective dose equivalent by summing over all isotopes. However, doing so does create a bounding estimate, above which the total dose estimated to the chronic inadvertent industrial well user will not exceed (upper dose limit from mean shallow aquifer concentrations = 4.2E-07 mrem/year, upper dose limit from median shallow aquifer concentrations = 1.1E-08 mrem/year, and upper dose limit from 95-percentile shallow aquifer concentrations = 2.6E-06 mrem/year), all of which are significantly lower than the 500 mrem/year intruder limit.

By using this same methodology and setting the dose to the inadvertent chronic industrial well user at 500 mrem/year, upper bounding equivalent depleted uranium isotopic concentrations can be reverse-calculated for SRS waste, assuming only the SRS depleted uranium wastes were disposed of in the Federal Cell (as are reported in Table 5 and 6 of Appendix 4 from version 1.2 of the Modeling Report).

TABLE – SRS Depleted Uranium Concentrations Equivalent to 500 mrem/year Chronic Well Isotopic Doses

ISOTOPE	ACTUAL MEAN SRS ACTIVITY FROM TABLES 5 AND 6 OF APPENDIX 4 (pCi/g)	NECESSARY SRS ACTIVITY TO CREATE AN ISOTOPIC-SPECIFIC 500 MREM/YEAR CHRONIC DOSE TO THE INADVERTENT INDUSTRIAL WELL USER (pCi/g)
Sr-90	47	5.69E+10
Tc-99	23800	2.88E+13
I-129	18.6	2.25E+10
Np-237	5.68	6.87E+09
U-233	478	5.78E+11
U-234	2170	2.62E+12
U-235	750	9.07E+11
U-236	1170	1.42E+12
U-238	6640	8.03E+12

When compared to the doses projected in Appendix 11 – Dose Assessment from version 1.2 of the Modeling Report, it is clear that doses from neither the proposed acute well driller inadvertent intruder nor the chronic industrial well user inadvertent intruder limit the analysis.

See also the response to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS.

183. INTERROGATORY CR R313-25-19-183/2: MEAT INGESTION

Round 1 Interrogatory Response is satisfactory.

184. INTERROGATORY CR R313-25-19-184/2: GOLDSIM SKIPS STABILITY CALCULATION

Depending on whether GoldSim Player 10.5 SP1 or SP4 is used, the same GoldSim DU PA model file can produce significantly different results. ES needs to determine, demonstrate, and document which GoldSim version produced the “correct” results.

Additionally, steps need to be taken to ensure that only the “right” GoldSim version is used in conjunction with the DU PA model file. For example, if ES

demonstrates that SP1 is giving “correct” results, then the DU PA model file should be “crippled” so as not to run under SP4, or anything other than SP1.

EnergySolutions’ Response: Version 1.2 of the Model is designed and correctly runs without error within the GoldSim 10.5 (SP4) platform. The GoldSim 10.5 (SP4) installation file (free for public distribution) will be provided with the final comprehensive deliverable for public review.

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4. REVISED DEPLETED URANIUM BEARING CAPACITY CALCULATION

DU Cylinder's Bearing Capacity Calculation

13-Jun-14

Find the bearing pressure of a DU cylinder's weight in a Double Stack DU cylinder configuration to verify its bearing pressure at the top of the clay liner.

Details of DU Cylinder(s):

Assume DU cylinder is 12' long x 4' diameter, made of 3/8" thick steel: assume cylinder weight of 4500 lbs. Assuming the the bulk density of U3O8 is 2.7 g/cm3 (Wikipedia 2014) from the Interrogatory:

Waste weight: $2.7 \text{ gm/cm}^3 = 168.534 \text{ lb/cf}$

Assume all cylinders are 100% full and that a cylinder placed on the lower tier supports 50% of the weight of each of two upper tier cylinders. Spaces in between cylinders are filled with flowable sand at a density of 112 pcf, which is included in the calculation.

<u>Size of Cylinder:</u>	<u>Length (ft)</u>	<u>Diameter (ft)</u>	<u>Volume (cf)</u>	<u>Area (sf)</u>	<u>Weight (lbs)</u>
Maximum DU Cylinder total waste weight (weight of two upper and one lower cylinder) -using 50% of each of the two upper cylinders.	12.0	4.0	150.7	48.00	59,803
Weight of flowable sand between the double stacked DU Cylinders	NA	NA	82.6	NA	9,247

<u>Soil Cover:</u>	<u>Thickness</u>	<u>Unit Weight</u>	<u>Unit Weight</u>
Liner Protective Cover	1 feet	97.6	pcf

Calculations:

Use Westergaard Theory (Fig. 8.26) to determine loading at level of Clay Liner. Center controls.

m value	2.00
n value	6.00
I-sigma value from Fig 8.26	0.193

Bearing Pressure of Component:	1,208 psf
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< CQA 3,000 psf allowable for large components

DU Cylinder & DU Drums Bearing Capacity Calculation

13-Jun-14

Find the bearing pressure of a DU cylinder weight in single Stack DU Cylinder Configuration with overlying 55 gallon DU drums to verify its bearing pressure at the top of the clay liner.

Details of DU Cylinder and 55 gallon DU Drums:

Assume DU Cylinder is 12' long x 4' diameter, made of 3/8" thick steel: assume cylinder weight of 4500 lbs.

Assume fourteen (14) 55 gallon DU drums above a 12x4 DU Cylinder, each empty 55 gallon DU drum weighs 50 lbs and contains 7.353 cf of DU waste as shown below. Drum sizes approximated at: 3' L x 2' Dia.

Assuming the the bulk density of U3O8 is 2.7 g/cm³ (Wikipedia 2014) from the Interrogatory:

Waste weight: $2.7 \text{ gm/cm}^3 = 168.534 \text{ lb/cf}$

Assume a cylinder placed in the lower tier supports the weight of fourteen upper tier 55 gallon drums and calculate the bearing capacity using the weight of these 100% filled cylinder and drums. Spaces around the cylinder and around the drums are filled with flowable sand at a density of 112 pcf, which is included in the calculation.

<u>Size of Cylinder:</u>	<u>Length (ft)</u>	<u>Diameter (ft)</u>	<u>Volume (cf)</u>	<u>Area (sf)</u>	<u>Weight (lbs)</u>
Maximum DU Cylinder total weight for one lower 12' x 4' DU cylinder.	12.0	4.0	150.7	48.00	29,901
Weight of 14 upper 55 gallon DU Drums bearing on one lower 12' x 4' DU cylinder.	3.0	2.0	7.353	NA	18,049
Volume of flowable sand around the single stacked DU Cylinder	NA	NA	41.3	NA	4,623
Volume of flowable sand between the DU Drums	NA	NA	37.2	NA	4,164

<u>Soil Cover:</u>	<u>Thickness</u>	<u>Unit Weight</u>	
Liner Protective Cover	1 feet	97.6	pcf

Calculations:

Use Westergaard Theory (Fig. 8.26) to determine loading at level of Clay Liner. Center controls.

m value	2.00
n value	6.00
I-sigma value from Fig 8.26	0.193

Bearing Pressure of Component:	1,010 psf
	< CQA 3,000 psf allowable for large components

DU Cylinder's Bearing Capacity Calculation

13-Jun-14

Find the bearing pressure of a DU cylinders weight in Single Stack DU cylinder configuration to verify its bearing pressure at the top of the clay liner.

Details of DU Cylinder:

Assume a DU cylinder is 12' long x 4' diameter, made of 3/8" thick steel: assume cylinder weight of 4500 lbs.

Assuming the the bulk density of U3O8 is 2.7 g/cm³ (Wikipedia 2014) from the Interrogatory:

Waste weight: $2.7 \text{ gm/cm}^3 = 168.534 \text{ lb/cf}$

Assume a cylinder placed in the lower tier and calculate the bearing capacity using the weight of this 100% filled cylinder. Spaces around the cylinder are filled with flowable sand at a density of 112 pcf, which is included in the calculation.

<u>Size of Cylinder:</u>	<u>Length (ft)</u>	<u>Diameter (ft)</u>	<u>Volume (cf)</u>	<u>Area (sf)</u>	<u>Weight (lbs)</u>
Maximum DU Cylinder total waste weight.	12.0	4.0	150.7	48.00	29,901
Weight of flowable sand between the single stacked DU Cylinder	NA	NA	41.3	NA	4,623

<u>Soil Cover:</u>	<u>Thickness</u>	<u>Unit Weight</u>	<u>Unit</u>
Liner Protective Cover	1 feet	97.6	pcf

Calculations:

Use Westergaard Theory (Fig. 8.26) to determine loading at level of Clay Liner. Center controls.

m value	2.00
n value	6.00
I-sigma value from Fig 8.26	0.193

Bearing Pressure of Component: 653 psf

< CQA 3,000 psf allowable for large components

Federal Cell Bearing Capacity Calculation

13-Jun-14

Find the bearing pressure of the Federal Waste cell in the location of a double stacked DU cylinder configuration to verify its maximum bearing pressure on the bottom in-situ clay (i.e. foundation).

Assume uniform waste weight of 125 pcf and various layers' thicknesses and weights as follows:

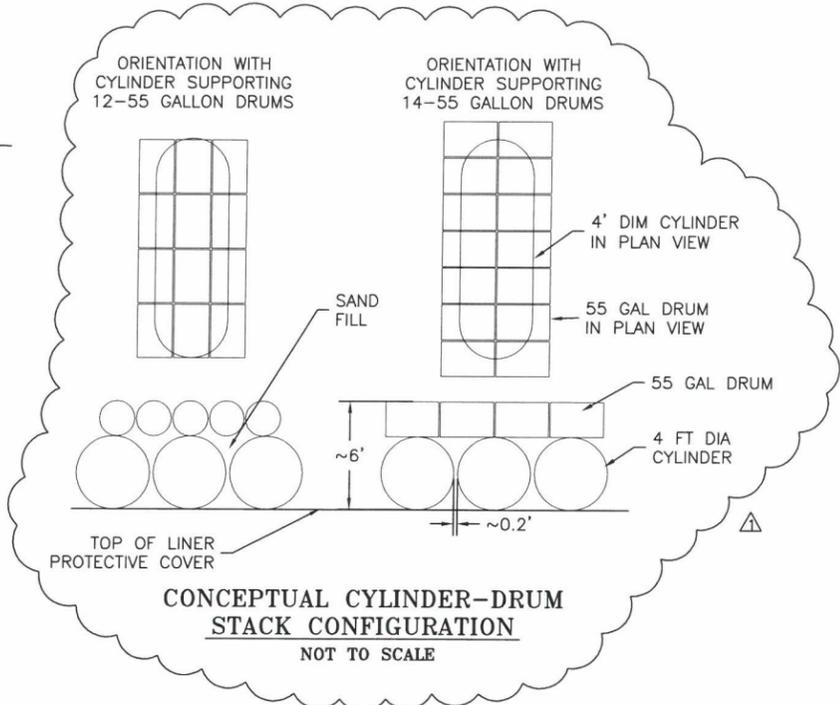
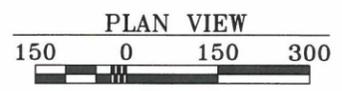
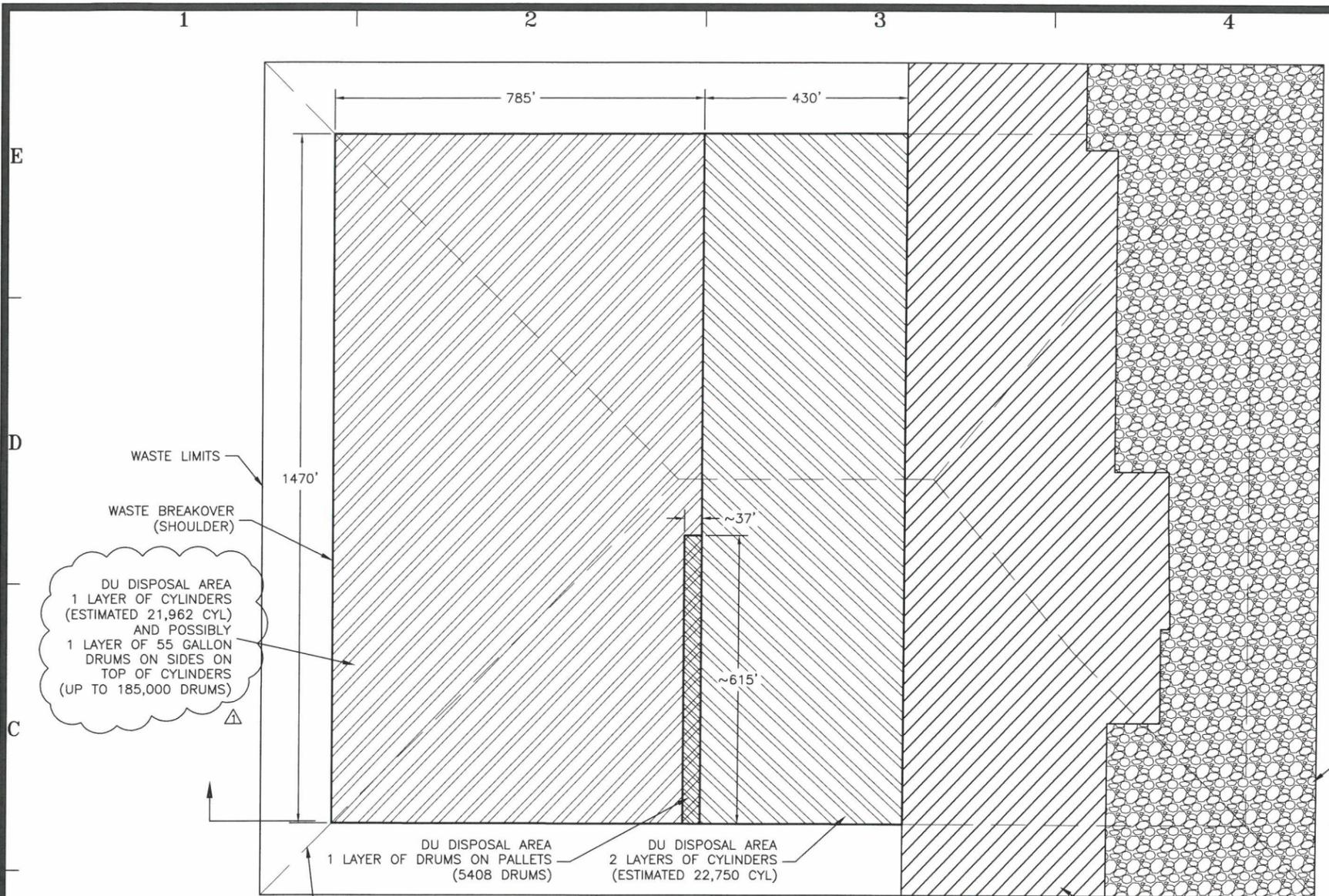
DU Waste weight: (Double Stack Bearing Load) 1,208 psf

<u>Embankment Layer:</u>	<u>Thickness</u>	x	<u>Unit Weight</u> (pcf)	psf
Clay Liner	2.0	feet	97.6	195.2
Liner Protective Cover	1.0		97.6	97.6
DU Waste (Cylinders)	7.3		165.5	1208.1
Waste above DU	42.8		125	5350.0
Radon Barrier	4.0		97.6	390.4
Filter Rock	1.0		142	142.0
Rock Cover	1.0		145	145.0
Total	59.1	feet		7,528.3 psf

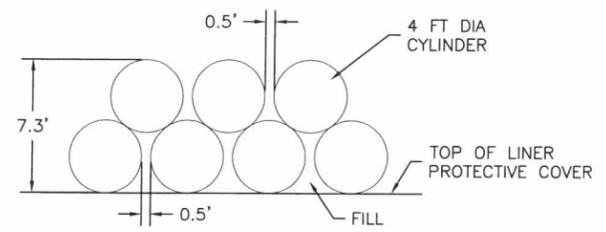
Assumptions:

Assume worst case scenario: Drums in double stack orientation at base of Federal Cell over one foot of protective cover over clay liner.

Values used for clay, rock, filter and waste units were taken from the Mixed Waste Design Engineering Report (DER), Dated May 7, 2003. The total value calculated in the DER for the Mixed Waste cell was 7,077.7 psf by comparison with the proposed Federal Cell.

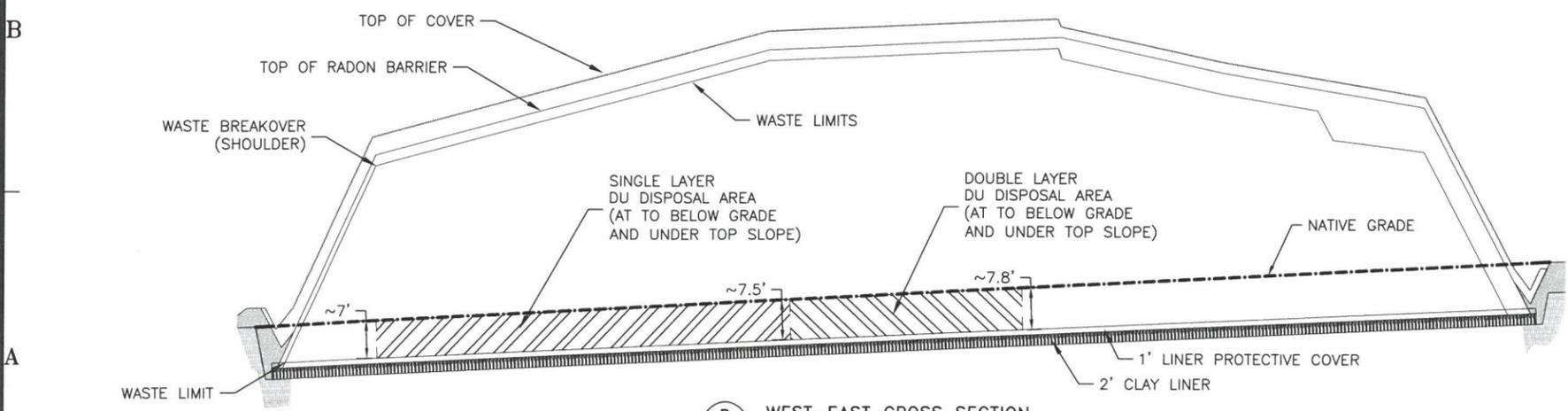


CONCEPTUAL CYLINDER-DRUM STACK CONFIGURATION
NOT TO SCALE



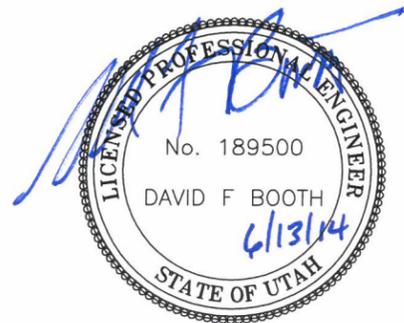
CONCEPTUAL DOUBLE STACK CONFIGURATION
NOT TO SCALE

- NOTES**
- LIMITS FOR SINGLE AND DOUBLE LAYER DISPOSAL ARE CONCEPTUAL ONLY, BASED ON CONSERVATIVE ASSUMPTIONS FOR NATIVE GRADE, CYLINDER SIZES, SPACING, AND STACKING CONFIGURATION.
 - ESTIMATED NUMBER OF CYLINDERS ASSUMES THAT ALL CYLINDERS ARE 12-Mg CYLINDERS (12' LONG X 4' DIA), AND ASSUMES THE FOLLOWING PLACED SPACING.
SINGLE LAYER: CYLINDERS ARE SPACED 0.2 FT END-TO-END AND SIDE-TO-SIDE, AND DRUMS ARE PLACED ON 4'X4' PALLETS SPACED AT 0.1 FT.
DOUBLE LAYER: CYLINDERS ARE SPACED 0.2 FT END-TO-END AND 0.5 FT SIDE TO SIDE, BOTH LAYERS.



WEST-EAST CROSS SECTION
HORIZONTAL SCALE: VERTICAL SCALE = 1:10

ENERGYSOLUTIONS
CLIVE FACILITY
FEDERAL WASTE CELL
CONCEPTUAL DU DISPOSAL PLAN
CLIVE, UTAH



DESIGNED BY	D. BOOTH
DRAWN BY	G. DUTSON
APPROVED BY	D. BOOTH
SCALE	AS NOTED
DATE	03/28/14
PROJECT NO.	14004
	L1

DATE	6/13/14	BY	DFB
DATE	3/31/14	BY	DFB
DATE		BY	

5. GOLDSIM V10.5 VERIFICATION PLAN

VERIFICATION PLAN
GOLDSIM VERSION 10.50 SP1

GoldSim Technology Group LLC

Issaquah, Washington

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1. INTRODUCTION

1.1 DOCUMENT PURPOSE

This document, referred to here as a *software verification plan*, is intended to provide all necessary information for verification of the computer program GoldSim. The definition of verification used here is as provided in SANDIA (1995): “The process of demonstrating that a computer software program performs its numerical and logical operations correctly.” Software verification should not be confused with validation, which is the demonstration that a computer program is appropriate for use in modeling a physical process.

1.2 BACKGROUND

GoldSim is a computer program developed by GoldSim Technology Group LLC for probabilistically evaluating the performance of complex environmental systems. It is essentially a complex contaminant transport model, consisting of a series of inter-connected, coupled component models with input/output relationships for contaminant transfer. Output from the model includes contaminant release rates, concentrations of contaminants in various environmental media, and time histories of dose or risk to specified human receptors. GoldSim runs only on personal computers having Microsoft Windows 98, NT, 2000 or XP as the operating system.

GoldSim’s capabilities are specified in two key documents: the GoldSim User Guide (Kossik and Miller (2008a)) the GoldSim Contaminant Transport User Guide (Kossik and Miller (2008b)), the GoldSim Reliability Module User Guide (2008c), the GoldSim Distributed Processing User Guide (2008d), and the GoldSim Dashboard Authoring Module (2008e). This verification plan is intended primarily to test all GoldSim capabilities which could affect the accuracy of results calculated by GoldSim. Secondly, it tests to ensure that all important user interface functions operate as intended.

1.3 DOCUMENT ORGANIZATION

This plan describes a series of tests intended to confirm that the GoldSim model performs all quality-affecting operations correctly. Chapter 2 describes the procedures that the Verifier should follow.

The verification tests are divided into major functional groups evaluating the core software, result presentation, Monte Carlo tests, Contaminant Transport and Reliability tests.

This plan incorporates by reference a suite of GoldSim input files, which are required in order to perform the specified tests. These files, which are listed in Appendix I, are controlled by the same quality procedures as the plan itself. The Verifier should be provided with both the plan and the test files.

In addition, there are a number of additional verification tests incorporated by reference into this document. These include tests evaluating the licensing and the Financial Module. These tests should be part of all full verification tests.

2. VERIFICATION PROCEDURE

Verifying GoldSim requires the user to generate results for each test problem, and compare those results with others that are known to be correct. Instructions on generating and viewing results are given in Section 3, and a discussion of the result required for each test problem is included in Sections 3 to 10. This section contains an explanation of how such comparisons are to be done.

The Verifier is expected to perform the verification according to a prescribed quality assurance procedure, which will specify any necessary qualifications or training required, and the form of the verification report to be produced. Typically the verification report is a brief summary confirming that all tests were performed, and identifying any cases where the expected results were not produced plus any other anomalous items.

2.1 INSTALLING GOLDSIM

GoldSim will be provided as a self-extracting install file which automatically installs GoldSim onto the tester's system. It is recommended that the user accept the default installation folder: c:\Program Files\GTG\GoldSim 9.

The GoldSim test files consist of a set of .gsm files which should also be copied to the test folder.

2.2 RUNNING GOLDSIM

GoldSim may be started from the Start/Programs menu.

2.3 OBTAINING VERIFICATION FILES

Verification files should be obtained from SourceSafe, and for major (full number) releases should be updated using the candidate version to verify the proper functioning of the conversion code. This should be done using a batch file that opens, runs and saves the verification files (the batch file is described in the User's Guide). When the files are opened for the verification tests, this process also serves to verify model serialization in the candidate version.

For major releases, the base files should be set aside to be checked into SourceSafe once verification is complete.

2.4 COMPARING RESULTS

The user will need to generate and view numerical and/or graphical results for many of the test problems. These results are then directly compared to the expected results given in Sections 3 and 4. GoldSim results generated for comparison can be viewed using several different methods. Typically, the user will right-click on the icon for the desired output, and GoldSim will then display the results.

In general, the computational verification tests are considered acceptable if the verification result agrees to **three** significant figures with the closed-form or benchmark-code solution. Any exceptions to this standard are described along with the particular test information.

3. BASIC GOLDSIM FUNCTIONAL TESTS

This Chapter tests all core computational functions of the GoldSim program.

3.1 BASIC GOLDSIM ELEMENT FUNCTIONALITY TESTS

The basic functionality tests address parsing, unit conversion, expression evaluation, probability distribution, and all of the basic GoldSim element classes: data, stock, selector, and table. They also test database links for data and stochastic elements. Finally, they test clones and external functions.

Parsing, Unit Conversions and Function Operations

A test file called ParseTest.dat has been developed to automatically test all of the basic parsing and unit conversion capabilities and most of the function operators in GoldSim. First copy file ParseTest.dat (available from the Units_Parse directory in Source Safe) to the root directory from which GoldSim is executed. GoldSim automatically executes this file when the Verifier presses Ctrl-F8. The results are written to an ASCII output file, ParseRes.txt. The Verifier then compares ParseRes.txt to the correct master result file, ParseRes01.txt which is provided along with the verification test problems. (Note that Word can be used to identify any differences between the two files). Any differences between the master and output file should be recorded.

The test file, ParseTest.dat, and the master file, ParseRes01.txt, are presented in Appendix II.

A second automatic test is initiated by pressing Ctrl-Alt-F9. This produces an output file "UnitsEcho.txt" which contains the conversion factors for all of GoldSim's built-in units. The Verifier should compare this file to the reference file, UnitsEcho0.txt (available from Source Safe in the Units_Parse directory, and also included in Appendix II), and note any differences.

General Simulation

GS0_Run_Controller

This test verifies the correct functioning of the run controller, including the run controller buttons, displays, and error checking.

1. Error States

Enter the container Error_Checks. This container tests error-checking and the Run Controller's Error state. The test proceeds as follows:

- a. Identifying invalid model expressions before the simulation:
 - i. In the element named Vector, type in the following formula in the equation field: Non_zero (i.e., type the name of the element Non_zero). Accept the warning message by clicking the Yes button.
 - ii. Run the model (i.e., click the Run button on the main toolbar).
 - iii. Before the Run Controller can appear, a dialog box should appear indicating that Vector has an invalid local expression. Click the OK button.
 - iv. Run the model again. This time when the invalid local expression dialog appears, click the Edit button. The properties dialog for Vector should appear. Replace the existing formula by typing Vector_Input in the equation field. You should be able to close the dialog without errors.
- b. Error State:
 - i. In the element named Divide_By_Zero, type the following formula in the equation field: Non_zero / Zero.
 - ii. Run the model (i.e., click the Run button on the main toolbar. When the Run Controller appears, click the Run button on the Run Controller). A runtime dialog should appear, indicating a divide-by-zero error in the first realization.
 - iii. Click OK to close the error dialog. The Run Controller now shows a status of Error. Ensure that clicking the run realization and run one timestep asks the user if they would like to restart the simulation.
 - iv. While in the Error state, you should be able to browse the model. Try this.
 - v. Click the Edit button and the model should return to the Edit Mode.
 - vi. Replace the formula in Divide_by_Zero with the value of 0.0.

Return to the main model window.

Ready, Running, and Paused States and Run Controller Options

Enter the container named Model. Tests in this container ensure that: 1) the Run Controller's Ready, Running, and Paused states, and 2) the Run Controller options work correctly.

- a. Ready State
 - i. Either click the Run button on the toolbar or hit the F5 key to launch the Run Controller. When the Run Controller appears, the GoldSim status bar should indicate "Run Mode" in a red box at the right side. The Run Controller should display a status of Ready.
 - ii. Press the Edit button on the Run Controller, or press the F4 button to switch to the Edit Mode. The Run Controller should close and the GoldSim status bar should indicate "Edit Mode".
 - iii. Alternately press F5 and F4 several times to activate and deactivate the Run Controller.

- iv. With the Run Controller active and in a Ready status (the model is in Run Mode), save and close the GoldSim model file. Re-open the file. The file should be in Edit Mode.
 - v. From the main GoldSim menu, open the Options Dialog (i.e., Model | Options, General tab).
 - vi. De-select the “Show Run Controller in Result Mode” box. Close the Model Options dialog.
 - vii. Run the model (i.e., click the Run button on the main toolbar, then click the Run button on the Run Controller, or simply press F5 twice instead of clicking on the Run buttons). Click OK on the Simulation Complete! dialog. The model should enter Result Mode (as indicated on the right side of the GoldSim status bar) and the Run Controller should close automatically.
 - viii. Re-enter the Run Controller Options and re-select the “Show Run Controller in Result Mode” box. Close the Model Options dialog.
 - ix. Run the model again. Click OK on the Simulation Complete! dialog. This time, the Run Controller should stay active when the model enters the Result Mode.
 - x. Close the Run Controller either by clicking on the Edit button or by pressing F4.
 - xi. Re-enter the Run Controller Options and select the “Begin Simulation immediately on entering Run Mode” box. Close the Model Options dialog.
 - xii. Run the model by clicking on the Run button on the GoldSim toolbar. The simulation should commence without clicking the Run button on the Run Controller. Click the Edit button on the Run Controller to return to Edit Mode (i.e., close the Run Controller).
 - xiii. Re-enter the Run Controller Options and de-select the “Begin Simulation immediately on entering Run Mode” box. Close the Model Options dialog.
 - xiv. Run the model by first clicking the Run button on the GoldSim toolbar (or pressing F5). This time, it should be necessary to also click the Run button on the Run Controller to start the simulation.
- b. Running State
- i. If the Run Controller is not already active, click Run on the GoldSim toolbar. When the Run Controller opens (if it is not already open), slide the speed-control slider to the left end (slow). This will allow use of a small model to test the Running state.
 - ii. Click the Run Controller’s Run button. Make sure that the Run Controller status changes from either Results or Ready (depending on the current state) to Running. The GoldSim status bar should also indicate that the model is in Run Mode.
 - iii. Make sure that the progress of the simulation is tracked by the timestep and realization progress bars, and by the elapsed and simulation time clocks.
 - iv. Click the Pause button. The simulation should pause and the Run Controller state should change to Paused. Click the Resume button to restart the simulation.
 - v. Slide the speed control to the right and ensure that the simulation speed increases accordingly.
 - vi. Rerun the simulation and click the Abort button during the first realization (it may be necessary to adjust the speed control to do this). Click Discard. The model should immediately switch to Edit mode and no results should be available.
 - vii. Rerun the simulation and click the Abort button during the first realization (it may be necessary to adjust the speed control to do this). Click Keep. The model should now be in results mode and results should be available until the time the simulation was aborted. The value of the Last_Update_Time Expression element in the final saved realization should equal to the time at which the simulation was aborted.
 - viii. Rerun the simulation and click the Abort button after the first realization is complete. Choose the Keep option but do not check the “Include results of current

- partially completed realization” box. The model should be placed in Result Mode and the run controller should show the model is in Abort mode. Check to ensure results are available only for the realizations prior to the realization during which the simulation was aborted.
- ix. Rerun the simulation and click the Abort button after the first realization is complete. Choose the Keep option and check the “Include results of current partially completed realization” box. The model should be placed in Result Mode and the run controller should show the model is in Abort mode. Check to ensure results are available for all realizations up to and including the realization during which simulation was aborted. Also ensure that the value of the Last_Update_Time Expression element in the final saved realization is equal to the time at which the simulation was aborted.
 - x. Re-run the model, Abort after several realizations are complete, and then choose to discard the results. The model should enter Edit Mode and no results should be available.
- c. Paused State
- i. Run the model again. Click the Pause button on the Run Controller to pause the model.
 - ii. Ensure that the Run Controller changes to the Paused state. The GoldSim cursor should now appear in red. The GoldSim status bar should still show Run Mode.
 - iii. Browse the model as if it were in Result Mode (although it should still be in Run Mode). Look for the following:
 - a. Tool tips should show the last value calculated (i.e., the value at the end of the last timestep, or a subsequent value if updated since the last timestep). Note that for vectors and matrices, the output port must be opened to view the last calculated value.
 - b. View time histories for several outputs. The time histories should show values up to the current simulation time.
 - c. You should be able to navigate the model, but containers should act as if they are sealed (i.e., you should not be allowed to make any changes to the model that would affect how it runs, nor add any Result elements). You also cannot save the model or close the model.
 - d. Click the Resume button to restart the simulation.
 - e. Click the Abort button to abort the simulation. You should experience model behavior as described in the previous test section.

Stepping Through a Simulation

- b. Simulate one realization - Ensure that this feature works by clicking the R button. After the simulation pauses, repeat some browsing tasks (see “Browse the model...” above). Open the Time_History plot in the Model container. Resume running the model (you may have to move the speed-control slider to the left). Ensure that the time history updates to reflect the current timestep (there may be some lag). Either pause and restart the model, or simply let it run to completion.
- c. Simulate one timestep - Ensure that this feature works by clicking the T button. After the simulation pauses, repeat some browsing tasks (see “Browse the model...” above). Open the Time_History plot in the Model container. Resume running the model (you may have to move the speed-control slider to the left). Ensure that the time history updates to reflect the current timestep (there may be some lag). Repeat for several timesteps.

- d. Complete the simulation by clicking the Resume button to ensure that the simulation completes normally.

<GS0a_Licensing – Removed and in a separate document “GoldSim_Licensing_Tests”. See section 9 for details>

GS00_User_Interface_Tests

This test exercises the GoldSim user interface (e.g., pull-down menu commands and context-sensitive menu commands). In essence, this test allows the verifier to “test drive” the user-interface in both a structured and verifier-prescribed manner in order to verify the major user-interface features and functionality. The test consists of six parts: the first four parts (1. through 4.) exercise the user interface via a pre-existing file (GS00_User_Interface.gsm), while the final part (5.) requires the user to build and run a simple model from scratch.

***** Before performing the test, save the open file (GS00_User_Interface base file.gsm) as a new file (GS00_User_Interface_tested.gsm) to ensure that no changes are made to the base file. Also, make sure the registered version of GoldSim includes CT or RT. *****

1. Structured (basic user interface tests): To execute the test, perform the following operations inside Container1, unless noted otherwise:
 - a. Open the Extension Modules dialog by pressing CTRL+M, then check the box under “Active” for Contaminant Transport (or Radionuclide Transport) module and click “OK”. The Materials container should appear in the upper-left corner of the main model window, and the Species and Water reference-fluid elements should be inside that container. Next, right-click in the main model window and select “Insert Element”. Ensure that a “Contaminant Transport” submenu has been added to the “Insert Element” menu. Next, reopen the Extension Modules dialog again, de-select the Contaminant Transport module, and click “OK”. A message should appear indicating that all environmental elements will be deleted from the model (there should be 2 such elements). Click “Yes” to unload the module.
 - b. From the File pull-down menu, select Send To. If the computer has an e-mail software program installed, a new e-mail message window should appear with this GoldSim file inserted as an attachment. Either enter an e-mail address and send the message or close the message window to cancel without sending the model.
 - c. From the File pull-down menu select Print Preview. Close the Print Preview screen, then go to File|Print and print the model. Ensure that the printed output properly displays the source model.
 - d. From the View pull-down menu, activate the model browser. Ensure that the containment and class views function for the browser operate appropriately. Ensure that elements are properly highlighted upon selection and that the graphical pane is correctly synchronized with the browser. Deactivate the browser, and then reactivate the browser. Repeat these tests using the appropriate buttons on the toolbar.
 - e. Ensure that the property dialog box for an element is opened when the element is double-clicked in the browser. Turn on the “Show Element Subitems” option (right click in the browser and select the option).

- f. Ensure that elements are properly highlighted upon a search and that the graphical pane is correctly synchronized with the browser. Ensure that the search control appears at the top of all browser windows (main browser and function of/affects view)
- g. Starting from the main model window, enter Container1, then ContainerA, then ContainerB. Use the “Go to previous container” menu button (i.e., the ‘back’ arrow) to navigate back out to the main model window. Use the “Go to next container” menu button (i.e., the ‘forward’ arrow) to navigate back down into ContainerB. Return to the main level of the model by clicking the “Go to the top” button (appears as a folder with a 1 inside).
- h. Superseded by GS00a_FilterGraphicsOptions.
- i. Using the Graphics pull-down menu, exercise the graphics functions (zoom, align, rotate) by selecting one or more of the items in the graphical pane.
- j. From the Run pull-down menu, select “Simulation Settings...” to open the Simulation Settings dialog box. Ensure that changes can be made in each of the input fields. Click the Cancel button to exit without making changes.
- k. Return to Container 1 and edit the output attributes for Data1 to have units (e.g., m). Close the dialog, and ensure that when you exit the Data1 element, it has a value and dimensions. Press F9 and ensure that the links that exist between Data1 and Stochastic1 and between Data1 and Event1 disappear. You should get a message indicating that the units don’t match (Data1 has units; Stochastic1 is dimensionless). Next, open the properties dialog for Stochastic1 and edit the distribution. (You may receive another message regarding input “mean” having incompatible data types. Press ”No”.) Cancel out of Stochastic1 (don’t change anything). Go back to Data1 and make its output dimensionless again. Exit Data1. Press F9 to update the links. The link between Data1 and Stochastic1 and Data1 and Event1 should re-appear.
- l. Select a number of the elements (including some with links to other elements) and then from the context menu, use the “Move To” command to move them into ContainerA. Press F9 to update the links. Ensure that the links update. Move the elements back out to the main model window and ensure that all of the links update.
- m. Copy and paste several elements (both single elements and groups of elements) into ContainerA. Delete the pasted elements.
- n. Move the cursor over several of the links (influence arrows) in the model. A tooltip window should appear with the number of links represented by the arrow. Double-click on the arrow and ensure that the “Influence Content” dialog appears, indicating the influences and link type for each link. Click the output and input element hyperlinks and ensure that the target element is properly selected, and that the link dialog closes.
- o. With the model in Edit Mode (the default for the file), move the cursor over each element in turn (the input and output ports and the element’s icon). Ensure that the tooltip window for each element appears and is yellow in color. The current value of each element should be reported, if appropriate. Activate the browser. Move the cursor over elements. Ensure that a yellow tooltip box appears with the name of the element and its value.

- p. With the screen scale setting at 100%, move the cursor over the input and output ports for each element. Ensure that the cursor changes from an arrow to a hand when the cursor passes over each port. Left mouse-click on each port and ensure that the input or output dialog boxes appear, respectively. Right-click on each port and ensure that the “Show Links” option appears. Click on any available influences options and ensure that the appropriate influences are displayed. Move the cursor over the expansion point for each container (i.e., the “+” portion of the icon). Ensure that the cursor changes from an arrow to an open book. Click and make sure that the container is opened.
- q. Repeat n. for two different model-window scale settings: 67% and 137%.
- r. Using the context menu, edit the appearance (font, fill, line, etc.) of several elements.
- s. Insert text using the Drawing Tools toolbar.
- t. Insert one object from each selection (e.g., line) in the Drawing Tools toolbar.
- u. Insert a picture into the document (e.g., bitmap) using the appropriate button on the Drawing Tools toolbar.
- v. Insert a hyperlink to a document (using the hyperlink button on the Drawing Tools toolbar) and ensure that the hyperlink works.
- w. Insert another hyperlink into the document, but this time link to an element in this model file. For example, for the link, select “Open container” from the drop down list and enter “\Container1\ContainerA” as the address. After creating this link, test the hyperlink to ensure that it works (i.e., double-click the hyperlink and the model window should switch to an internal view of ContainerA. Similar tests can be conducted for elements by selecting “Go to element” from the drop down list and entering the path to an element in the link field.
- x. Inside Container1, ensure that the label for Stochastic4 is underlined (and possibly in blue text, depending on GoldSim preference settings) in the main model window, indicating that a note is attached to this element. Point to the label, ensure that the cursor changes to a hand, and then click on the label to activate the note pane. The note should read “Test note for Stochastic4”. Next, run the cursor over the icon for Stochastic4 in the main model window. Repeat this test in the main browser. Next, select an element, activate the note pane using the note icon on the standard toolbar, and enter a note for that element. Close the note window and ensure that the label for the element changes to underlined (and in blue) in the main model window.
- y. Run the model. An error message should appear indicating that the model cannot be run, and that the problem lies with element External1. Click on the “Edit...” button and ensure that the dialog box for External1 opens. Click “Cancel” to escape without making any changes.
- z. Delete the spreadsheet element and external element. Then, in the Model Simulation Settings, set the duration to 0 days, and enter 1000 for the number of realizations. Add Stochastic1 as an input to Result4. Run the model. Open Result4 and view the result distribution for Stochastic1 in chart and table form. Ensure that both look appropriate

- (e.g., the PDF looks normal with the correct mean value, etc.). Modify the style settings for the chart form and ensure that the changes “stick”.
- aa. With the model in Results Mode (the default for the file now that the model has been run), move the cursor over each element in turn (the input and output ports and the element’s icon). Ensure that the tooltip window for each element appears and is green in color. The current value of each element should be reported, if appropriate. Activate the browser. The names of all elements for which results are available should be shown in bold text. Move the cursor over elements. Ensure that a green tooltip box appears with the name of the element and the value, if appropriate.
 - bb. Select a group of element icons in the main model window. Then, from the File pull-down menu, select Export Graphic Selection. Assign a file name and location in the file dialog box and click “OK”. Open that file and ensure that the file displays an image of the selected items.
 - cc. Switch to edit mode. Copy Container 1_1 and paste the new container (Container1_1_1) next to Container 1_1. Accept the “copy as localized container” message. Enter Container1_1_1 so that the contents are visible in the Graphical pane. Next, open the browser (e.g., using the browser button on the GoldSim toolbar). From the browser, highlight Container1_1_1 and then delete it. The container should be deleted from the model, the browser should update automatically to reflect the deletion, and the Graphical pane should return to a view of the main model window. Re-enter Container1 and ensure that Container1_1_1 has been deleted.
 - dd. Insert a new Data element. Try to re-name the element with any of the “protected” function names (e.g., SIN, COS, etc.) and ensure that the names are rejected by GoldSim.
2. Structured (property-dialog-box tests): Inside Container1_1 (which is inside Container1), test the property dialog box for each element type. In general, click on every radio button, check box, and enter something in every field (although not necessarily all at the same time). Ensure that the changes “stick”. Additional specific items for each element type include the following:
- a. Data elements (Data3) – click on the “Type” button and make the following changes one at a time, followed by clicking “OK” and closing the “Type” dialog after each change. The tests include the following: Change the type of the Data element to a condition from a value (click “OK” on the “Type” dialog), and then back again. Next, change the order to a vector, then to a matrix, then back to a scalar.
 - b. Stochastic elements (Stochastic3) – click on the “Edit Distribution” button. Change the type of the distribution from the drop-down scroll menu. Edit the values for the distribution parameters. Click “OK” to exit this dialog. Re-enter the “Edit Distribution” dialog and ensure that the changes “stick”. Repeat several times. Click on the “Importance Sampling” button. Change the option to “high end” or “low end”. Change the factor to a number greater than 1 but less than 10. Exit this dialog and then re-enter to make sure that the changes “stick”.
 - c. Time histories (InfoTimeSeries1 and MaterialTimeSeries1) – Click the “Edit Table” button to access the local table-definition dialog. Add data points, then exit this dialog and re-enter to ensure that the changes “stick” (i.e., correct values, correct number of rows and columns, etc.). Convert the element to vector type and repeat the same tests.
 - d. Integrator and Reservoir elements – follow the instructions for the Data element.

- e. Expression element - Follow the same instructions as for the Data element.
 - f. Previous Value element – change the type of the previous value element and ensure that its outputs are updated and that the input field requires the selected type.
 - g. Extrema element – Add an input and ensure the link is made.
 - h. Selector elements (Selector3) – Test the type as for the Data elements. Then, click on the “Edit Switches” button to access the switches dialog. Add a switch and edit its fields. Exit the dialog and re-enter to confirm the changes. Click on a switch and then delete it. Ensure that the switch is deleted.
 - i. Splitter and Allocator – Add new outputs, and change the type from value to discrete change. Ensure that fields are editable when appropriate.
 - j. Sum element – Add and delete inputs from the main dialog. Ensure that the links are made properly.
 - k. Table elements (Table1) – Click the “Edit Data” button to access the local table-definition dialog. Test the table in 1D, 2D, and 3D modes by adding rows (1D, 2D, 3D), columns (2D, 3D), and layers (3D). Add entries into those new rows and columns, then exit this dialog and re-enter to ensure that the changes “stick” (i.e., correct values, correct number of rows and columns, etc.).
 - l. Convolution element – Check that settings stick and ensure that the lag local property is available in input fields.
 - m. History Generator – Ensure all settings stick and that the correlation features matrix is enabled when the Type is changed to Vector.
 - n. And, Or and Not Elements – follow the instructions for the Sum element.
 - o. File element – no special instructions.
 - p. Event and Delay type elements – no special instructions except for the “type” of consequence. For this, follow the instructions for the Data element. Ignore triggering.
 - q. Result elements – add inputs or outputs (as appropriate) and delete them. Ensure that all options for selecting realizations function.
3. Structured (units, dimensions, and links): Enter Container2 and look at the elements contained within. Then enter Container3. Following the instructions below, duplicate in Container3 the elements and links contained in Container2. The intent is to test the elements for proper functioning of units, dimensions, and links through the process of inserting new elements and creating new links. The steps are as follows:
- a) Insert two of each of the following elements. Leave the first element of each type dimensionless, but assign display units of meters (m) to the second of each type. The values that should be assigned to each element of each type are discussed below:
 - i) Data - assign a value of 1 and 1 m, respectively, to the two elements.
 - ii) Stochastic - accept the default input distribution, which is uniform between 0 and 1 and 0 m and 1m, respectively.
 - iii) Lookup Tables
 - (a) Create two 1-D tables – one dimensionless and one with a Result Dimension of m. Enter a Row unit of m for the independent variable in the table with a Result Dimension of m . Enter a value of 1 and 1, respectively,

for the independent and dependent variable in both tables. The two tables will therefore have only one row and one output value.

- (b) Create two 2-D tables – one dimensionless and one with a Result Dimension of m. Enter a Row and Column unit of m for the independent variable in the table with a Result Dimension of m. Define the table locally, and input the values shown in Table GS00-1

Table GS00-1

	0	1
0	0	2
1	1	3

- (c) Create two 3-D tables – one dimensionless and one with a Result Dimension of m. Enter a Row, Column and Layer unit of m for the independent variable in the table with a Result Dimension of m. Define two layers – 0 and 1. Enter values of 0 and 1, for the row and column variables. Input 0s in all of the dependent variable fields in layer 0. On layer 1, input the dependent variable values in Table GS00-1. The table will therefore have two rows, two columns, two layers, and eight dependent variable values.
- iv) Expression – Expression4 should be dimensionless and given a value of 1. Expression5 should have display units of m and a value of 1m.
- v) Selector – Define a switch that has a value of 1 (1m for the dimensional Selector) if the dimensionless (dimensional) Data element has a value of 1 (1m). Otherwise, a value of 0 will be implemented by the ‘Else’ case of the Selector.
- vi) Integrator – Assign an initial value of 1 (1m for the dimensional Integrator).
- vii) Reservoir – Assign an initial value of 1 (1m for the dimensional Reservoir).
- viii) Extrema – Assign a value of 1 (1m for the dimensional Extrema)
- b) Now, save the model if you have not already done so.
- c) Add an expression element and leave its display units as dimensionless. In the equation box, create the sum of all the main outputs for the dimensionless elements created in a) above (e.g., Data + Stochastic + ... + Extrema). For the lookup table elements, use the dimensionless Data element for the independent variable(s). Save the model.
- d) Repeat c) for the dimensional elements (i.e., units of m). Save the model.
- e) In the model simulation settings dialog box, set the model duration to 1 day, use 1 timestep, and one realization. Run the model. Ensure that the output values, units, and dimensions for all of the elements created in a), c), and d) above are correct. In particular, ensure that the expressions that add the other elements have the correct value (i.e., the sum of all the component elements should be between 13 and 14 (13m and 14m), depending on the value realized for the stochastic elements and on the values entered in the table elements).
- f) Save the model, close the file, re-open the file, re-run the model and check results again. Ensure that all the answers are still correct.
- g) Return to edit mode and create three data elements inside Container 3 (call them A, B, and C). Set C’s definition to equal ‘A+B’. Close the dialog for C. Open the dialog box

- for C and edit C's definition so that it no longer references A or B. Ensure that while the definition is being edited that the links to A and B do not disappear until a valid definition is entered. Move the cursor out of the input field and ensure that the links to A and B disappear.
4. Structured (sealing and locking containers): Activate the property dialog for the container Container4 . Click on the "Protection" checkbox. The tester's computer or login username should appear in the Author box.
 - a) Click on the "Seal" option and press OK. The dialog should close. Look for Container4 in the browser. Its name should be grayed out, as should the names of all elements within Container4. Pass the cursor over Container4 in the main browser and in the main model window. The tooltip window for the container should state that the container is localized and sealed.
 - b) Next, re-open the properties dialog for Container4. When you click on the Protection option, the dialog box will display text indicating that the container was "Sealed by: ..." the login user, and the date and time that the seal was created. Next, click on the "Protection" checkbox. When prompted as to whether you wish to remove the seal, press the "Yes" button. You should be returned to the property dialog box. The seal information should no longer be visible.
 - c) Re-seal Container4 as described in a) above.
 - i) Next, enter Container4 and attempt to edit the name and an input value for several of the elements. Each time, a message box should appear stating that the container is sealed and asking if you want to continue and break the seal. Click "No" to cancel the action.
 - ii) Try to insert a new element into Container4. The same message should appear. Click "No" to cancel the action and retain the seal.
 - iii) Exit Container4. Try to move the element Data4 into Container4. The same message should appear. Again, click "No" to cancel the action.
 - iv) Select the output port for Data4, then double-click on the output "Data4" to activate the link cursor. Next, enter Container4 and attempt to link with the input of one of the Expression elements. The same message should appear, and again click "No" to cancel the action.
 - v) Exit Container4 . Insert a new Data element. Enter Container4 , select the output port for one of the elements, then double-click to select an output for that element and activate the link cursor. Exit Container4 and try to link with the input of the new element. This operation should be allowed.
 - vi) Inside Container4 , try to move elements within the model window, changing the appearance of text and labels, etc. These cosmetic changes should be allowed without a message warning appearing.
 - d) Repeat c) i) above for one element, except this time click "Yes" to break the seal. Then make the change to the element, close the element properties dialog box, and then re-

- activate the properties dialog for Container4. The sealing information should now document when the seal was broken, and by whom.
- e) Re-seal the container as described in a) above. Then reactivate the properties dialog for Container4 and ensure that the sealing information includes when the container was sealed and by whom.
 - f) Remove the seal. Click the “Protection “ checkbox again, and select the “Lock Container” option. Enter a password in the appropriate fields (if desired, but this is not required), then click “OK”. The dialog should disappear. Pass the cursor over Container4 in the main browser and in the main model window. The tooltip window for Container4 should state that the container is localized and locked. The name for Container4 and all of its elements should be grayed out in the main browser.
 - g) Enter the locked Container4. The edit and drawing menus should be grayed out, and no changes of any kind should be allowed within the container or to any elements within the container. However, the properties dialog boxes should still be accessible (but unalterable), as should be the properties of the links among elements.
 - h) Activate the link cursor by selecting the output for Data1 inside the locked Container4. Exit Container4. Enter a link to Data1 as the input to Data4. Ensure that a link arrow appears between the output of Container4 and Data4.
5. New Model Wizard: Close GS00_User_Interface.gsm by opening a new file. The New Model Wizard should appear (if it does not, go into the Model/Options dialog and make sure the “Display New Model Wizard when opening a new file” checkbox is selected).
- a) Fill in the Author Name and Analysis Description. Select “Elapsed time” in the duration pick list. On the next screen, select 100 for the duration, Year for the display unit, and 200 for the number of timesteps and click Next. On the next screen, select “Use Monte Carlo” and enter 200 for the number of realizations. Click Finish. Open the Simulation Settings dialog and make sure the settings you selected have been placed in the appropriate fields. In particular, make sure the “Duration” radio button is selected and the duration and time units are correct.
 - b) Create another new model and fill in the author and description. Select Calendar Date/Time in the duration pick list. Change the Start Date, Start Time, End Date, End Time, and Number of Timesteps. Click Next. Leave the defaults on the next screen, and click Finish. Open the Simulation Settings dialog and make sure the settings you selected have been placed in the appropriate fields. In particular, make sure the “Date-Time” radio button is selected and proper start and end date and times are entered.
 - c) Create another new model and fill in the author and description. Select “Zero Duration” in the duration pick list. Select Use Monte Carlo and change the number of realizations. Open the Simulation Settings dialog and make sure the settings you selected have been placed in the appropriate fields. In particular, make sure the duration is set to 0 days.

GS00a_FilterGraphicsOptions

This test verifies the proper functioning of custom influences and graphics options in GoldSim.

To run the test, the verifier should open the file called GS00a_FilterGraphicsOptions.gsm and run through the following tests (it is not necessary to run the model):

1. Ensure that all link types have the color and weight specified in the Graphics tab of the model root container's property dialog.
2. Resize and change the color of the graphics pane and ensure these changes are reflected in the model root. Continue by changing the influence shape, color, weight, and filtering options for the different link types.
3. Enter the TopLevel1 and TopLevel2 containers and ensure none of these changes have been propagated to the lower level containers.
4. Customize a number of influences and then see that they are reset when the Reset customized influences option is checked in the Graphics tab.
5. Apply the changes to the TopLevel1 container. See that the appropriate changes are made in the TopLevel1 container, and that no changes are made to the TopLevel2 subcontainer.
6. Apply the changes to the model and select the "Nested" option. Ensure that all links in the model have been changed to reflect the graphical changes.

GS00b_Password

This test verifies the proper functioning of password protection for models. The test file is a simple GoldSim file protected by a password (the password is *GoldSim!*).

The verifier should follow these steps to ensure that the protection functions correctly.

1. Open the model file by double clicking on it in Windows Explorer – you should be prompted to enter a password. Enter an incorrect password. GoldSim should prevent you from opening the model and create a new model instead. Close GoldSim.
2. Reopen the model file by double clicking on it in Windows Explorer – you should be prompted to enter a password. Enter the correct password. The model should open successfully.
3. Create a new model file using CTRL+N, then try to open the test model file. Enter an incorrect password. GoldSim should not open the model.
4. Try to open the model file again, but enter the correct password. The model should open successfully.
5. Set up a single DP slave on the local machine and run the model file. It should run successfully and it should not be necessary to enter a password.
6. Save a Player version of the file. Attempt to open it in the GoldSim Player. You should be prompted for a password. Enter an incorrect password. The Player file should not open and you should be returned to the Player splash screen. Reopen the Player file and specify the correct password. The Player file should open correctly.

7. Create a new model file, then attempt to import the test file as a SubModel. You should be required to enter the password. Enter an incorrect password. The import should fail and a new blank SubModel should be created.
8. Create a second Submodel and attempt to import the test file. Enter the correct password and ensure that the model is correctly imported as a SubModel.
9. Place a copy of the test file in the installation directory of the candidate build. Run the model file from the command line using `goldsim -r`. Ensure you are prompted for a password. Enter an incorrect password – the file should not be opened or run. Close GoldSim and start a new run from the command line. Enter the correct password and ensure that the file is run correctly.
10. Open the test file and remove protection by entering the current password and then specifying a blank password. Save the model file as `GS00b_Unlocked.gsm`. Create a new model file using `CTRL+N`, then reopen `GS00b_Unlocked.gsm`. It should not be necessary to provide a password.

GS01_Spreadsheet: Spreadsheet Elements

This file verifies that the Spreadsheet Element correctly uploads and retrieves values from specified cells in an Excel spreadsheet, and that the visual selection of cells in Excel works properly. It also verifies that offsets and shifts work correctly, and that the spreadsheet correctly handles error conditions.

The verifier should note that these instructions describe the procedures for running these tests using `.xls` files saved in Excel 2003. These tests should be repeated a second time with Excel 2007 using the `_2007` version of the test file and copies of the test spreadsheets saved in Excel 2007's `.xlsx` format.

1. The first test of the spreadsheet can be found in the container called "Link_Tests." The GoldSim file defines two scalar inputs (Data Elements A and B), one 3 x 1 vector input (Data Element C), and one 3 x 2 matrix input (Data Element D). These elements are linked as inputs to cells in the EXCEL spreadsheet `GS01.xls` via a Spreadsheet Element (`SS_01`). Each spreadsheet takes the input values in its cells in Sheet1, applies simple formulas to the values, and records the results in Sheet2. GoldSim then retrieves the results of the EXCEL calculations by defining two scalar outputs (Data Elements D10 and AB), one 3 x 1 vector output (Data Element AC), and one 3 x 2 matrix input (Data Element CD) to be equal to the values in the cells in Sheet2 of `GS01.xls`.

To run the test, the verifier must first construct the links in the spreadsheet element. The first input and output link should be created using the Wizard. The steps are as follows:

- a) Open the `SS_01` element and ensure that `GS01.xls` is specified as the linked spreadsheet.
- b) Open `GS01.xls` and ensure that the input fields on Sheet1 are blank.
- c) Construct links to and from the spreadsheet according to Table `GS01_1` and `GS01_2`. Try creating these links with and without the Spreadsheet Wizard.

Data Exported to Excel:

Table GS01_1		
Input Name	Output Element	Destination Cell
A	A	Sheet1!C6
B	B	Sheet1!C7

C	C	Sheet1!C9:C11
D	D	Sheet1!C15:D17

Data Imported from Excel:**Table GS01_2**

Output Name	Output Type	Linked Cell
Output1	Scalar	Sheet2!C6
Output2	Scalar	Sheet2!C7
Output3	Vector (3X1) [Rows3]	Sheet2!C9:C11
Output4	Matrix (3X2) [Rows3,Col89]	Sheet2!C15:D17

- d) Press <F9> to parse the model. Links should appear between SS01 and Constant10, AB, AC, and Dplus10. If they do not, ensure that Constant10, Output2, Output3 and Output4 are defined as indicated in Table GS01_3.

Table GS01_3

Data Element	Definition
Constant10	SS01.Output1
AB	SS01.Output2
AC	SS01.Output3 (Each item in the vector must be linked individually)
Dplus10	SS01.Output4 (Each item in the vector must be linked individually)

The results should be confirmed in two ways (expected results are shown in the ToolTip window for the output Data Elements and in Table GS01_4).

First check the outputs after clicking the Update Spreadsheet option in the Options button menu.

Table GS01_4

Element Being Tested (Check output in both containers)	Expected Output
SS 01.Output1	Constant10 = 10
SS 01.Output2	AB = 14
SS 01.Output3	AC = { 21 28 35 }
SS 01.Output4	Dplus10 = $\begin{bmatrix} 16 & 19 \\ 17 & 20 \\ 18 & 21 \end{bmatrix}$

Then confirm the results by running the model and viewing the outputs in Result mode.

2. This part of the test is used to check the correct functioning of cloning in the Spreadsheet element.

- a) The verifier should clone the Original_Spreadsheet element and enter the cloned element. Ensure the properties for both elements are identical.

- b) Open the cloned element and create a new Input to export Vector3 to the spreadsheet. Place vector three in the indicated location in the linked spreadsheet. Close the element and check that the input is added to the original element.
- c) Add a new Output to the original element that brings in the 2 column matrix called "Vector3 added to both columns of the 2 column matrix" in the spreadsheet. This output should be a matrix of Days and Set1_2. Close the element and ensure this output is added to the clone.
- d) Run the model and ensure that the outputs are as follows:

Original_Spreadsheet - Matrix_Vector1_and_2

45	78
21	22
78	2
412	78
88	67
12	91
5	82

Original Spreadsheet - Vector3 added to both columns

46	79
31	32
143	67
450	116
106	85
27	106
61	138

- e. Change the linked spreadsheet to GS01_Clone_2.xls. Ensure that the outputs of both the original and cloned elements are as follows:

Changed Spreadsheet - Matrix_Vector1_and_2

78	45
22	21
2	78
78	412
67	88
91	12
82	5

Changed Spreadsheet - Vector3 added to both columns

79	46
32	31
67	143
116	450
85	106
106	27
138	61

In the clone, remove the Matrix_Vector1_and_2 output. Ensure this change is reflected in the original element.

3. Enter the container entitled Data_Types. The spreadsheet element GS01_2 in this container tests GoldSim's ability to correctly read certain Excel cell formats. The verifier should create the outputs listed in Table GS01_5. If there are already links for GS01_2, delete all existing links first.

Data Imported from Excel:

Table GS01_5

Output Name	Output Type	Linked Cell
Number	Scalar	Sheet1!C4
Text	Scalar	Sheet1!C5
Blank	Scalar	Sheet1!C6
Currency	Scalar	Sheet1!C7
Percentage	Scalar	Sheet1!C8
Date	Scalar	Sheet1!C9
Date_days	Scalar (units of days)	Sheet1!C9
Date_datetime	Scalar (units of datetime)	Sheet1!C9
Boolean_True	Scalar (dimensionless)	Sheet1!C10
Boolean_False	Scalar (dimensionless)	Sheet1!C11

After creating the outputs, the verifier should run through the following steps:

- Run the model - GoldSim should generate a fatal error due to the text in the second input.
- Delete the text input and re-run the model. Another fatal error should occur when the blank cell is read in.
- The blank output should be deleted and the model re-run.
- Re-run the model - another fatal error should occur when the date input is read in to a dimensionless output. Delete the Date output and rerun the model. The tester should ensure that the valid links generate the expected values noted in the spreadsheet element's tool-tip and in Table GS01_6.

Table GS01_6

Output Name	Expected Output
Numbers	2
Currency	5.5
Percentage	0.72
Date (in days)	38018 days
Date (in datetime)	2/1/2004

Boolean_True	1
Boolean_False	0

4. The verifier should enter the Offsets container and proceed through the following steps to test the Offset functionality of the Spreadsheet element:
 - a) Ensure that the value of Output of the Offset_SS element equals the output of the Offset_Stochastic element.
 - b) Specify a spreadsheet input called “Test” that exports the Offset_Stochastic value with a target cell of Sheet1!A1, and a row, column and sheet offset of -2,-2, and -2. Run the model and ensure that GoldSim generates a fatal error, as the offset targets a cell outside of the worksheet.
 - c) For testing Excel 2003 and the corresponding file, modify the “Test” input offset, specifying a row offset of 70000 a column offset of 300, and a sheet offset of 0. Run the model and ensure that GoldSim generates a fatal error, as the offset targets a cell outside of the worksheet. For testing Excel 2007 and the corresponding file, modify the “Test input offset, specifying a row offset of 1,200,000 a column offset of 20,000.
 - d) Modify the input with a row, column and sheet offset of 0, 0, and 4. Run the model and verify that GoldSim has added two new sheets to the spreadsheet, and that the Offset_Stochastic value has been properly placed in cell A1 of Sheet5.

5. This portion of the test verifies the proper functioning of the Shift functionality in the Spreadsheet element. The verifier should enter the Range_Shift container and then proceed through the following steps:
 - a) Open the spreadsheet element called Shift_Tests.
 - b) Select the “TopLeftCorner” input and attempt to use the Shift function to shift the target cell up and to the left. In both cases, an error message should be displayed, stating that the edge of the spreadsheet has been reached.
 - c) Select the BottomRightCorner output and attempt to shift it down and to the right. In both cases, an error message should be displayed, stating that the edge of the spreadsheet has been reached.
 - d) Select ShiftCells1 and ShiftCells2, and shift them in the following order – right, up, left, down. It should be confirmed that each shift changes the “Location in Spreadsheet” value, and that the “Location in Spreadsheet” value at the end of the test is Sheet1!C5 for ShiftCells1, and Sheet1!E7 for Shift Cells2.
 - e) Leave ShiftCells1 and ShiftCells2 selected. Click the Change Sheet button and select Sheet2. Ensure the sheet reference for ShiftCells1 and ShiftCells2 both change to Sheet2 and that TopLeftCorner and BottomRightCorner still refer to Sheet1. Run the model - an error should be generated. Change the sheet reference for ShiftCells1 and ShiftCells2 back to Sheet1 and run the model. No errors should be generated.

6. The final test involves verifying the proper functioning of the Create and Select option in the spreadsheet element. For this test, create a new dynamic GoldSim model, and call it GS01_Spreadsheet_Calc.
 - a) Create a new spreadsheet element in the root level of the model. Select the Create and Select option, and save a new spreadsheet file (GS01_Created.xls). Open the file (using the Open option) and set it up to accept an argument into cell A1, and then set B1 equal to 2*A1. Save the spreadsheet file, export ETime to cell A1 and import the value of cell B1 to GoldSim. Run the model and ensure that the output is equal to 2*ETime throughout the simulation.

GS01b_Spreadsheet_Update: Spreadsheet Update Tests

Spreadsheets can operate in one of three modes: import only, export only or recalculated during the simulation. This test verifies that GoldSim accesses the spreadsheet exactly at the times specified in the manual.

The verifier should note that these instructions describe the procedures for running these tests using .xls files saved in Excel 2003. These tests should be repeated a second time with Excel 2007 using the _2007 version of the test file and copies of the test spreadsheets saved in Excel 2007's .xlsx format.

1. Import Only – When a GoldSim spreadsheet element only imports data, the values of the spreadsheet element's outputs are only updated when the output's offset changes. To run this portion of the test, open GS1b_Import.gsm and run it. The model imports two values – Output1 has a row offset equal to ETime|s|, so it is imported each timestep. while Output2 has no offset, and is only imported at the start of the simulation. The graph of the Result Time History element should look like Fig. GS01b-1:

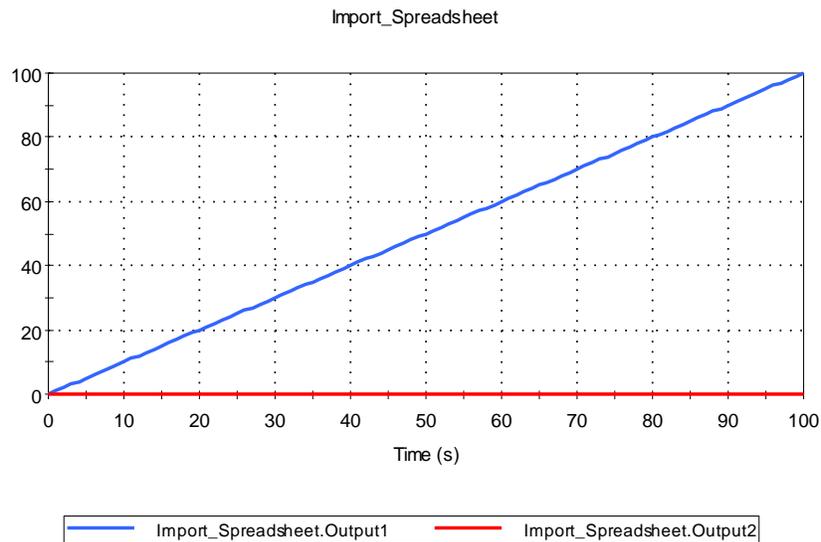


Fig. GS01b-1

2. Export Only – When a GoldSim spreadsheet element only exports data, the value of the spreadsheet element's outputs are only updated at the end of the simulation or when an offset changes. The model exports two values – Output1 has a row offset equal to ETime|s|, so it is exported each timestep. while Output2 has no offset, and is only exported at the end of the simulation. To run this portion of the test, open GS1b_Export.xls and delete any data inside. Save and close the spreadsheet and then run the model file. Reopen the spreadsheet – column A should contain integer numbers from 0 to 100, while cell B1 should contain a value of 100.
3. Export and Import – When a Spreadsheet element exports and imports data, the result depends on whether a) the spreadsheet is recalculated or b) whether offsets are used. This portion of the test checks all four possible combinations of those settings. To conduct the

test, open GS1b_Export_Import.gsm and run it. Ensure the following results (also repeated in Fig GS01b-2):

- No_Recalc_No_Offsets: constant 0 (unless an offset changes Excel ignores the Recalculate setting).
- Recalc_No_Offsets: Value returned from the spreadsheet should be $10 \cdot ETime$. (Imported cell is equal to $10 \cdot Exported Cell$)
- No_Recalc_Offsets: Should be a constant 25 except at time 50, where it is 0..
- Recalc_Offsets: Value returned from the spreadsheet should be $5 \cdot ETime$. (Imported cell is equal to $5 \cdot Exported Cell$)

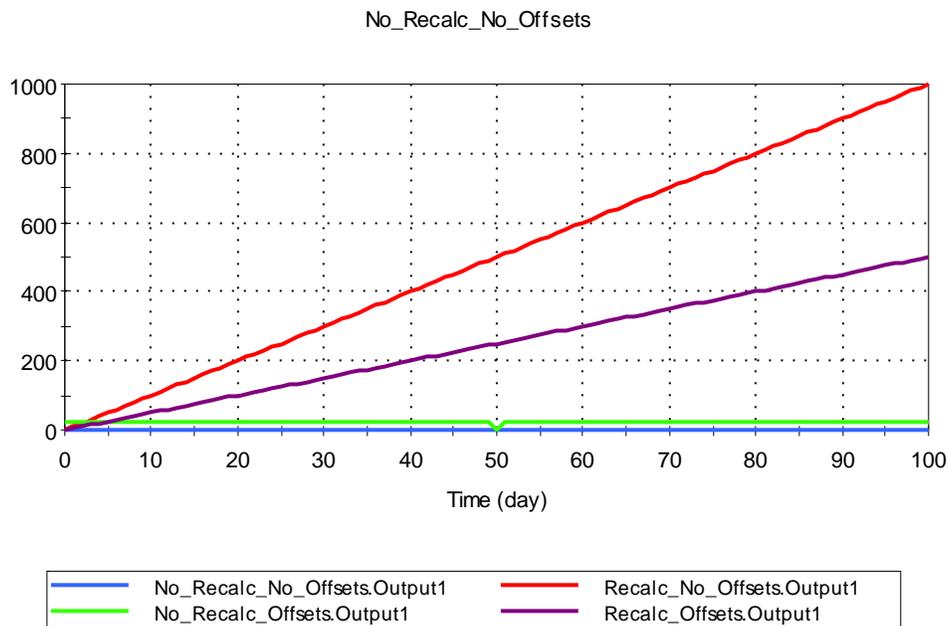


Fig. GS01b-2

GS01c_Large_Spreadsheet: Large Spreadsheet Tests

This test checks that GoldSim can successfully deal with large spreadsheets being accessed by multiple elements on multiple sheets.

The verifier should note that these instructions describe the procedures for running these tests using .xls files saved in Excel 2003. These tests should be repeated a second time with Excel 2007 using the _2007 version of the test file and copies of the test spreadsheets saved in Excel 2007's .xlsx format.

To run the test, close any open instances of Excel and run the model. The model should run without errors, and after the simulation is complete the verifier should ensure that there are no instances of Excel showing in the processes tab of the Task Manager. The verifier should then check that the spreadsheet outputs are as follows:

- Spreadsheet1: Output should be 5*ETime for the duration of the simulation.
- Spreadsheet2: Output should be 25*ETime for the duration of the simulation.
- Spreadsheet3: Output should be 50*ETime for the duration of the simulation.
- Spreadsheet4: Output should be 100*ETime for the duration of the simulation.

GS02_Expressions: Expressions and Data

Expressions with data links are verified by creating a model with an element for each expression to be tested and comparing model results with known results. The expected results for each static output are presented in the tool tip window for each element for easy comparison with the current value output. Where applicable, tests are conducted to ensure that appropriate functions also support term-by-term operations on array input arguments. The functions checked in this section include:

Trigonometry functions

- sine function **sin**(x)
- cosine function **cos**(x)
- tangent function **tan**(x)
- cotangent function **cot**(x)
- arcsine function **asin**(x)
- arccosine function **acos**(x)
- arctangent function **atan**(x)
- hyperbolic sine function **sinh**(x)
- hyperbolic cosine function **cosh**(x)
- hyperbolic tangent function **tanh**(x)

Math functions

- addition
- subtraction
- multiplication
- division
- square root function **sqrt**(x),
- power function $x^{**}y$
- absolute value function **abs**(x)
- logarithmic function (base 10) **log**(x)

- natural logarithmic function (base “e”) **ln(x)**
- minimum value function **min(x,y)**
- maximum value function **max(x,y)**
- modulus function **mod(x)**
- exponent function **exp(x)**
- truncate number function **trunc(x)**
- round number function **round(x)**
- vector of minima from a matrix
- vector of maxima from a matrix
- row in which minimum value occurs in a vector, **rowmin(vector)**
- row in which maximum value occurs in a vector, **rowmax(vector)**
- search for a value within a vector output, return its fractional index.
- interpolate for a value within a vector output given its fractional index.

Special Functions

- error function **erf(x)**,
- Bessel function **bess(x,v)**,
- Beta function **beta(x,y)**,
- if function **if(x,y,z)**
- if function **if(x then y else z)**

Probability Functions

- Standard Normal Probability function **normprob(U)**, where $U = (x - \text{mean}) / \text{stddev}$
- Inverse Standard Normal Distribution function **normsds(prob)**
- Student’s t-distribution function **tdist(prob, dof)**, where dof is the degrees of freedom
- Cumulative t-distribution probability function **tprob(tdists, dof)**
- Gamma function **gamma(k)**, where k = positive scalar

Financial Functions

- present value function **ftop(x,y)**
- future value function **ptof(x,y)**
- present value of annuity **atop(x,y)**
- future value of annuity **atof(x,y)**
- annuity amount of p **ptoa(p,x)**
- periodically compounded to continuously compounded interest rate **pc2cc(x,y)**

- continuously compounded to periodically compounded interest rate **cc2pc**(x,y)
- geometric mean to continuous mean **gm2cm**(x)
- continuous mean to geometric mean **cm2gm**(x)
- arithmetic mean to continuous mean **ari2cm**(x)
- arithmetic mean/SD to volatility **ari2vol**(x,y)
- geometric mean/SD to volatility **geo2vol**(x,y)

Special Operators

- equality operator “==“
- inequality operator “<>“
- greater than operator “>”
- less than operator “<”
- greater than or equal to operator “>=“
- less than or equal to operator “<=“
- and operator “&&”
- or operator “||”
- not operator “!”
- complex dimension change operation **sin**(x|s|{deg}), where x is in seconds

Get Functions

- GetItem(vector,row)
- GetRowCount(Vector)
- GetItem(Matrix, Row, Column)
- GetRowCount(Matrix)
- GetColCount(Matrix)
- GetRow(Matrix, Row)
- GetColumn(Matrix, Column)

Array Indexing Functions

- Retrieving items from vectors and matrices with named and indexed array label sets
- Retrieving vectors from matrices using the * wildcard
- Dynamically retrieving items from vectors and matrices

The verification results are presented in Tables GS2_1 to Table GS2_3. It is not necessary for the user to enter any data but the model must be run to see certain results. The user compares model current values against results presented in the tables to verify the expressions and functions.

TABLE GS2_1

Containers	Test Element	Expected Result
Trig_Functions		
	SIN_function	0.84147
	COS_function	0.54030
	TAN_function	1.5574
	ASIN_function	48.590 deg
	ACOS_function	41.410 deg
	ATAN_function	36.870 deg
	SINH_function	0.52110
	COSH_function	1.1276
	TANH_function	0.46212
	COT_function	0.64209
Math_Functions		
	ADD_function	5
	SUBTRACT_function	3
	MULTIPLY_function	10
	DIVIDE_function	2.5
	SQRT_function	2
	POWER_function	25
	ABS_function	2
	LOG_function	2.3464
	LN_function	-0.69315
	MIN_function	1
	MAX_function	5
	MOD_function	2
	EXP_function	2.7183
	TRUNC_function	1
	ROUND_function	1
Vector	Vector_of_mins	{ 0 1 -2 1 }
Vector	Vector_of_maxes	{ 4 3 2 3 }
Vector	Rowmin1	1
Vector	Rowmax1	4
Special_Functions		
	BESS_function	2.5154e-007
	BETA_function	0.50000
	ERF_function	0.842701
	IF_function	1
	IF_function2	1
	IF_Invalid_Not_Used	0 at t = 0 50 at t = 0.02 No errors should be generated due to this expression.
Financial_Functions		
	FTOP_function	\$61.39
	PTOF_function	\$162.89
	ATOP_function	\$772.17
	ATOF_function	\$1257.79

TABLE GS2_1

Containers	Test Element	Expected Result
	PTOA_function	\$12.950
	PC2CC	0.0988
	CC2PC	0.1013
	GM2CM	0.0953
	CM2GM	0.1052
	ARI2CM	0.04472
	ARI2VOL	1.2686
	GEO2VOL	0.9699
Special_Operators		
	Equality_operator	0
	Inequality_operator	1
	Greater_operator	0
	Less_operator	1
	Greater_Equal_operator	0
	Less_Equal_operator	1
	And_operator	0
	Or_operator	1
	Not_operator	0
	Complex_dimension_change	0.86602
Probability_Functions		
	StdNormCDF_1	0.02275
	StdNormCDF_2	0.97725
	InvStdNormCDF_1	2
	InvStdNormCDF_2	-2
	t_Distr_1	0.765
	t_Distr_2	1.708
	CumProb_t_Distr_1	0.75
	CumProb_t_Distr_2	0.95
	GammaFunction_1	2
	GammaFunction_2	362880

TABLE GS2_2 – Array Argument Tests

Containers	Test Element	Expected Result
Trigonometry_Tests		
	SIN_function	0, 0.7071 0.7071, 1
	COS_function	1, 0.7071 0.7071, 0
	TAN_function	0, 1 1, approaching infinity
	ASIN_function	0 deg, 45 deg 45 deg, 90 deg
	ACOS_function	0 deg, 45 deg 45 deg, 90 deg
	ATAN_function	0 deg, 45 deg

TABLE GS2_1

Containers	Test Element	Expected Result
		45 deg, 90 deg
	SINH_function	0, 0.8687 0.8687, 2.3013
	COSH_function	1, 1.3246 1.3246, 2.5092
	TANH_function	0, 0.6558 0.6558, 0.917152
	COT_function	0.642093, 1.83049 -0.642093, -1.33865
Math_Tests		
	SQRTX	2 m, 4 m 3 m, 5 m
	ABS_U	1, 0.5 1, 2.5
	ABS_X	4 m ² , 16 m ² 9 m ² , 25 m ²
	LOG_U1	0, -0.3010 0, 0.3979
	LN_U1	0, -0.6931 0, 0.9163
	MIN_U_U1	1, 0.5 -1, 2.5
	MAX_U_U1	1, 0.5 1, 2.5
	MOD_X_X	0 m ² , 0 m ² 0 m ² , 0 m ²
	EXP_U	2.7183, 1.6487 0.3679, 12.1825
	TRUNC_U	1, 0 -1, 2
	ROUND_U	1, 1 -1, 3
Special_Functions_1		
	BESS_function	0.440051, 0.352834 0.309063, 0.281129
	BETA_function	1, 0.16666 0.03333, 0.00714286
	ERF_function	0.842701, 1 1, 1
	IF_function	1,2,3,4
	IF_function2	1,2,3,4
	ScalarOr	True, False
	ScalarAnd	True, False
Financial_Tests		
	FTOP_function	\$231.38, \$694.13 \$462.75, \$925.51
	PTOF_function	\$4321.94, \$12965.83

TABLE GS2_1

Containers	Test Element	Expected Result
		\$8643.89, \$17287.77
	ATOP_function	\$15372.45, \$46117.35 \$30744.90, \$61489.80
	ATOF_function	\$66438.85, \$199316.54 \$132877.70, \$265755.39
	PTOA_function	\$65.05, \$195.15 \$130.10, \$260.21
	PC2CC	0.0998 0.0749 0.0200 0.0500
	CC2PC	0.1002 0.0751 0.0200 0.0500
	GM2CM	0.0953 0.0723 0.0198 0.0488
	CM2GM	0.1052 0.0779 0.0202 0.0513
	ARI2CM	0.0894 0.0624 0.0074 0.0354
	ARI2VOL	0.4724 0.6064 1.4075 0.8326
	GEO2VOL	0.4339 0.5364 1.0559 0.6937
Probability Expressions		
	StdNormCDF_1	0.5, 0.8413 0.1587, 0.02275
	StdNormCDF_2	0.5, 0.158655 0.841345, 0.97725
	InvStdNormCDF_1	0, -1, 1, 2
	InvStdNormCDF_2	0, 1, -1, -2
	t_Distr_1	0, 0, 0.740667, 1.47586
	CumProb_t_Distr_1	0.5, 0.5, 0.75, 0.90
	GammaFunction_1	1, 1, 2, 6
	GammaFunction_2	24, 720, 40320, 362880
Comparison_Tests		
	GreaterThan	True, True False, True
	GreaterThanEqual	True, True False, True
	IsEqualTo	All False
	LessThan	True, True False, True
	LessThanEqual	True, True False, True
	NotEqualTo	All True
	ScalarGreaterThan	False, True
	ScalarGreaterThanEqual	True, True
	ScalarIsEqualTo	True, False

TABLE GS2_1

Containers	Test Element	Expected Result
	ScalarLessThan	False, True True, True
	ScalarLessThan	True, False False, False
	ScalarNotEqualTo	False, True True, True

TABLE GS2_3

Get_Functions		
	Item_From_Vector	4
	Row_Count	7
	Item_From_Matrix	32
	Mat_Row_Count	3
	Mat_Col_Count	4
	Row_from_Matrix	[21,22,23,24]
	Column_from_Matrix	[13,23,33]
	Row_From_Vector	33
Get_Functions_Condition		
	Item_From_Vector	False
	Row_Count	5
	Item_From_Matrix	True
	Mat_Row_Count	4
	Mat_Col_Count	5
	Row_from_Matrix	[False, False, True, True, True]
	Column_from_Matrix	[False, True, False, True]
	Row_From_Vector	False
Array_Indexing_Value		
	Item_From_Named_Vector	4
	Dynamic_Value_Result	See GS02_Array_1 plot below
	Item_From_Indexed_Vector	4
	Dynamic_Value_Result_Indexed	See GS02_Array_2 plot below
	Item_from_Matrix	32
	Row_from_Matrix	[21, 22, 23,24]
	Column_from_Matrix	[13,23,33]
	Dynamic_Matrix_Plot	See GS02_Array_3 plot below
Array_Indexing_Condition		
	Item_From_Named_Vector	True
	Dynamic_Value_Result	See GS02_Array_4 plot below
	Item_From_Indexed_Vector	True
	Dynamic_Value_Result_Indexed	See GS02_Array_5 plot below
	Item_from_Matrix	True

	Row_from_Matrix	[False, True, False, False]
	Column_from_Matrix	[False, True, False]
	Dynamic_Matrix_Plot	See GS02_Array_6 plot below

Dynamic Named Vector Access

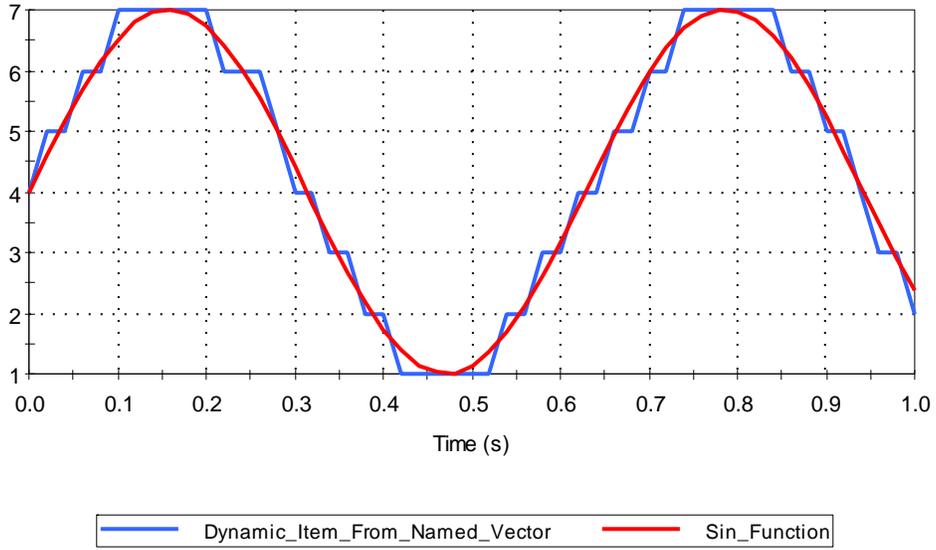


Fig. GS02_Array_1

Dynamic Indexed Vector Access

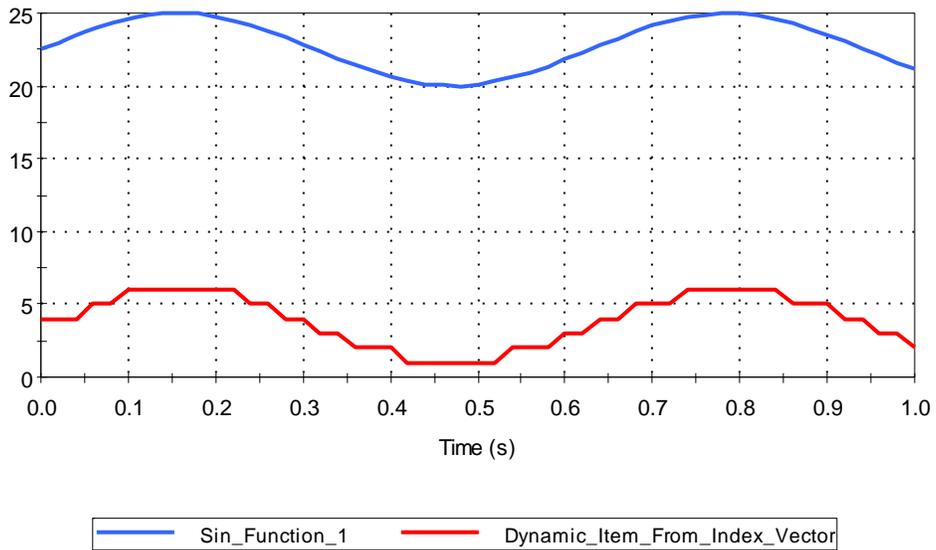


Fig. GS02_Array_2

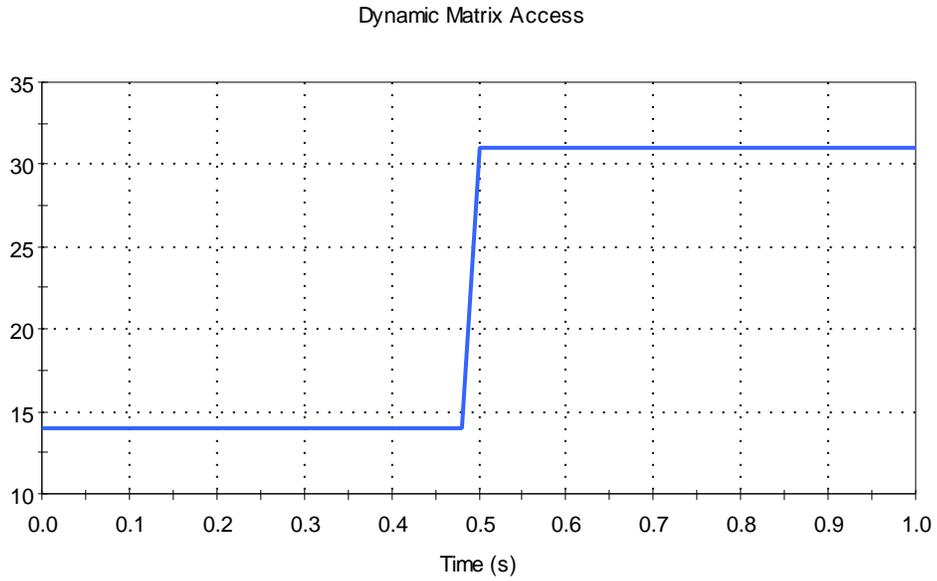


Fig. GS02_Array_3

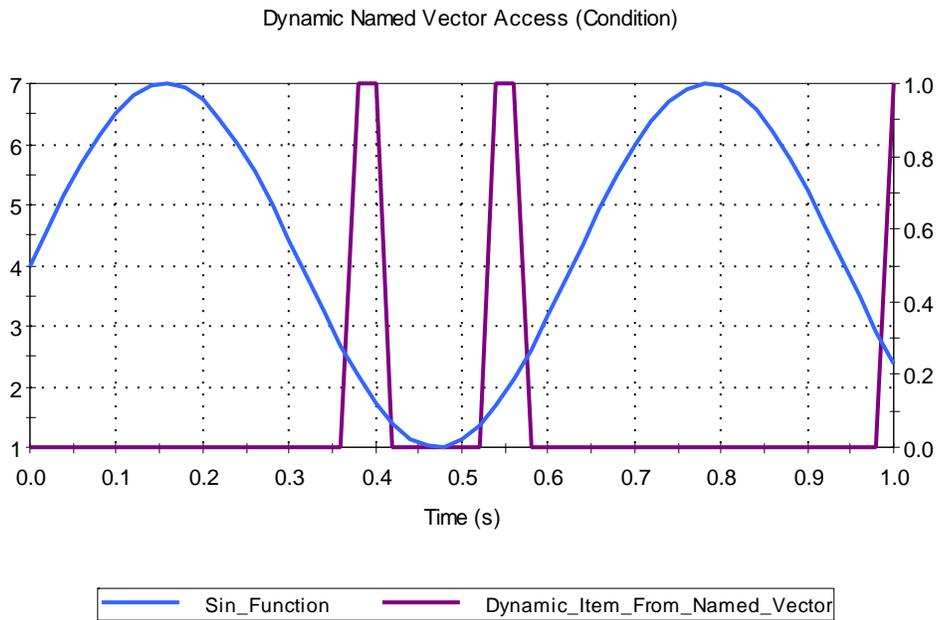


Fig. GS02_Array_4

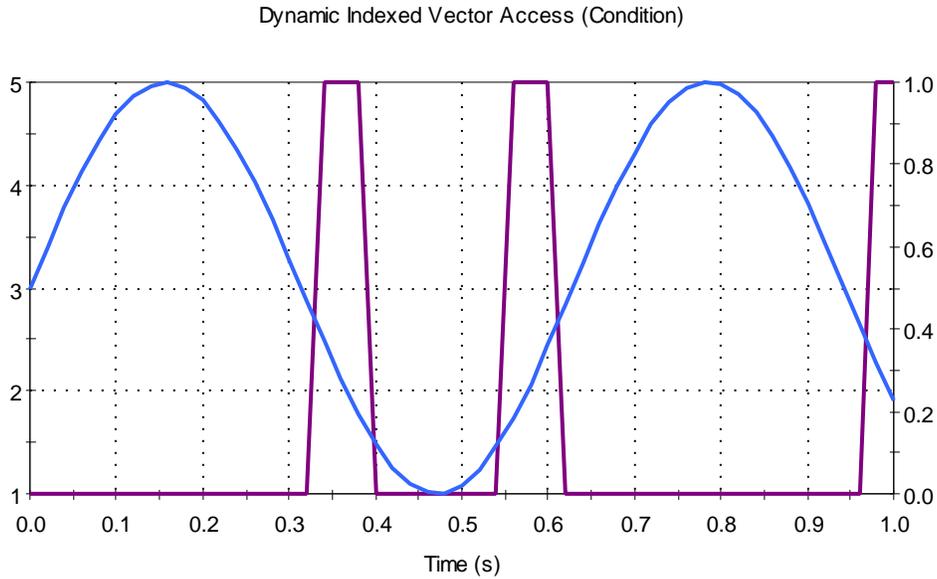


Fig. GS02_Array_5

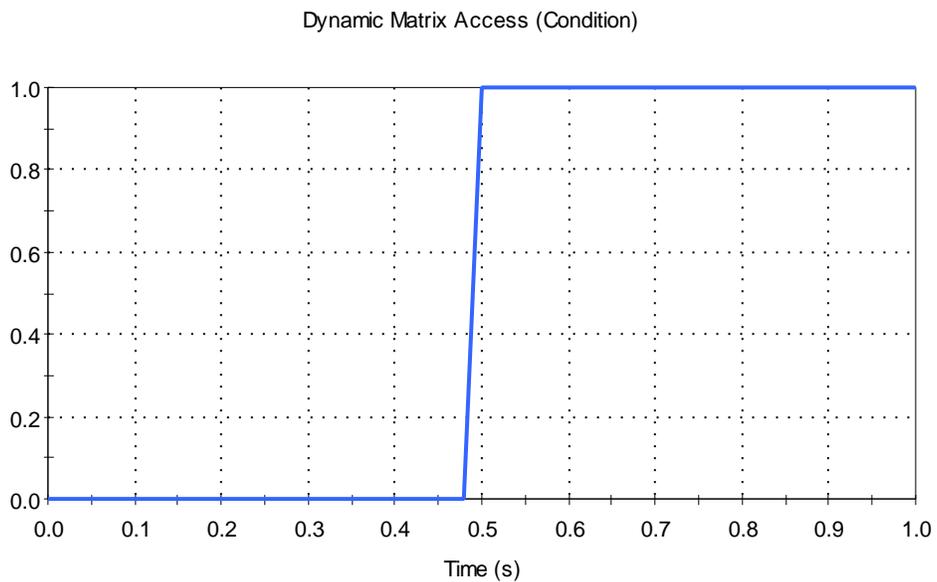


Fig. GS02_Array_6

GS02b_ExpressionsConstructor

This test verifies that vector and matrix constructors function correctly. The verifier should run the test and confirm that the results match the expected values listed in Table 2-4.

Arrays (vectors and matrices) are tested in two parts. The first set of tests involves Array Operators. The second set of tests involves miscellaneous array functionality, such as pasting data into arrays.

TABLE GS2_4

Container	Element	Expected Value
Vector_Matrix_Static _Single		
	Vector_Positive	[5,5,5] [m]
	Vector_Negative	[-4,-4,-4] [ft/s^2]
	Matrix_Positive	$\begin{bmatrix} 5 & 5 & 5 \\ 5 & 5 & 5 \\ 5 & 5 & 5 \end{bmatrix}$ [kg]
	Matrix_Negative	$\begin{bmatrix} -4 & -4 & -4 \\ -4 & -4 & -4 \\ -4 & -4 & -4 \end{bmatrix}$ [ft/s]
Vector_Matrix_Static		
	Vector_Static	[2, -5, 3.048][m]
	Matrix_Static	$\begin{bmatrix} 5 & 0 & 22.7 \\ 0.05 & 3 & -10 \\ 1 & 2 & 3 \end{bmatrix}$ [kg]
Vector_Matrix_Dynamic _Single		
	Max_Deviation_Vector	<1E-6
	Max_Deviation_Matrix	<1E-6
Vector_Matrix_Dynamic		
	Max_Deviation_Vector	<1E-6
	Max_Deviation_Matrix	<1E-6
Row_Column		
	Vector_Row	[1 1 5]
	Matrix_Row_Column	$\begin{bmatrix} 1 & -10 & 1 \\ 1 & -10 & 1 \\ -10 & -10 & -10 \end{bmatrix}$
Matrix_From_Vectors		
	Square_Matrix	$\begin{bmatrix} 1 & 10 & 100 \\ 5 & 50 & 500 \\ 1 & 10 & 100 \end{bmatrix}$ [kg]
	Two_Rows_Three_Cols	$\begin{bmatrix} 5 & 5 & 5 \\ 100 & 100 & 100 \end{bmatrix}$ [d]
	Two_Rows_Three_Cols	$\begin{bmatrix} 1 & 100 \\ 2 & 100 \\ 3 & 100 \end{bmatrix}$ [d]

GS03_Array: Array Operators and Data

Arrays (vectors and matrices) are tested in two parts. The first set of tests involves Array Operators. The second set of tests involves miscellaneous array functionality, such as pasting data into arrays.

1. Array Operators. Array operators with data links are verified by creating a model with each operator and comparing model results with known results. The expected results for each output are presented in the notes window, or tool tip window, for each element for easy comparison with the calculated array final values. The operators and functions checked in this section include:

Vector Operators (Term-by-Term for Values)

- vector sum **sumv**(Xi)
- vector minimum **minv**(Xi)
- vector maximum **maxv**(Xi)
- vector mean **meanv**(Xi)
- vector standard deviation **sdv**(Xi)
- vector/vector addition $X_i + Y_i$
- vector/vector subtraction $X_i - Y_i$
- vector/vector dot product $X_i * Y_i$ (scalar result)
- vector/scalar multiplication $X_i * a$
- vector/scalar division X_i / a
- change signs of vector $-X_i$
- term-by-term use of lookup tables by vectors
- search for a value within a vector output, return its fractional index.
- interpolate for a value within a vector output given its fractional index.

Matrix Operators (Term-by-Term for Values)

- matrix row sum **sumr**(Xij)
- matrix row mean **meanr**(Xij)
- matrix row standard deviation **sdr**(Xij)
- matrix row maximum **mixr**(Xij)
- matrix row minimum **minr**(Xij)
- matrix column sum **sumc**(Xij)
- matrix column mean **meanc**(Xij)
- matrix column standard deviation **sdc**(Xij)
- matrix column maximum **maxc**(Xij)

- matrix column minimum **minc**(Xij)
- nested matrix operation, $X_{ij} * \mathbf{trans}(Y_{ik})$
- term by term multiplication of two matrices **prod**(Xij, Xij)
- term by term division of two matrices **div**(Xij, Xij)
- matrix multiplication by scalar $a * X_{ij}$
- matrix division by scalar X_{ij} / a
- term-by-term use of lookup tables by vectors

Linear Algebra (Matrix and Vector Operations for Values)

- matrix - vector multiplication **mult**(Xii, Vi)
- vector - matrix multiplication **mult**(Yi, Xii)
- matrix – matrix multiplication **mult**(Xij, Yjk)
- vector – vector multiplication (matrix product) **vvmatrix**(V1, V2)
- matrix transpose of values
- matrix inversion
- vector/vector dot product **dot**(Xi, Yi) (scalar result)

Vector and Matrix Operators (Term-by-Term for Conditions)

- OR of elements in row of matrix **sumr**(M1)
- OR of elements in column of matrix **sumc**(M2)
- AND of elements in row of matrix **prodr**(M1)
- AND of elements in column of matrix **prodc**(M1)
- OR of elements in vector **sumv**(V1)
- AND of elements in vector **prodv**(V1)
- matrix transpose of conditions

Complex Operators

- nested matrix and vector operation **sin**((pi/180)* (6+Yi*(Yi*Xii)))
- nested matrix and vector operation **asin**((Yi*(6+Yi*(Xii***inv**(Xii))))/3)
- nested matrix operation $X_{ii} * \mathbf{inv}(X_{ii})$

The verification results are presented in Table GS03_1. It is not necessary for the user to enter any data but it is necessary to run the model. The user compares model current or final values against results presented in Table GS03_1 to verify the array operators.

TABLE GS03_1

Container	Test Element	Expected Result
Vector_ TermbyTerm		
	SUMV_Function	28
	MINV_Function	1
	MAXV_Function	7
	MEANV_Function	4
	SDV_Function	2
	Sort_123_Function	1 ,2, 3, 4, 5, 6, 7
	Sort_321_Function	7, 6, 5, 4, 3, 2, 1
	Vector_Vector_multiplication	1, 4, 9
	Vector_Scalar_multiplication	2, 4, 6, 8, 10, 12, 14
	Vector_Vector_Division	1, 1, 1
	Vector_Scalar_division	0.5, 1, 1.5, 2, 2.5, 3, 3.5
	Vector_Vector_addition	8, 8, 8, 8, 8, 8, 8
	Vector_Vector_subtraction	-6, -4, -2, 0, 2, 4, 6
	PRODV_function	6
	Scalar_Vector_division	2, 1, 0.6667, 0.5, 0.4, 0.333, 0.2857
	Lookup_Term_by_Term_Vector	[10, 20, 30]
	vIndexFunc	3.674
	vInterpTest	0.5 in
Matrix_ TermbyTerm		
	SUMR_Matrix_function	3 7
	PRODR_Matrix_function	6 48
	MEANR_Matrix_function	1.5 3.5
	MAXR_Matrix_function	2 4
	MINR_Matrix_function	1 3
	SDR_Matrix_function	0.5 0.5
	SUMR_Matrix	6 12
	SUMC_Matrix_function	4 6
	PRODC_Matrix_function	3 8

TABLE GS03_1

Container	Test Element	Expected Result
	MEANC_Matrix_function	2 3
	MAXC_Matrix_function	3 4
	MINC_Matrix_function	1 2
	SDC_Matrix_function	1 1
	SUMC_Matrix	3 6 9
	PRODC_Matrix	2 8 18
	TRANS_Matrix_function	1 3 2 4
	INV_Matrix_function	-2 1 1.5 -0.5
	Matrix_matrix_multiplication	1 4 9 16
	Matrix_matrix_division	1 1 1 1
	Nested_matrix_mult_trans	1 6 6 16
	Matrix_Scalar_multiplication	2 4 6 8
	Matrix_Scalar_division	0.5 1 1.5 2
	Scalar_Matrix_division	2 1 0.667 0.5
	Lookup_Term_by_Term_Matrix	10 20 30 40 50 60
Linear_Algebra		
	Matrix_Multiplication (mult(M1, M2))	14, 28 28, 56
	Matrix_times_Vector (mult(M, V))	14 28
	Vector_times_Matrix (mult(V, M))	14, 28
	Vector_times_Vector (vvmatrix(V1,V2))	1, 2, 3 2, 4, 6 3, 6, 9

TABLE GS03_1

Container	Test Element	Expected Result
	Vector_Dot_Product (dot(V1, V2))	14
Complex_Operations		
	Nested_sin_vector_matrix	1
	Nested_asin_vector_matrix	90 deg
	Matrix_inverse_product	1, 0, 0 0, 1, 0 0, 0, 1
Condition_Tests		
	Prodr_Conditions_1	True,True,True
	Prodr_Conditions_2	True,False,True
	Sumr_Conditions	True,True,True
	Prodc_Conditions_1	True,True,True
	Prodc_Conditions_2	True,False,True
	Sumc_Conditions	True,True,True
	TRANS_Condition_Matrix_function	false, true, true false, true, false false, true, false
	Prodv_Conditions_1	True
	Prodv_Conditions_2	False

TABLE GS03_1

Container	Test Element	Expected Result
	Sumv_Conditions	True

2. Miscellaneous Array Functionality

Before beginning this portion of the test, GoldSim should be placed in Edit mode.

Pasting data into Arrays. This test verifies that data (e.g., from an Excel spreadsheet) can be pasted into Arrays (vectors or matrices). Test elements are located in the Pasting container, and the test proceeds as follows:

- a. Throughout the test, ensure that the “Edit Data” dialog boxes can be resized.
- b. Before beginning the rest of the test, change the vector and matrix elements to scalars which will remove any existing data. The Vector_Data element should then be changed back to a vector of Months, and the Matrix_Data element should be changed back to a Matrix of Months by Days.
- c. Double-click on the hyperlink to the spreadsheet containing the data to be pasted (labeled “Pasting Data”). In the workbook named “Pasted cells to keep GS tests.xls”, Enter the worksheet named “GS03”. Copy (CTRL C) the range of cells intended to be pasted into the element Vector_Data (as directed in the spreadsheet).
- d. Enter the container named Pasting and open the “Edit Vector” dialog for the element Vector_Data.
- e. Paste (CTRL V) the copied cells into Vector_Data by clicking on the upper left cell (above the row heading “January”). Ensure that the pasted values match the copied values.
- f. Close the element dialog and then re-open it to ensure that it shows the correct values.
- g. In the spreadsheet, copy (CTRL C) the range of cells intended to be pasted into the element Matrix_Data (as directed in the spreadsheet).
- h. Open the “Edit Matrix” dialog for the element Matrix_Data.
- i. Paste (CTRL V) the copied cells into Matrix_Data by clicking on the upper left cell (above the row heading “January”). Ensure that the pasted values match the copied values.
- j. Close the element dialog and then re-open it to ensure that it shows the correct values.
- k. Save the file, exit, re-open it, and ensure that all values are still shown correctly.

Tool-tip display for Array Cells. Enter the container Tool_Tip_Test. Open the properties dialog box for the Data element Check_Display. Run the cursor over all of the cells and ensure that the tool-tip window correctly reports the value in each cell, including 1.#INF for infinity.

Invalid Arguments for Vector or Matrix Functions. Copy several of the existing test Expression elements (e.g., from containers Vector_TermByTerm or Matrix_TermByTerm) that utilize a vector or matrix operator (e.g., sumv(), maxr(), etc.). Try to replace the valid argument with a scalar (e.g., 5). In all cases, GoldSim should provide you with a message indicating that vector or matrix inputs are required. When done, delete the elements that were pasted for this portion of the test.

GS04_Stoc: Stochastic Distributions

Stochastic elements are verified by creating a model with each distribution and comparing model results with analytical results, numerical integration, or results generated from At Risk®. The expected results for each output are viewed in the edit distribution window of the element dialog. The distributions checked in this section include:

Distributions

- Uniform
- Log-Uniform
- Triangular
- Log-Triangular
- Normal
- Log-Normal
- Truncated Normal
- Truncated Log-Normal
- Beta
- Binomial
- Boolean
- Cumulative
- Discrete
- Gamma
- Truncated Gamma
- Poisson
- Weibull
- Truncated Weibull
- Student-t
- Exponential
- Pareto
- Negative Binomial

These test problems verify correct evaluation of stochastic elements and represent each of the 22 probability distributions supported by Goldsim. The tests verify the probability and cumulative distributions based on the parameter inputs. These tests include verifying distribution moments (i.e. mean and standard deviation when applicable) and several selected percentiles. The function of the Goldsim calculator is also verified with these tests. The distribution form is verified by comparing the displayed values at various percentiles against the “true” form of the distribution. The “true” form was calculated mathematically for those distributions for which a closed-form solution was readily available. Otherwise, the “true” form was approximated using results from @Risk by running 100,000 realizations employing Latin-Hypercube sampling. @Risk was used to compute the “true” form for the following distributions: normal, lognormal, truncated normal, truncated lognormal, and gamma. In some instances, numerical integration was applied to compute the cdf. This method was checked against @Risk results with both methods in close agreement (to 4 significant figures). The numerical integration method was used to compute the “true” form for the following distributions: truncated gamma and truncated weibull. Note that because random sampling is involved, small differences between the “true” values and the values reported by Goldsim are to be expected. This is also relevant for “true” results generated by @Risk. Also, some error is introduced using the numerical integration method. For the purposes of this verification, comparisons involving random sampling error (i.e., @Risk simulations) and numerical integration error must agree to 3 significant figures to pass the verification.

The verification results are presented in Table GS04_1. It is not necessary to run the model to verify results. The user compares verification results to displayed values in the “Edit Distribution” window of each element. Percentile results are viewed by clicking on the “%” icon in the lower left-hand corner of the “Edit Distribution” window. It is necessary for the user to enter data in the calculator box of the edit distribution window to verify calculator results. The required value or cumulative probability inputs to the calculator are also presented in Table GS04_1.

TABLE GS04_1

Tests Element	Result Type	Expected Results
Uniform	Element dialog, edit distribution	Mean = 500 St. Dev. = 289 5%: x = 50.0 25%: x = 250 50%: x = 500 75%: x = 750 90%: x = 900
	Element dialog, edit distribution, calculator value input 900	Cum. Prob. = 0.900 Prob. Density = 0.001
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 900 Prob. Density = 0.001

TABLE GS04_1

Tests Element	Result Type	Expected Results
Uniform_Log	Element dialog, edit distribution	Mean = 215 St. Dev. = 250 5%: x = 12.6 25%: x = 31.6 50%: x = 100 75%: x = 316 90%: x = 631
	Element dialog, edit distribution, calculator value input 100	Cum. Prob. = 0.500 Prob. Density = 0.00217
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 631 Prob. Density = .000344
Triangular	Element dialog, edit distribution	Mean = 46.7 St. Dev. = 19.3 5%: x = 19.5 25%: x = 31.3 50%: x = 43.9 75%: x = 60.3 90%: x = 74.9
	Element dialog, edit distribution, calculator value input 50	Cum. Prob. = 0.603 Prob. Density = 0.0159
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 74.9 Prob. Density = .00797
Triangular_Log	Element dialog, edit distribution	Mean = 34.7 St. Dev. = 16.7 5%: x = 14.3 25%: x = 22.1 50%: x = 30.8 75%: x = 43.5 90%: x = 59.1
	Element dialog, edit distribution, calculator value input 50	Cum. Prob. = 0.827 Prob. Density = 0.0100
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 59.1 Prob. Density = 0.00643
Normal	Element dialog, edit distribution	5%: x = 67.1 25%: x = 86.5 50%: x = 100 75%: x = 113 90%: x = 126
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.159 Prob. Density = 0.0121
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 126 Prob. Density = .00877

TABLE GS04_1

Tests Element	Result Type	Expected Results
Normal_Log	Element dialog, edit distribution	geo. Mean = 89.4 geo. St. Dev. = 1.60 5%: x = 41.1 25%: x = 65.0 50%: x = 89.4 75%: x = 123 90%: x = 164
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.407 Prob. Density = 0.0103
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 164 Prob. Density = 0.00227
Normal_Truncated	Element dialog, edit distribution	5%: x = 70.6 25%: x = 87.2 50%: x = 100. 75%: x = 113 90%: x = 124
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.142 Prob. Density = 0.0127
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 124 Prob. Density = 0.0104
Normal_Log_Truncated	Element dialog, edit distribution	geo. Mean = 89.4 geo. St. Dev. = 1.60 5%: x = 54.5 25%: x = 69.6 50%: x = 88.0 75%: x = 111 90%: x = 130
	Element dialog, edit distribution, calculator value input 80	Cum. Prob. = 0.395 Prob. Density = 0.0136
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 130 Prob. Density = 0.00624
Gamma	Element dialog, edit distribution	5%: x = 5.47 25%: x = 10.1 50%: x = 14.7 75%: x = 20.4 90%: x = 26.7
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.735 Prob. Density = 0.0351

TABLE GS04_1

Tests Element	Result Type	Expected Results
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 26.7 Prob. Density = 0.0156
Gamma_Truncated	Element dialog, edit distribution	5%: x = 6.43 25%: x = 10.1 50%: x = 13.8 75%: x = 18.1 90%: x = 21.6
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.838 Prob. Density = 0.0422
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 21.6 Prob. Density = 0.0357
Weibull	Element dialog, edit distribution	Mean = 18.9 St. Dev. = 4.63 5%: x = 12.3 25%: x = 15.4 50%: x = 18.3 75%: x = 21.8 90%: x = 25.2
	Element dialog, edit distribution, calculator value input 25	Cum. Prob. = 0.895 Prob. Density = 0.0316
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 25.2 Prob. Density = 0.0303
Weibull_Truncated	Element dialog, edit distribution	Mean = 17.7 5%: x = 12.1 25%: x = 15.0 50%: x = 17.7 75%: x = 20.5 90%: x = 22.8

TABLE GS04_1

Tests Element	Result Type	Expected Results
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.707 Prob. Density = 0.0822
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 22.8 Prob. Density = 0.0557
Beta (generalized)	Element dialog, edit distribution	5%: x = 9.76 25%: x = 24.3 50%: x = 38.6 75%: x = 54.4 90%: x = 68.0
	Element dialog, edit distribution, calculator value input 30	Cum. Prob. = 0.348 Prob. Density = 0.0176
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 68.0 Prob. Density = 0.00837
Binomial	Element dialog, edit distribution	Mean = 25.0 St. Dev. = 4.33 5%: x = 18 25%: x = 22 50%: x = 25 75%: x = 28 90%: x = 31
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.149 Prob. Density = 0.0493
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 31 Prob. Density = 0.0344
Boolean	Element dialog, edit distribution	Mean = 0.75 5%: x = 0 25%: x = 1 50%: x = 1 75%: x = 1 90%: x = 1
	Element dialog, edit distribution, calculator value input 0	Cum. Prob. = 0.25
	Element dialog, edit distribution, calculator cumulative probability input 0.75	Value = 1

TABLE GS04_1

Tests Element	Result Type	Expected Results
Cumulative	Element dialog, edit distribution	Mean = 50 5%: x = 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 90
	Element dialog, edit distribution, calculator value input 60	Cum. Prob. = 0.60 Prob. Density = 0.01
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 90 Prob. Density = 0.01
Discrete	Element dialog, edit distribution	Mean = 50 St. Dev. = 28.4 5%: x = 5 25%: x = 25 50%: x = 50 75%: x = 75 90%: x = 95
	Element dialog, edit distribution, calculator value input 26	Cum. Prob. = 0.252 Prob. Density = 0
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 95 Prob. Density = 0.200
Exponential	Element dialog, edit distribution	Mean = 20 SD = 20 5%: x = 1.026 25%: x = 5.754 50%: x = 13.863 75%: x = 27.726 90%: x = 46.052
	Element dialog, edit distribution, calculator value input 46.052	Cum. Prob. = 0.90 Prob. Density = 0.005
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 46.052 Prob. Density = 0.005
Pareto	Element dialog, edit distribution	Mean = 5.2632 SD = 0.2774 5%: x = 5.013 25%: x = 5.072 50%: x = 5.176 75%: x = 5.359 90%: x = 5.610
	Element dialog, edit distribution, calculator value input 5.610	Cum. Prob. = 0.90 Prob. Density = 0.357
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 5.610 Prob. Density = 0.357

TABLE GS04_1

Tests Element	Result Type	Expected Results
Poisson	Element dialog, edit distribution	Mean = 25cm St. Dev. = 5.00cm 5%: x = 17cm 25%: x = 22cm 50%: x = 25cm 75%: x = 28cm 90%: x = 32cm
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.185 Prob. Density = 0.0519 1/cm
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 32 Prob. Density = 0.0286 1/cm
Truncated Pareto	Element dialog, edit distribution	Mean = 5.2052 5%: x = 5.012 25%: x = 5.067 50%: x = 5.161 75%: x = 5.314 95%: x = 5.588
	Element dialog, edit distribution, calculator value input 5.488	Cum. Prob. = 0.90 Prob. Density = 0.602
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 5.488 Prob. Density = 0.602
Negative Binomial	Element dialog, edit distribution	Mean = 3.3333 SD = 2.1082 5%: x = 0 25%: x = 2 50%: x = 3 75%: x = 5 95%: x = 7
	Element dialog, edit distribution, calculator value input 7	Cum. Prob. = 0.960 Prob. Density = 0.039
	Element dialog, edit distribution, calculator cumulative probability input 0.90	Value = 6 Prob. Density = 0.0688
Student-t	Element dialog, edit distribution	Mean = 0 SD = 1.0426 5%: x = -1.708 25%: x = -0.684 50%: x = 0 75%: x = 0.684 95%: x = 1.708
	Element dialog, edit distribution, calculator value input 1.708	Cum. Prob. = 0.95 Prob. Density = 0.940
	Element dialog, edit distribution, calculator cumulative probability input 0.95	Value = 1.708 Prob. Density = 0.940

TABLE GS04_1

Tests Element	Result Type	Expected Results
Beta_Success_Failure	Element dialog, edit distribution	Mean = 0.4444 SD = 0.07326 Skewness = 0.0645 5%: x = 0.325 25%: x = 0.394 50%: x = 0.444 75%: x = 0.494 95%: x = 0.567
	Element dialog, edit distribution, calculator value input 0.5	Cum. Prob. = 0.774 Prob. Density = 4.004 CTE=0.542
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 0.540 Prob. Density = 2.347 CTE = 0.574
Extreme Probability (Maximum)	Element dialog, edit distribution	Mean = 0.8333 SD = 0.1409 Skewness = -1.183 5%: x = 0.549 25%: x = 0.758 50%: x = 0.871 75%: x = 0.944 95%: x = 0.990
	Element dialog, edit distribution, calculator value input 0.8	Cum. Prob. = 0.328 Prob. Density = 2.048 CTE = 0.915
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 0.979 Prob. Density = 4.599 CTE = 0.990
Extreme Probability (Minimum)	Element dialog, edit distribution	Mean = 0.0909 SD = 0.0830 Skewness = 1.517 5%: x = 0.0050 25%: x = 0.0280 50%: x = 0.0667 75%: x = 0.129 95%: x = 0.259
	Element dialog, edit distribution, calculator value input 0.3	Cum. Prob. = 0.972 Prob. Density = 0.404 CTE = 0.362
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 0.205 Prob. Density = 1.262 CTE = 0.276
Extreme Value (Maximum)	Element dialog, edit distribution	Mean = 6.1544 SD = 2.5651 Skewness = 1.14 Kurtosis = 2.4 5%: x = 2.806 25%: x = 4.347

TABLE GS04_1

Tests Element	Result Type	Expected Results
		50%: x = 5.733 75%: x = 7.492 95%: x = 10.94
	Element dialog, edit distribution, calculator value input 7	Cum. Prob. = 0.692 Prob. Density = 0.127
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 9.501 Prob. Density = 0.047
Extreme Value (Minimum)	Element dialog, edit distribution	Mean = 8.268 SD = 3.848 Skewness = -1.14 Kurtosis = 2.4 5%: x = 1.089 25%: x = 6.262 50%: x = 8.900 75%: x = 10.98 95%: x = 13.29
	Element dialog, edit distribution, calculator value input 7	Cum. Prob. = 0.308 Prob. Density = 0.0849
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 12.50 Prob. Density = 0.0768
Pearson	Element dialog, edit distribution	Mean = 16 SD = 4.2426 Skewness = 1.4142 5%: x = 11.07 25%: x = 12.88 50%: x = 15.04 75%: x = 18.08 95%: x = 24.23
	Element dialog, edit distribution, calculator value input 20	Cum. Prob. = 0.8454 Prob. Density = 0.039
	Element dialog, edit distribution, calculator cumulative probability input 0.9	Value = 21.67 Prob. Density = 0.027

GS04a_Stoc_Array

Version 8.00 of GoldSim added the capability to specify a Stochastic element that is an array. This test uses the array Days and specifies uniform distributions that range from 1-10 for Sunday to 7-10 for Saturday. The test confirms that the specified distributions are correctly sampled, that no inadvertent correlations are created, and that triggering a new sample at each time step works correctly.

After running the test the correlation matrix should be displayed. All of the off-diagonal terms should be small, typically less than 0.02.

The CDF's for the seven terms in the vector should also be displayed, to confirm that they represent uniform distributions with the specified lower and upper bounds.

GS04b_Conditional_Tail_Expectation

This test verifies the correct functioning of the Conditional Tail Expectation (CTE) calculations in the Stochastic element and the Result Distribution element.

These elements use different methodologies for calculating the value of the CTE. To verify the performance of the elements the tester should check that the CTE values for the Stochastic element and the corresponding Result Distribution match the expected values listed below:

Normal/Result_Normal:

Probability level of 0.75 should result in a CTE of 16.355.
Value of 0 should result in a CTE of 10.276.

Lognormal/Result_Lognormal:

Probability level of 0.32 should result in a CTE of 10.988.
Value of 4 should result in a CTE of 10.

Uniform/Result_Uniform:

Probability level of 0.05 should result in a CTE of 0.525.
Probability level of 0.25 should result in a CTE of 0.625.
Probability level of 0.5 should result in a CTE of 0.75
Probability level of 0.90 should result in a CTE of 0.95.
Value of 0.3 should result in a CTE of 0.65.
Value of 0.8 should result in a CTE of 0.9.
Value of 1.5 should result in a CTE of 1.

Triangular/Result_Triangular:

Probability level of 0.4 should result in a CTE of 54.0.
Value of 65 should result in a CTE of 68.33

GS04c_Sampled_Results

This test verifies the correct functioning of the Sampled Results and Sampled Results (Extrapolated) distributions.

The Sampled Results distribution is tested by sampling values from a Uniform distribution and then pasting those into the Sampled Results distribution. Since both should produce roughly identical results the verifier should confirm that the Mean, Standard Deviation, Skewness, Kurtosis and PDF plots for the two distributions in the Comparison result element are statistically identical.

The Sampled Results (Extrapolated) option extrapolates the distribution at both ends of the sampled data to predict the value at cumulative probability levels of 0 and 1. This is done by

drawing a line between the fifth from extreme observation and the extreme observation until it reaches the 0 or 1 cumulative probability level.

To confirm the proper functioning of this option the verifier should enter the Sampled_Extrapolated Stochastic element. The verifier should confirm the following using the Stochastic element's probability calculator:

- Cumulative probability of 0 should result in a value of 9.975 (calculated slope is $10.53 - 10.16 = 0.37$, $10.16 - 0.37/2 = 9.975$)
- Cumulative probability of 1 should result in a value of 20 (calculated slope is $19.74 - 19.22 = 0.52$, $19.74 + 0.52/2 = 20$)

GS04d_Correlation_Matrix

All of the multivariate result elements should show the following correlations (these are shown in the _Correlations Multivariate Result elements):

	1	2	3	4	5
1	1	0	0.75	0	0
2	0	1	0	0.1	0.35
3	0.75	0	1	0	0
4	0	0.1	0	1	0.93
5	0	0.35	0	0.93	1

The verifier should note that the correlations predicted by the Multivariate Result elements may not exactly agree with the matrix specified in the History Generator elements, especially for the t-distribution copula with one degree of freedom.

The verifier should also check that the correlation between variables agrees with the correlation type specified. To do this, the verifier should check the _Plots Multivariate Result elements. The Gaussian and Iman and Conover correlations should show a stronger correlation in the middle than at the tails. The 1 degree of freedom t-distribution copula should show a stronger correlation at the tails than in the middle. The 25 degree of freedom t-distribution copula should resemble the Gaussian copula (as the number of degrees of freedom increases, the t-distribution copula begins to approximate the Gaussian copula).

GS04e_Percentile

This test verifies the proper functioning of Percentile correlation, where a distribution reports the specified percentile of its distribution.

A source distribution (Uniform on 0,1) is resampled each model update. This is used as the input to the correlation input field for both a Normal [0,1] and a Uniform [0,1] distribution with Percentile correlation enabled. It is possible to directly calculate the value that should be sampled for both the normal and uniform distribution. The expected and calculated values are compared and an Extrema element is used to identify the largest deviation.

The verifier should run the model and then ensure that the Extrema element reports a negligible value (less than 1E-6).

GS05_Integrator1: Integrator Elements (formerly Quantity and Accumulator Elements)

Integrators with data links are verified by creating a model with Integrator elements and comparing model results with known results. The expected results for each static output are presented in the tool tip window for each element for easy comparison with the current value output when appropriate. Expected values are presented in the element notes for vector results. The functions checked in this section include:

Scalar Integrators

Integrator with scalar initial value and scalar rate of change

Integrator with scalar initial value and time dependent rate of change

Vector (or Matrix) Integrators

Vector (or matrix) of Integrators with vector (or matrix) of initial values and vector (or matrix) of rates of change

The verification results are presented in Table GS05_1. It is not necessary for the user to enter any data but it is necessary to run the model. The user compares model current values against results presented in Table GS05_1 to verify the Integrator elements.

TABLE GS05_1

Tests Element	Result Type	Expected Values
Integrator_Simple	Element tool tip , time histories	At 20s = 300
Integrator_Time_Dep	Element tool tip , time histories	At 10s = 50 At 20s = 150
Vector_Integrator	Element time histories	At 20s = [30,50,70,90,110,130,150]
Matrix_Integrator	Element time histories	At 20s = (2x2 matrix) 120 20 20 1020

GS06_Integrator 2: More Integrator-Element Tests

This file contains tests to verify that Integrator Elements correctly manipulate initial values, rates of change, and discrete changes. The file evaluates calculated (dimensionless) quantities over a 200-day simulation and uses a one-day timestep. Calculated results are compared to theoretical results evaluated using EXCEL. Note that the first few tests in this file duplicate several of the scalar tests in GS05_INTEGRATOR1, but are included in GS06_INTEGRATOR2 for completeness.

Basic Tests

1. Rate-integration tests (initial value = 0; no discrete changes)
 - a) Rate of change of 0 / day
 - b) Rate of change of 1 / day
 - c) Rate of change of -10 / day
 - d) Rate of change of (Time in days / 1 day) { 1 / day }
 - e) Rate of change of (Time in days / 1 day) { 1 / day }, backwards-difference option
 - f) Rate of change equal to the value of a time-dependent variable (normal forward-difference option).
2. Initial-value tests (rate of change = 0; no discrete changes)
 - a) Value input directly into the Integrator Element's initial-value field directly
 - b) Initial value is a link to a Data Element
 - c) Initial value is a link to an Expression Element
 - d) Initial value is a link to a Selector Element
3. Discrete-change tests (initial value = 0; rate as specified below)
 - a) Input from a Discrete Change: Add a constant
 - b) Input from a Discrete Change: Replace by a constant
 - c) Multiple, discrete changes (from three Discrete Changes)
 - d) Discrete change at a specified time (replace by constant) AND a rate of change equal to (Time in days / 1 day) { 1 / day }

The model must be run to see calculated results. The expected outputs are shown either in the tooltip window for each Integrator Element (i.e., move the cursor over the Integrator Element being evaluated, and a tooltip window will automatically appear) or graphically as specified in the file. Specific tests and expected results are shown in Table GS06_1.

Table GS06_1

Element being evaluated	Test	Expected Result / Output
Integrator 1	1 a)	Value of 1 for all times
Integrator 2	1 b)	A linear increase in value from 0 at time 0 to 100 at time 100 days
Integrator 3	1 c)	A linear decrease from 0 at time 0 to -1,000 at time 100 days
Integrator 4	1 d)	Parabolic with a value of 0 at time 0 and a value of 4999 at time 100 days
Integrator 4b	1 e)	Parabolic with a value of 0 at time 0 and a value of 5001 at time 100 days (rate of change is 0.02/day greater than test 1 d).
Integrator 5	1 f)	See Figure GS06.1
Integrator 6	2 a)	Expected output is a value of 10 at time 0 and a value of 110 at time 100 days.
Integrator 7	2 b)	Expected output is a value of

		10 at time 0 and a value of 110 at time 100 days.
Integrator 8	2 c)	Expected output is a value of 10 at time 0 and a value of 110 at time 100 days.
Integrator 8b	2 d)	Expected output is a value of 10 at time 0 and a value of 110 at time 100 days.
Integrator 9	3 a)	Expected output is an increase in value from 0 to 1 at time 50 days.
Integrator 10	3 b)	Expected output is a decrease in value from 10 to 5 at 50 days.
Integrator 12	3 c)	Expected output is a change in value from 0 to 25 at time 50 days.
Integrator 13	3 d)	See Figure GS06.2

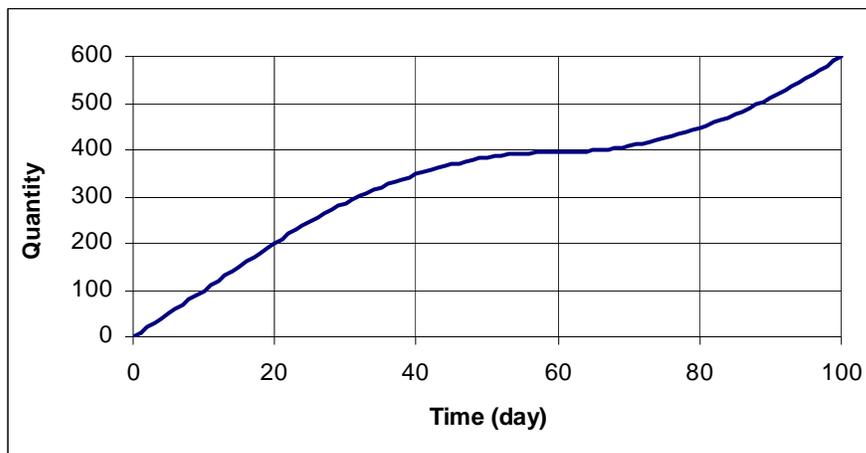


Figure GS06.1. Expected results for Test 1 f).

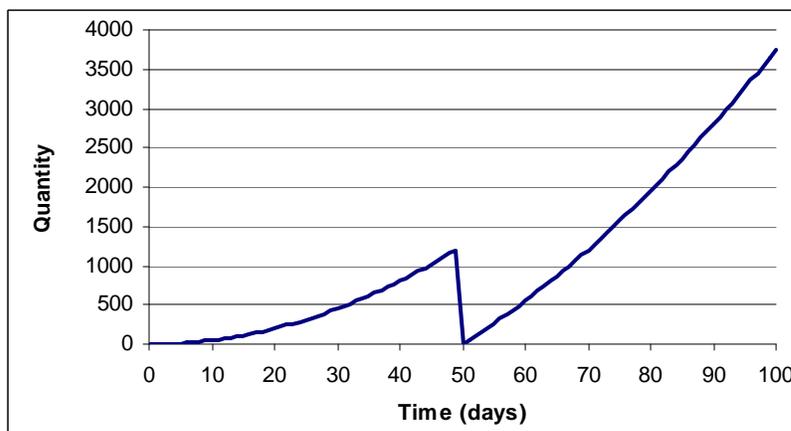


Figure GS06.2. Expected results for Test 3 d)

GS07_Selc: Selectors

Selector functions with data links are verified by creating a model with selector elements and comparing model results with known results. The expected results for each non-time dependent output are presented in the tool tip window for each element for easy comparison with the current value output. Expected values for time dependent selector tests are presented in the element notes for vector results. The functions checked in this section include:

Basic Tests

- first two conditions are false, third is true (== operator is tested)
- first two conditions are false, third is true (!= operator is tested)
- first two conditions are false, third is true (< operator is tested)
- first two conditions are false, third is true (> operator is tested)
- first two conditions are false, third is true (<= operator is tested)
- first two conditions are false, third is true (>= operator is tested)
- first four conditions are false, last is true
- all conditions are false, uses default value

Time Dependent Tests

- time dependent conditions
- time dependent conditions and time condition in output IF statement
- time dependent conditions and time as the output

Nested Test

- time dependent condition with a linked time dependent selector as the output

The verification results are presented in Table GS07_1. It is not necessary for the user to enter any data but it is necessary to run the model. The user compares model final values or time histories against results presented in Table GS07_1 to verify the selector elements.

TABLE GS07_1

Tests Element	Result Type	Expected Values
Selector_Basic_1	Element tool tip, time histories	Selector_Basic_1 = 3

TABLE GS07_1

Tests Element	Result Type	Expected Values
Selector_Basic_2	Element tool tip, time histories	Selector_Basic_2 = 3
Selector_Basic_3	Element tool tip, time histories	Selector_Basic_3 = 3
Selector_Basic_4	Element tool tip, time histories	Selector_Basic_4 = 3
Selector_Basic_5	Element tool tip, time histories	Selector_Basic_5 = 3
Selector_Basic_6	Element tool tip, time histories	Selector_Basic_6 = 3
Selector_Basic_7	Element tool tip, time histories	Selector_Basic_7 = 5
Selector_Basic_8	Element tool tip, time histories	Selector_Basic_8 = 5
Selector_Time_1	Element time histories	time=0 to <1s value = 0 time=1 to <2s value = 1 time=2 to <3s value = 2 time=3 to <4s value = 3 time=4 to <5s value = 4 time>=5 value = 5
Selector_Time_2	Element time histories	time<5s value = 0 time=5s to <10s value = 1 time >= 10s value = 2

TABLE GS07_1

Tests Element	Result Type	Expected Values
Selector_Time_3	Element time histories	time <= 5s, value = time time >5s value = 1s
Selector_Nested	Element time histories	time=0 to <1s value = 0 time=1 to <2s value = 1 time=2 to <3s value = 2 time=3 to <4s value = 3 time=4 to <5s value = 4 time=5 to <10s value = 5 time>=10s value = 10

GS08_Look: Look-up Tables

<REVISED LOOKUP TABLES WERE INTRODUCED IN VERSION 9 –SUPPORT FOR OLD STYLE TABLES WAS DISCONTINUED IN VERSION 9.60>

<THIS TEST SUPERCEDED BY GS50 FOR VERSION 9.60 AND LATER>

GS09a_Dbas: Database Links/Downloading

Linking and downloading from the Yucca Mountain, Simple, and Generic databases is verified by setting up a model with elements prepared for download execution.

Yucca Mountain Database

The Yucca Mountain database link/download tests include:

Constants

- scalar constant with length conversion
- scalar constant with mass conversion
- scalar constant with time conversion
- vector data definition
- matrix data definition

Tables

- 1-D table
- 2-D table

Stochastics

- Uniform
- Log-Uniform
- Triangular

- Log-Triangular
- Normal
- Log-Normal (importing arithmetic mean and geometric mean)
- Truncated Normal
- Truncated Log-Normal (importing arithmetic mean and geometric mean)
- Beta
- Binomial
- Boolean
- Cumulative
- Discrete
- Gamma
- Truncated Gamma
- Poisson
- Weibull
- Truncated Weibull
- Exponential
- Pareto
- Negative Binomial
- Truncated Pareto

The database links/download tests set up for failure include:

- Attempting to import scalar constant with incompatible units
- Attempting to import scalar constant with no units declared in the database
- Attempting to import 1-D table with incompatible units
- Attempting to import 2-D table with incompatible units
- Attempting to import stochastic distribution with incompatible units
- Attempting to import stochastic distribution with no units declared in the database
- Attempting to import a matrix with more than 60 columns
- Attempting to import a matrix with too many records in the Value Component Table
- Attempting to import a vector with an incorrect parameter code in the Parameter Table
- Attempting to import a vector without enough records in the Value Component Table

In order to access and download from the Yucca Mountain database that is set up for verification testing, the user must perform the following steps:

1. Copy file **GS09_Yucca_DB.MDB** to the root directory from which GoldSim is executed.
2. Open the WINDOWS control panel and double click the "Administrative Tools" icon. Double click the "ODBC Data Sources (32 Bit)" icon.
3. In the "System DSN" tab click the "Add" button, highlight Microsoft Access Driver in the new dialog window and click the "Finish" button. This will open a dialog window called "OBDC Microsoft Access 97 Setup". In the "Data Source Name" box type "Yucca Database Verification" then click the "Select" button in the "Database" box. Another dialog window called "Select Database" will open, select the directory in which the file **GS09_Yucca_DB.MDB** is located and select the file **GS09_Yucca_DB.MDB** . Click the "OK" button to close all ODBC dialog windows.
4. In the GoldSim model GS09a_DBAS.gsm do the following for each element:
 - a. Open each element in the container labeled "Yucca_Mountain_Database" and click on its "Database" tab.
 - b. Select "Yucca Mountain Database" from the dropdown menu for the Database Type, and select "Yucca Database Verification" from the dropdown menu for Database.
 - c. Click the "Download Now" button. If the download was successful the "Status" box in the "Database" dialog of the element will display a message indicating the time of the successful download.
 - d. Compare each downloaded element against results presented in Table GS09_DBAS_1 to verify linking to the Yucca Mountain database. **For the old style table elements (prior to version 9) the user may have to choose the option "do not link to database" in the database tab of the element dialog to view table data.** Re-connect to the Yucca Mountain Database after verifying the contents of tables.
 - e. Leave each element connected to the Yucca Mountain database after it has been successfully downloaded.

It is not necessary to run the program.

Simple Database

The Simple database link/download tests include:

Constants

- scalar constant with length conversion
- vector data definition
- matrix data definition

Stochastics

- Uniform
- Log-Uniform
- Triangular
- Log-Triangular
- Normal
- Log-Normal (importing arithmetic mean and geometric mean)
- Truncated Normal
- Truncated Log-Normal (importing arithmetic mean and geometric mean)
- Beta
- Binomial
- Boolean
- Cumulative
- Discrete
- Gamma
- Truncated Gamma
- Poisson
- Weibull
- Truncated Weibull
- Exponential
- Pareto
- Negative Binomial
- Truncated Pareto

The database links/download tests set up for failure include:

- Attempting to import scalar constant with incompatible units
- Attempting to import scalar constant with no units declared in the database
- Attempting to import stochastic distribution with incompatible units
- Attempting to import stochastic distribution with no units declared in the database
- Attempting to import a vector with a row index in the Array Value Table out of bounds
- Attempting to import a vector with a column index in the Array Value Table out of bounds

- Attempting to import a vector with too many records in the Array Value Table
- Attempting to import a vector without enough records in the Array Value Table
- Attempting to import a vector with an argument mismatch in the Parameter Table (the dimensions in the Parameter Table do not match those of the vector)
- Attempting to import a vector with a column entry of zero in the Array Value Table
- Attempting to import a matrix with no records in the Array Value Table

In order to access and download from the Simple database that is set up for verification testing, the user must perform the following steps:

1. Copy file **GS09_SIMPLE_DB.MDB** to the root directory from which GoldSim is executed.
2. Open the WINDOWS control panel and open the “ODBC Data Sources (32 Bit)” folder.
3. In the “System DSN” tab click the “Add” button, highlight Microsoft Access Driver in the new dialog window and click the “Finish” button. This will open a dialog window called “ODBC Microsoft Access 97 Setup”. In the “Data Source Name” box type “Simple Database Verification” then click the “Select” button in the “Database” box. Another dialog window called “Select Database” will open, select the directory in which the file **GS09_SIMPLE_DB.MDB** is located and select the file **GS09_SIMPLE_DB.MDB**. Click the “OK” button to close all ODBC dialog windows.
4. In the GoldSim model GS09_DBASa.gsm do the following for each element:
 - a. Open each element in the container labeled “Simple_Database” and click on its “Database” tab.
 - b. Select "Simple GoldSim Database" from the dropdown menu for the Database Type, and select “Simple Database Verification” from the dropdown menu for Database.
 - c. Click the “Download Now” button. If the download was successful the “Status” box in the “Database” dialog of the element will display a message indicating the time of the successful download.
 - d. The user compares each downloaded element against the verification results presented in Table GS09_DBAS_2 to verify linking to a Simple database. The user may have to choose the option “do not link to database” in the database tab of the element dialog to view tables. Re-connect to the Simple Database after verifying table data.
 - e. Leave each element connected to the Simple database after it has been successfully downloaded.

Generic Database

The Generic database link/download tests include:

- Scalar constant with length conversion
- Scalar constant with mass conversion
- Scalar constant with time conversion

In order to access and download from the generic database that is set up for verification testing the user must perform the following steps:

1. Copy file **GS09_GEN_DB.MDB** to the root directory from which GoldSim is executed.
2. Open the WINDOWS control panel and open the “ODBC Data Sources (32 Bit)” folder.
3. In the “System DSN” tab click the “Add” button, highlight Microsoft Access Driver in the new dialog window and click the “Finish” button. This will open a dialog window called “ODBC Microsoft Access 97 Setup”. In the “Data Source Name” box type “Generic Database Verification” then click the “Select” button in the “Database” box. Another dialog window called “Select Database” will open, select the directory in which the file **GS09_GEN_DB.MDB** is located and select the file **GS09_GEN_DB.MDB**. Click the “OK” button to close all ODBC dialog windows.
4. In the GoldSim model GS09a_DBAS.gsm open each element in the container labeled “Container_Generic_Database” and click on the “Database” tab.
5. Select “Generic Database” from the dropdown menu for the Database Type, and select “Generic Database Verification” from the dropdown menu for the Database.
6. Enter the following into the "Database" tab for each of the test elements listed below (note that you may need to first clear the database link, by setting the “Select Database Type” pick list back to “No Database”, and then re-establish it in order to view the correct results):

	Define Fields	Where	Incoming Units
Constant_Generic_Volume:	Value	ID = 'one'	m ³
Constant_Generic_Mass:	Value	ID = 'two'	kg
Constant_Generic_Time:	Value	ID = 'three'	sec

7. Click the “Download Now” button. If the download was successful the “Status” box in the “Database” dialog of the element will display a message indicating the time of the successful download.
8. The user compares each downloaded element against results presented in Table GS09_DBAS_3 to verify linking to a Generic database.
9. Leave each element connected to the Generic database after it has been successfully downloaded.

TABLE GS09a_DBAS_1 - Yucca Mountain Database

Tests Element	Result Type	Expected Values
Constant_Length	Element tool tip	Constant_Length = 3.281 ft Linked To: Yucca Mountain Database Status: Download Succeeded at (date/time of last download) Effective Date : 1999-06-25 00:00:00

**TABLE GS09a_DBAS_1 - Yucca
Mountain Database**

Tests Element	Result Type	Expected Values																																																
		Reference Document: Constant Document ID: B00000000-01717-4301-00003 DTN: LL9807079704242.042 MOL: MOL.19980724.092																																																
Constant_Mass	Element tool tip	Constant_Mass = 2.2046 lbm																																																
Constant_Time	Element tool tip	Constant_Time = 1 hr																																																
Vector_Days	Element dialog, edit Vector	<table border="1"> <tr><td>Sun</td><td>1</td></tr> <tr><td>Mon</td><td>2</td></tr> <tr><td>Tues</td><td>3</td></tr> <tr><td>Wed</td><td>4</td></tr> <tr><td>Thur</td><td>5</td></tr> <tr><td>Fri</td><td>6</td></tr> <tr><td>Sat</td><td>7</td></tr> </table>	Sun	1	Mon	2	Tues	3	Wed	4	Thur	5	Fri	6	Sat	7																																		
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Tues	3																																																	
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Fri	6																																																	
Sat	7																																																	
Matrix_Days_X_Weeks	Element dialog, edit Matrix	<table border="1"> <thead> <tr> <th></th> <th>S</th> <th>M</th> <th>T</th> <th>W</th> <th>T</th> <th>F</th> <th>S</th> </tr> </thead> <tbody> <tr><td>w1</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>1</td><td>2</td></tr> <tr><td>w2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr> <tr><td>w3</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td></tr> <tr><td>w4</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td></tr> <tr><td>w5</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>1</td><td>2</td></tr> </tbody> </table>		S	M	T	W	T	F	S	w1	27	28	29	30	31	1	2	w2	3	4	5	6	7	8	9	w3	10	11	12	13	14	15	16	w4	17	18	19	20	21	22	23	w5	24	25	26	27	28	1	2
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w2	3	4	5	6	7	8	9																																											
w3	10	11	12	13	14	15	16																																											
w4	17	18	19	20	21	22	23																																											
w5	24	25	26	27	28	1	2																																											
Table_1D	Element properties	0 gal -40 F 1 gal 0 F 2 gal 32 F 3 gal 100 F																																																
Table_2D	Element properties	<table border="1"> <thead> <tr> <th></th> <th colspan="3">col</th> </tr> <tr> <th>row</th> <th>1 g</th> <th>2 g</th> <th>3 g</th> </tr> </thead> <tbody> <tr><td>1 ft</td><td>-10 C</td><td>10 C</td><td>100 C</td></tr> <tr><td>2 ft</td><td>-20 C</td><td>20 C</td><td>200 C</td></tr> <tr><td>3 ft</td><td>-30 C</td><td>30 C</td><td>300 C</td></tr> </tbody> </table>		col			row	1 g	2 g	3 g	1 ft	-10 C	10 C	100 C	2 ft	-20 C	20 C	200 C	3 ft	-30 C	30 C	300 C																												
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2 ft	-20 C	20 C	200 C																																															
3 ft	-30 C	30 C	300 C																																															
Uniform	Element dialog, edit distribution	min = 0 min max = 1000 min																																																
Uniform_Log	Element dialog, edit distribution	min = 1 hr max = 1000 hr																																																
Normal	Element dialog, edit distribution	mean = 100 mol/l st. dev. = 20 mol/l																																																
Normal_Truncated	Element dialog, edit distribution	mean = 100 mol/gal st. dev. = 20 mol/gal min = 60 mol/gal max = 140 mol/gal																																																
Normal_Log_geo	Element dialog, edit distribution	geometric mean = 89.4521 ft/day geometric st. dev. = 1.60381																																																
Normal_Log_trunc_geo	Element dialog, edit distribution	geometric mean = 89.4521 ft/day geometric st. dev. = 1.60381 min = 50 ft/day max = 150 ft/day																																																
Normal_Log_true	Element dialog, edit distribution	true mean = 100 m/s true st. dev. = 50 m/s																																																
Normal_Log_trunc_true	Element dialog, edit distribution	true mean = 100 m/s true st. dev. = 50 m/s																																																

**TABLE GS09a_DBAS_1 - Yucca
Mountain Database**

Tests Element	Result Type	Expected Values
		min = 50 m/s max = 150 m/s
Triangular	Element dialog, edit distribution	min = 10 acre most likely = 30 acre max = 100 acre
Triangular_Log	Element dialog, edit distribution	min = 10 ha most likely = 30 ha max = 100 ha
Cumulative	Element dialog, edit distribution	probability value 0 0 deg 0.1 10 deg 0.2 20 deg 0.3 30 deg 0.4 40 deg 0.5 50 deg 0.6 60 deg 0.7 70 deg 0.8 80 deg 1.0 100 deg
Discrete	Element dialog, edit distribution	probability value 0.1 $\pi/2 = 1.570796$ rad 0.2 $\pi = 3.141593$ rad 0.3 $3\pi/2 = 4.712389$ rad 0.4 $2\pi = 6.283185$ rad
Poisson	Element dialog, edit distribution	expected value = 25
Beta	Element dialog, edit distribution	mean = 40 gpm st. dev. = 20 gpm min = 0 gpm max = 100 gpm
Gamma	Element dialog, edit distribution	mean = 16 mg st. dev. = 8 mg
Gamma_Truncated	Element dialog, edit distribution	mean = 16 g st. dev. = 8 g min = 5 g max = 25 g
Weibull	Element dialog, edit distribution	min = 10 day Weibull slope = 2 mean-min = 8.8625 day
Weibull_Truncated	Element dialog, edit distribution	min = 10 a Weibull slope = 2 mean-min = 8.8625 a max = 25 a
Binomial	Element dialog, edit distribution	batch size = 100 probability = 0.25
Boolean	Element dialog, edit distribution	probability of true = 0.75
Student's t	Element dialog, edit distribution	degrees of freedom = 20
Exponential	Element dialog, edit distribution	Mean = 20 d

**TABLE GS09a_DBAS_1 - Yucca
Mountain Database**

Tests Element	Result Type	Expected Values
Pareto	Element dialog, edit distribution	a = 20, b = 5
Negative Binomial	Element dialog, edit distribution	number of successes = 10 probability of success = 0.5
Truncated Pareto	Element dialog, edit distribution	a = 10, b = 5 Maximum = 5.75\$
Beta (Success, Failures)	Element dialog, edit distribution	Number of successes = 5 Number of failures = 15
Extreme Value (Min)	Element dialog, edit distribution	Location = 20 gal Scale = 2 gal
Extreme Value (Max)	Element dialog, edit distribution	Location = 150 kg Scale = 10 kg
Extreme Probability (Min)	Element dialog, edit distribution	Number of samples = 5
Extreme Probability (Max)	Element dialog, edit distribution	Number of samples = 20
Pearson Type III	Element dialog, edit distribution	Location = \$50000 Scale = \$500 Shape = 2
Sampled Result	Element dialog, edit distribution	50 52 52 53 54
Sampled Result (Extrapolated)	Element dialog, edit distribution	95 100 105 120 130
Constant_Length_Fail	Element dialog, download status	download failed
Constant_Mass_Fail	Element dialog, download status	download failed
Matrix_Fail_Too_Many_Rows	Element dialog, download status	download failed
Matrix_Fail_Too_Many_Columns	Element dialog, download status	download failed
Vector_Fail_Too_Few_Rows	Element dialog, download status	download failed
Vector_Fail_Bad_Param_Code	Element dialog, download status	download failed
Normal_Fail_Units	Element dialog, download status	download failed
Normal_Fail_No_Units	Element dialog, download status	download failed
Table-1D_Units	Element dialog, download status	download failed
Table-2D_Units	Element dialog, download status	download failed

TABLE GS09a_2 - Simple Database

Test Element	Result Type	Expected Value
Data1	Element tool tip	Data1 = 105 Linked to: Simple GoldSim Database Status: Download Succeeded at (date/time of download)
Vector	Element dialog, edit vector	Sun 7
		Mon 6
		Tues 5
		Wed 4
		Thur 3
		Fri 2
		Sat 1
Matrix	Element dialog, edit matrix	W P P H
		A 6 5 4 3
		O 5 4 3 2
		P 4 3 2 1
Uniform_1	Element dialog, edit distribution	min = 25 max = 50
Uniform_Log_1	Element dialog, edit distribution	min = 0.01 m max = 1 m
Normal_1	Element dialog, edit distribution	mean = 25 st. dev. = 5
Normal_Truncated_1	Element dialog, edit distribution	mean = 100 \$ st. dev. = 20 \$ min = 60 \$ max = 140 \$
Normal_Log_geo_1	Element dialog, edit distribution	geometric mean = 89ft geometric st. dev. = 1.6
Normal_Log_trunc_geo_1	Element dialog, edit distribution	geometric mean = 89 geometric st. dev. = 2 min = 80 max = 150
Normal_Log_true_1	Element dialog, edit distribution	true mean = 100 true st. dev. = 50
Normal_Log_trunc_true_1	Element dialog, edit distribution	true mean = 100 true st. dev. = 50 min = 50 max = 150
Triangular_1	Element dialog, edit distribution	min = 10 most likely = 30 max = 100
Triangular_Log_1	Element dialog, edit distribution	min = 10 most likely = 30 max = 100
Cumulative_1	Element dialog, edit distribution	probability value 0 0 0.2 1 0.3 7 1.0 8
Discrete_1	Element dialog, edit distribution	probability value 0.1 1

		0.4 2 0.5 3
Poisson_1	Element dialog, edit distribution	expected value = 40
Beta_1	Element dialog, edit distribution	mean = 40 st. dev. = 20 min = 0 max = 100
Gamma_1	Element dialog, edit distribution	mean = 16 st. dev. = 8
Gamma_Truncated_1	Element dialog, edit distribution	mean = 16 st. dev. = 8 min = 5 max = 25
Weibull_1	Element dialog, edit distribution	min = 10 Weibull slope = 2 mean-min = 8
Weibull_Truncated_1	Element dialog, edit distribution	min = 10 Weibull slope = 2 mean-min = 8 max = 25
Binomial_1	Element dialog, edit distribution	batch size = 60 probability = 0.25
Boolean_1	Element dialog, edit distribution	probability of true = 0.75
Student's t	Element dialog, edit distribution	degrees of freedom = 15
Exponential	Element dialog, edit distribution	Mean = 30 d
Pareto	Element dialog, edit distribution	a = 30, b = 10
Negative Binomial	Element dialog, edit distribution	number of successes = 15 probability of success = 0.6
Truncated Pareto	Element dialog, edit distribution	a = 30, b = 10 Maximum = 12
Beta (Success, Failures)	Element dialog, edit distribution	Number of successes = 12 Number of failures = 35
Extreme Value (Min)	Element dialog, edit distribution	Location = 10 kg Scale = 1kg
Extreme Value (Max)	Element dialog, edit distribution	Location = 30 gal Scale = 3 gal
Extreme Probability (Min)	Element dialog, edit distribution	Number of samples = 25
Extreme Probability (Max)	Element dialog, edit distribution	Number of samples = 100
Pearson Type III	Element dialog, edit distribution	Location = \$1000 Scale = \$250 Shape = 2
Sampled Result	Element dialog, edit distribution	10 12 12 10 11
Sampled Result (Extrapolated)	Element dialog, edit distribution	201 203 210

		215
Vector_Row_Num_too_Big	Element dialog, download status	download failed
Vector_Col_Num_too_Big	Element dialog, download status	download failed
Vector_Too_Many_Records	Element dialog, download status	download failed
Vector_Not_Enough_Records	Element dialog, download status	download failed
Vector_Parm_Arg_Mismatch	Element dialog, download status	download failed
Vector_Zero_Entry	Element dialog, download status	download failed
Matrix_No_Records_In_AVT	Element dialog, download status	download failed
Constant_Length_Fail_1	Element dialog, download status	download failed
Constant_Mass_Fail_1	Element dialog, download status	download failed
Normal_Fail_Units_1	Element dialog, download status	download failed
Normal_Fail_No_Units_1	Element dialog, download status	download failed

Table GS09a_3 - Generic Database

Test Element	Result Type	Expected Value
Constant_Generic_Volume	Element tool tip	Constant_Generic_Volume = 264 gal
Constant_Generic_Mass	Element tool tip	Constant_Generic_Mass = 1000 g
Constant_Generic_Time	Element tool tip	Constant_Generic_Time = 60 min

GS09b_Dbas: Database Links/Downloading - Global Download

Linking and downloading from the Yucca Mountain, Simple, and Generic databases are verified by setting up a model with elements prepared for download execution.

1. Save GS09a_DBAS.gsm and then save it again as GS09b_DBAS.gsm.
2. This test also uses the ODBC connections as those used in GS09a.
3. Press the global download button labeled "DB" in the toolbar and click "OK" to use the default date shown in the control.
4. A Run Log should appear that displays 21 warnings. These warnings should only appear for the elements that were set up for failure.
5. Compare the downloaded elements against the results presented in Tables GS09a_DBAS_1, GS09a_DBAS_2, and GS09a_DBAS_3 to verify linking to a Yucca Mountain, Simple, and Generic database.
6. Press the global download button again and check the box to set a specific date. Change the date to "2/25/99" and click "OK".

7. A Run Log should appear that displays 21 warnings. These warnings should only appear for the elements that were set up for failure.
8. Compare the downloaded elements linked to the Yucca Mountain database against the results presented in Table GS09b_1.

Table GS09b_1 - Yucca Mountain Database, 2/25/99 Effective Date

Test Element	Result Type	Expected Value							
Constant_Length	Element tool tip	Constant_Length = 6.56ft							
Constant_Mass	Element tool tip	Constant_Mass = 4.4092 lbm							
Constant_Time	Element tool tip	Constant_Time = 2 hr							
Vector_Days	Element dialog, edit Vector	Sun	7						
		Mon	6						
		Tues	5						
		Wed	4						
		Thur	3						
		Fri	2						
		Sat	1						
Matrix_Days_X_Weeks	Element dialog, edit Matrix		<i>S</i>	<i>M</i>	<i>T</i>	<i>W</i>	<i>T</i>	<i>F</i>	<i>S</i>
		w1	1	2	3	4	5	6	7
		w2	8	9	10	11	12	13	14
		w3	15	16	17	18	19	20	21
		w4	22	23	24	25	26	27	28
		w5	29	30	31	32	33	34	35
Table_1D	Element properties	0gal -40F 1gal -0F 2gal 32F 3gal 100F							
Table_2D	Element properties	Col row 1g 2g 3g 1ft -10C 10C 100C 2ft -20C 20C 200C 3ft -30C 30C 300C							
Uniform	Element dialog, edit distribution	min = 0min max = 1000min							
Uniform_Log	Element dialog, edit distribution	min = 2hr max = 2000hr							
Normal	Element dialog, edit distribution	mean = 200mol/l st. dev. = 40mol/l							
Normal_Truncated	Element dialog, edit distribution	mean = 200mol/gal st. dev. = 40mol/gal min = 120mol/gal max = 280mol/gal							
Normal_Log_geo	Element dialog, edit distribution	geometric mean = 178.90419ft/day geometric st. dev. = 3.20762							
Normal_Log_trunc_geo	Element dialog, edit distribution	geometric mean = 178.90419ft/day geometric st. dev. = 3.20762							

		min = 100ft/day max = 300ft/day
Normal_Log_true	Element dialog, edit distribution	true mean = 200m/s true st. dev. = 100m/s
Normal_Log_trunc_true	Element dialog, edit distribution	true mean = 200m/s true st. dev. = 100m/s min = 50m/s max = 150m/s
Triangular	Element dialog, edit distribution	min = 20acre most likely = 60acre max = 200acre
Triangular_Log	Element dialog, edit distribution	min = 20ha most likely = 60ha max = 200ha
Cumulative	Element dialog, edit distribution	probability value 0 0deg 0.1 10deg 0.2 20deg 0.3 30deg 0.4 40deg 0.5 50deg 0.6 60deg 0.7 70deg 0.8 80deg 1.0 100deg
Discrete	Element dialog, edit distribution	probability value 0.1 $\pi = 3.141593\text{rad}$ 0.2 $3\pi/2 = 4.712389\text{rad}$ 0.3 $2\pi = 6.283185\text{rad}$ 0.4 $4\pi = 12.566\text{rad}$
Poisson	Element dialog, edit distribution	Expected value = 50
Beta	Element dialog, edit distribution	mean = 80gpm st. dev. = 40gpm min = 0gpm max = 200gpm
Gamma	Element dialog, edit distribution	mean = 32mg st. dev. = 16mg
Gamma_Truncated	Element dialog, edit distribution	mean = 32g st. dev. = 16g min = 10g max = 50g
Weibull	Element dialog, edit distribution	min = 20day Weibull slope = 2 mean-min = 17.7250029day
Weibull_Truncated	Element dialog, edit distribution	min = 20a Weibull slope = 2 mean-min = 17.72499a max = 50a
Binomial	Element dialog, edit distribution	batch size = 200 probability = 0.5

Boolean	Element dialog, edit distribution	probability of true = 0.80
Student's t	Element dialog, edit distribution	degrees of freedom = 10
Exponential	Element dialog, edit distribution	Mean = 35 d
Pareto	Element dialog, edit distribution	a = 15, b = 7
Negative Binomial	Element dialog, edit distribution	number of successes = 20 probability of success = 0.8
Truncated Pareto	Element dialog, edit distribution	a = 5, b = 15\$ Maximum = 17\$
Beta (Success, Failures)	Element dialog, edit distribution	Number of successes = 28 Number of failures = 46
Extreme Value (Min)	Element dialog, edit distribution	Location = 50 gal Scale = 3 gal
Extreme Value (Max)	Element dialog, edit distribution	Location = 190 kg Scale = 13 kg
Extreme Probability (Min)	Element dialog, edit distribution	Number of samples = 20
Extreme Probability (Max)	Element dialog, edit distribution	Number of samples = 5
Pearson Type III	Element dialog, edit distribution	Location = \$200000 Scale = \$10000 Shape = 5
Sampled Result	Element dialog, edit distribution	100 105 108 108 110
Sampled Result (Extrapolated)	Element dialog, edit distribution	200 220 250 260 270

GS09c_File Element: Finding Local Files for File Elements

This file tests the ability of the File Element to locate a local text file and to download a file defined in a Yucca database. Open File. Ensure that the local file "FileHere.txt" is in the test folder. Next, click on the "Database" button, then click again to deactivate it. This will cause the element to search for the specified local file name. Ensure that "FileHere.txt" is still found (i.e., the message "Local File" shows up Status box).

Then delete FileHere.txt, connect to the Yucca test database, and download. Confirm that a file is downloaded to the current directory, with the local file name that you specified.

Next, turn off the download and delete FileNotHere.txt from your folder if it exists. Open File_Failed and ensure that "Local file missing" is the message reported (the file that File_Failed is trying to find in fact does not exist locally).

Finally, try to download File_Failed from the database. The download should fail because the database does not contain a CRC code for the file. However, a copy of the file should be placed into your folder.

GS10_Clone1: Basic Clone Tests

This file contains a number of tests to verify the proper performance of cloned elements in GoldSim. The test consists of two major parts.

1. Cloning of elements: Cloned elements in GoldSim are verified by setting up a model with 5 containers holding every possible element that can be cloned. The container “Container_Basic_Element_Clones” holds clones of basic elements side by side. To verify the clone characteristics of basic elements, the user changes the value and parameters in one clone and checks that the other clone element is updated to the changed parameters. The element description, notes, and Save Results options are not cloned. The Script element is not allowed to be cloned. To test the Script element, try cloning the Test_Script_Element container. Then go into the Test_Script_Element container, and try cloning the Script element. In both cases you should receive an error message. The user does not need to run the model.

Stochastic clones are stored in a separate container “Container_Stochastic_Clones”. Each type of stochastic distribution is present in this container, along with elements intended to exercise the advanced stochastic features such as correlation and importance sampling.

A third container “Container_Numerous_Clones” holds 57 clones of a data element. To verify the clone characteristics of multiple clones of the same element the user changes the value of any one of the elements and checks that the current value of all the clones has updated to the new value. The user does not need to run the model.

The environment clone elements are held in the containers “Container_Enviro_Element_Clon1” and “Container_Enviro_Element_Clon2”. To verify the clone characteristics of environmental element clones the user changes the parameters of any one element in “Container_Enviro_Element_Clon2” and checks that the parameters are updated in the clone element in “Container_Enviro_Element_Clon1”. The user does not need to run the model.

2. Sealing of cloned containers: This test verifies that sealing of cloned containers works properly. In this container, Container5_1 is the clone of Container5. To perform the test, proceed as follows (first, ensure that all containers inside Container1 are neither locked nor sealed):

1. Seal Container5 (path: \C1\C2\C5). Ensure that the clone, Container5_1, has also been sealed as a result of sealing C5. Containers \C5\C6 and \C5_1\C6 should also now be sealed (e.g., look at the containers' tooltip windows or in the main browser to confirm the sealed status).
2. Remove (don't break) the seal on Container5, and ensure the seal on Container5_1 is also removed as a result. Containers \C5\C6 and \C5_1\C6 should still be sealed.
3. Re-seal Container5. Next, break the seal on Container5 by changing the input value for the element Data1 inside Container5. Ensure that the seal for Container5_1 is also broken. However, the seals for containers \C5\C6 and \C5_1\C6 should still be intact.

4. Lock Container5. Container5_1 and all of the contents of Containers5 and 5_1 should now be locked (as evidenced by their names being grayed out in the main browser window and the unavailability of menu and toolbar options inside the locked elements.
 5. Unlock Container5, then seal Container1. Try to clone an element that resides inside Container5. Cloning should not be allowed without breaking the seal. Repeat for a locked Container1. Unlock Container1, Container2, and Container5.
 6. Seal Container5. Try to change the input value, type, display units, results flags and database links for Data1_Clone. None of these changes should be allowed without breaking the seal. Repeat for a locked Container5.
3. Database Linked Clones: This test verifies cloning of elements linked to a database works properly. The side by side elements are clones. To perform the test, proceed as follows: Open the original element (left-hand or top element of the pairs) and download from the Yucca Mountain Database (Use the same database connection that was required to perform GS09_DBAS). Open the clone element and check that the parameters match the values of the original element. This applies to elements "Constant Length", "Normal", "Table_1D", and "Table_2D" in "Container_DBAS_Linked_Clones".

GS11_Clone2: Cloned Containers and Models

This file contains two simple tests of container-cloning functionality:

1. Dam_System_A describes the occurrence and consequences of a dam break for one dam in a site system. The container and all of its elements are all original (not cloned). Dam_System_A_1 is a clone of Dam_System_A and should show the same average results, since both share identical inputs. Dam_System_A_1_1 is a clone of Dam_System_A_1. Run the model to see results. Expected results are shown in the tool-tip window for the integrator element within each container, and are also shown in Table GS11_1. Note that the results for these cloned containers will not be identical because cloned stochastics are sampled independently.
2. Dam_System_A_2 is a clone of Dam_System_A, but A_2 uses a different rate of occurrence for dam breaks. Expected results are shown in the tool-tip window for the integrator element within each container, and are also shown in Table GS11_1.

Table GS11_1

Elements Tested	Test	Expected Output / Result
Dam_System_A, A_1, A_1_1	1	Expected result is a Cum_Flood_DamBreak between 10,000 and 20,000 m3 over 10 dam breaks (range in possible results is due to stochastic element used in the model)
Dam_System_A_2	2	Expected result is a Cum_Flood_DamBreak

		between 5,000 and 10,000 m3 over 5 dam breaks
--	--	--------------------------------------------------

3. Copying and Moving Tests:

- a) Copy container A11 and ensure that the copy is not a clone by changing the properties of a number of elements inside the copied container, and rerunning the model – results in the Dam_System_A_1_1 container should not change.
- b) Delete the copied container and place container A1 and A11 inside a new container (call it Original).
- c) Make changes to Dam_System_A, and ensure these changes are reflected in the clones inside the Original container. Now copy the Original container and paste it (call it Copied).
- d) In the Copied container, Dam_System_A_1 and Dam_System_A_1_1 should still be clones. Confirm this by making a number of changes to one of the cloned Dam_System containers. Ensure these changes are reflected in the other cloned container within the Copied container, but not in Dam_System_A or the Dam_System containers inside the Original container.

GS11b_SubSystem_Cloning

This test verifies that cloning works properly for Conditional, Internal Clock and Looping Containers.

To run the test, clone each of the Submodels and run the model. The verifier should then ensure that the results within both containers correspond with the expected results below (also pasted to the left of each container in the model).

Conditional Container: The container is activated at 20s and deactivated at 80s. It contains an Integrator element whose value increases by 1s/s. Therefore, the Integrator element inside the original and cloned Submodel should have a value of 60s.

Internal Clock Submodel: The container has a Timed Event that occurs four times per second, and a Triggered Event that is triggered each time the clock changes. Events cannot occur between timesteps inside the Submodel, and the minimum timestep length is 0.5s. Therefore, the TriggeredEvent element inside the original and cloned Submodel should have a value of 201.

Looping Container: A function element inside the looping container is equal to the current value of local.LoopCount. The container loops until the value of local.LoopCount is 50. Therefore, in Time History view, the Function element inside the original and cloned Submodel should have a constant value of 50.

GS12_External: External Functions

This test verifies the correct functioning of the External element for Value and Condition type outputs (time series and table definition types are tested in GS29_External2).

The verifier should first enter the Value container. External function elements in GoldSim are verified by calling the external function “XF004”. The function returns the sum and product of two input values. To call the external function the user must map the path to the file “cfstubs.dll” in the element dialog. To verify the external function capability of GoldSim the user must change the element inputs to 5 and 10 in the element dialog, run the model and check that outputs “sum” = 15 and “product” = 50. The outputs can be checked by opening the element in the left-hand

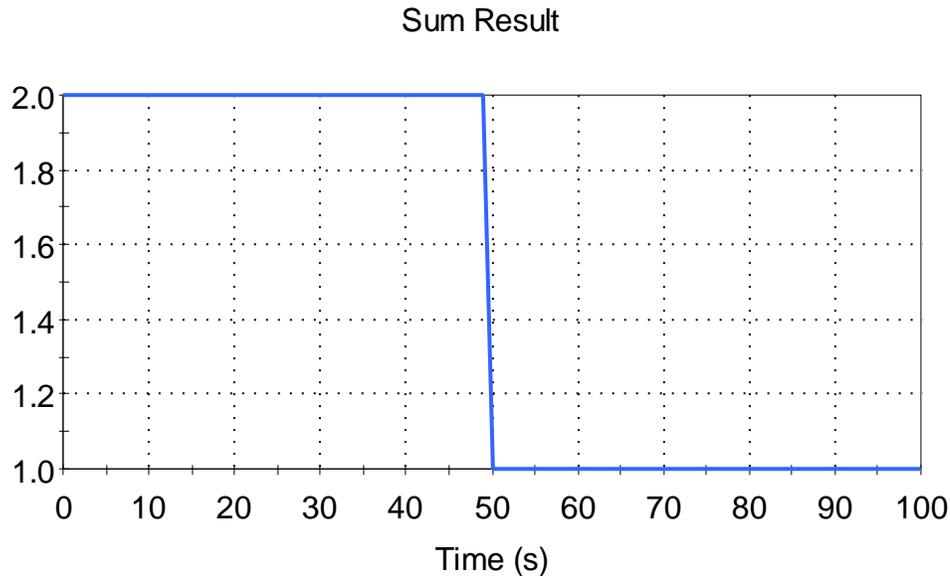
browser and pointing to the outputs sum and product. The outputs can also be checked by clicking on the green diamond on the right-hand side of the “External” element.

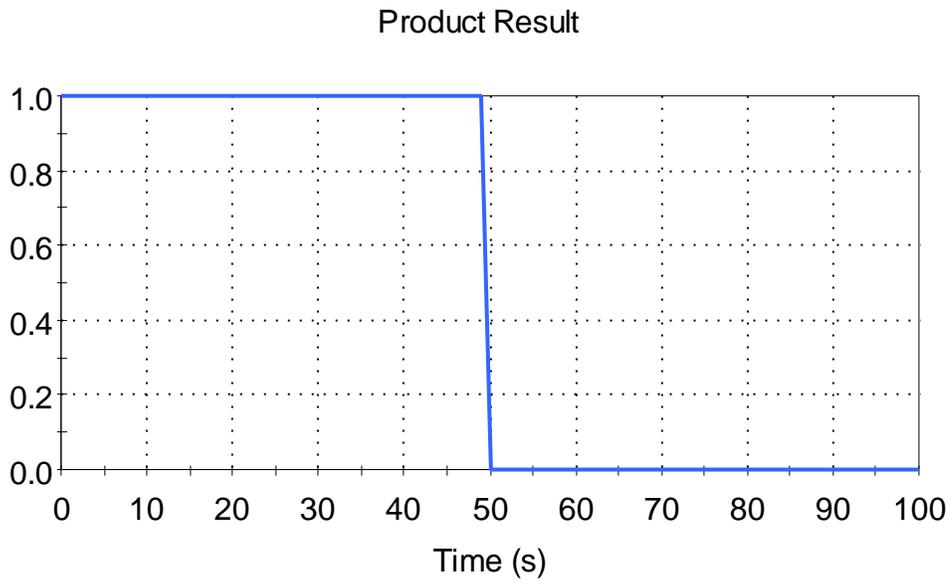
In order to test the ability for a DLL to return an error message, change the value of the first input to the external to 99, and rerun. You should see an error message indicating that a value of 99 was used.

Repeat both tests with the ‘Run in Separate Process’ check-box checked.

The verifier should then enter the Condition container. Again the External function element uses the cfstubs.dll and the XF004 external function, but this time a conditional value (True_Then_False) is passed as the first argument, and a value of 1 is passed as the second argument. The External element is also modified so that the Product result is returned as a condition (a value of 1 equals true, and 0 equals false). The conditional argument is treated as a 1 when true and a 0 when false.

Expected results for the two Time History elements are as follows:





Repeat both tests in the \Conditional container with the 'Run in Separate Process' check-box checked.

The test should be repeated in its entirety a second time with a 64-bit version of the test file and DLL (GS12_External64.gsm and cfstubs64.dll).

GS12b_External_Options

This test verifies the proper functioning of the Unload and Cleanup options in the External element. The test DLL that is used provides a pop-up dialog that informs the user when it is opened, called, and cleaned up.

The verifier should start the test with the Unload and Cleanup options turned off. The model should then be run. The DLL should be called and cleaned up when the tester brings up the run controller. It should be called and cleaned up again when the model is run. The DLL should then be opened and called 4 times.

The Unload option should then be enabled and the model run. Again the DLL should be called (but not calculated) when the run controller is opened and the model is run. It should then then be loaded/unloaded/calculated 4 times.

The Unload option should then be cleared and the Cleanup option checked. The DLL should be called and cleaned up when the run controller is opened and the model run. The DLL should be called twice per realization and then unloaded at the end of each realization.

This test should be repeated with a 64-bit version of the test DLL (GS12b_External_Options64.gsm and GSCoreTestDLL64.dll).

GS13_Sum: Sum Elements

This file contains all of the tests for the Sum Element. Tests include the following:

1. scalar + scalar
2. vector + vector (scalar vector elements; vector dimension is 1 x 4)

3. matrix + matrix (scalar matrix elements; 4 x 3 matrices)
4. vector + vector (time-variable vector elements; vector dimension is 1 x 4)
5. sum of five vectors (vector dimension is 1 x 4)
6. matrix + matrix (time-variable matrix elements; 4 x 3 matrices)

The model must be run to calculate results. Expected results are shown in the tooltip window for each Sum Element or in tables in the file. Expected results are also shown in Table GS13_1.

Table GS13_1

Element being tested	Test	Expected Output / Result
Scalar_Scalar	1	7
Vector_Vector	2	{2 0 6 0}
Matrix_Matrix	3	{2 0 6}, {4 0 8}, {6 0 10} and {8 0 12} for rows 1, 2, 3, and 4 respectively
Vector_Vector_from_expressions	4	{7 10 15 16}
Multiple_vectors	5	{14 15 26 21}
Matrix_Matrix_from_expressions	6	{4 0 6}, {10 0 8}, {20 0 10} and {22 0 12} for rows 1, 2, 3, and 4 respectively

GS14_Extrema: Extrema Elements

This file contains all of the tests for the Extrema Element. The file makes use of four time-dependent expressions (each is a different time-varying function). The following tests are conducted:

Basic Tests (up to a specified time of 100 days)

1. Maximum value of a function
2. Minimum value of a function
3. Vector of maximum values from a vector of time-varying functions (vector dimension is 1 x 4)
4. Vector of minimum values from a vector of time-varying functions vector dimension is 1 x 4)
5. Matrix of maximum values from a matrix of time-varying functions (matrix dimension is 2 x 2)
6. Matrix of minimum values from a matrix of time-varying functions (matrix dimension is 2 x 2)
7. ETime at which maximum/minimum value occurs

The model must be run to calculate results. Expected results are shown in a table located in the file, and are shown in Table GS14_1.

Table GS14_1

Element being tested:	Test	Expected Result / Output
X_max	1	0.992

X_min	2	-0.969
Vector_of_maxes	3	{0.992, 0.866, 0.992, 1}
Vector_of_mins	4	{-0.969, -0.901, -0.969, 0}
Matrix_of_maxes	5	0.992 0.992 0.866 1
Matrix_of_mins	6	-0.969 -0.969 -0.901 0
Time_of_Max (for X)	7	53.9 days
Time_of_Min (for X)	7	42.1 days

GS15_Logical: Logic Elements

This file contains all of the tests for the Logic Elements (AND, OR, NOT). The test makes use of condition-type Data Elements X, Y, and Z, and condition-type Selector Element A. Tests include the following:

1. X AND Y
2. X AND Y AND Z
3. X OR Y
4. X OR Y OR Z
5. X AND A
6. X OR A
7. NOT X
8. NOT A
9. NOT(X OR Y OR Z)
10. NOT(X AND A)

The model must be run to see time-dependent results. Expected results are found in a table located in the file, and are presented in Table GS15_1.

Table GS15_1

Element being tested	Test	Expected Output / Result
And_X_Y	1	TRUE (value of 1)
And_X_Y_Z	2	FALSE (value of 0)
Or_X_Y	3	TRUE
Or_X_Y_Z	4	TRUE
And_X_A	5	FALSE for time <= 50 days; TRUE for time > 50 days
Or_X_A	6	TRUE for all times
Not_X	7	False
Not_A	8	TRUE for time <= 50 days; FALSE for time > 50 days
Not_Or	9	False
Not_And	10	TRUE for time <= 50 days; FALSE for time > 50 days

GS16_Delay: Delay Elements

This test requires the use of two test files, GS16a_Delays - Event and Discrete Change.gsm and GS16b_Information and Material Delays.gsm. The tests verify that Delays function properly by testing inputs, outputs, dispersion, and delay times.

GS16a_Delays - Event and Discrete Change:

This file contains tests for the Event Delay and the Discrete Change Delay. The verifier should run the model and then proceed through the tests below.

1. Enter the Erlang_Dispersion container. In this container, there are a number of event and discrete change delays with different Erlang dispersions ($n = 1, 10$ and 100). Verify that the Event_Delay_Erlang and Discrete_Change_Delay_Erlang result element graphs correspond with the graphs pasted inside the container, and in figure GS16_01 and GS16_02 below.

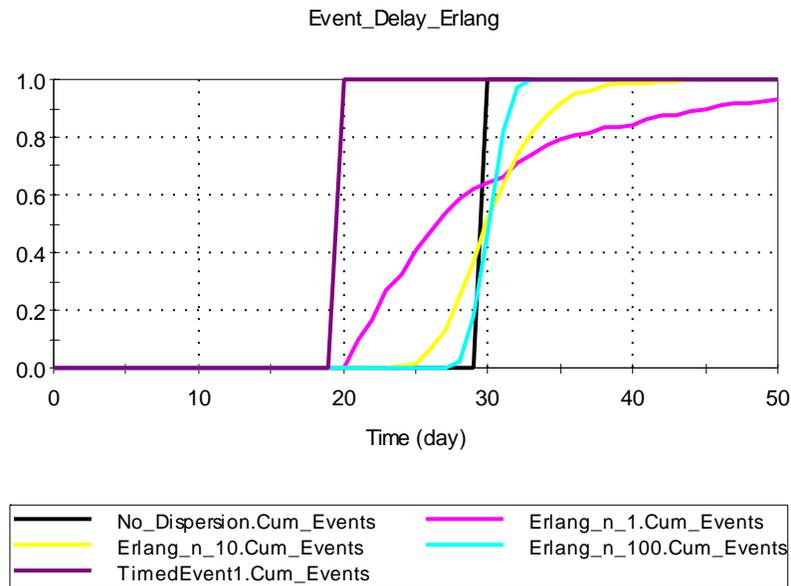


Figure GS16_01

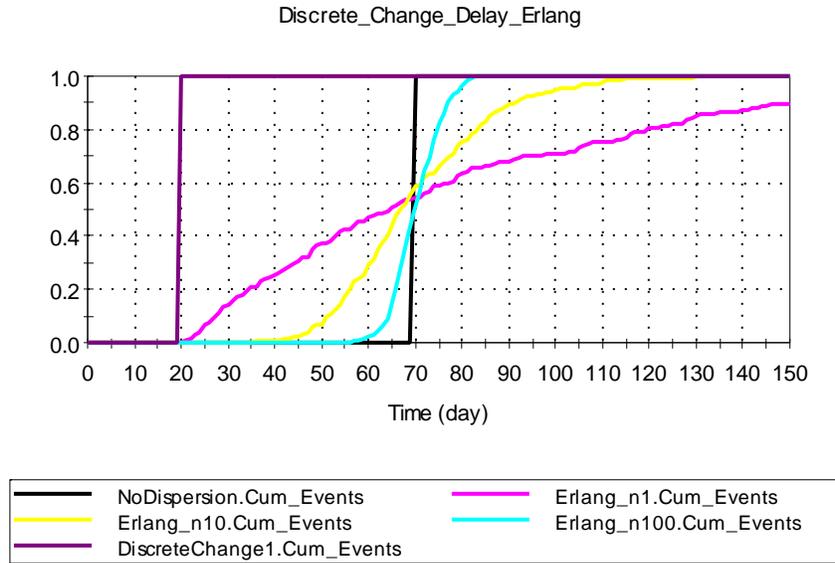


Figure GS16_02

2. Enter the Erlang_Dispersion_1 container. This container tests that conveyor and non-conveyor behavior both work correctly. In this test, the mean delay time is reduced to zero after the timed event enters the delay at 20d. This means that the conveyor delay should emit the event at 20d, while the non-conveyor element is not affected (and is emitted after a 10d delay with an Erlang dispersion with an n value of 1). Compare the output for Event_Delay_Erlang and DC_Delay_Erlang to their expected outputs in Figure GS16_03 and GS16_03b below (also reproduced in the model).

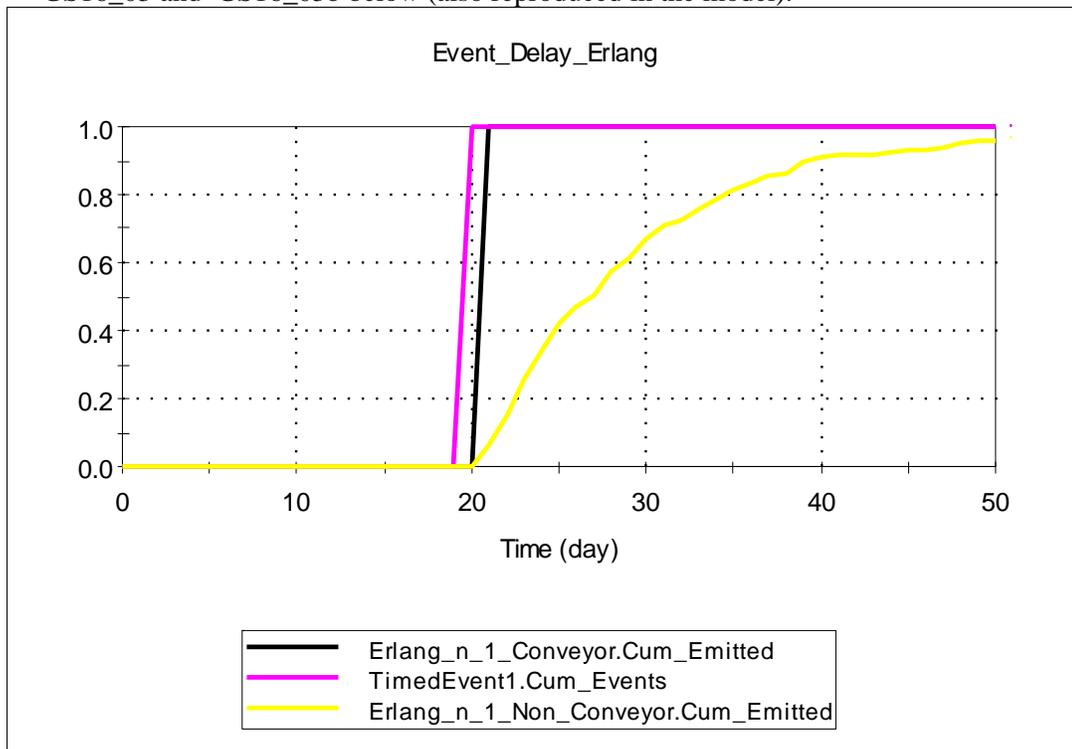


Figure GS16_03

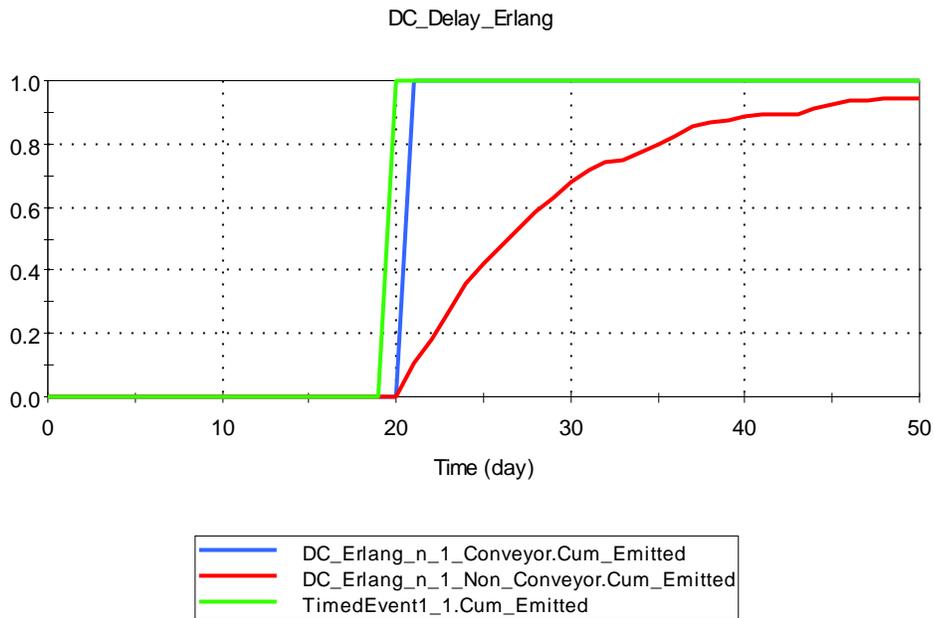


Figure GS16_03b

3. Enter the Std_Dev_Dispersion container. In this container, there are a number of event and discrete change delays with different standard deviation dispersions (S.D. = 0, the delay, one half of the delay). Verify that the Event_Delay_Erlang and Discrete_Change_Delay_Erlang result element graphs correspond with the graphs pasted inside the container, and in figure GS16_04 and GS16_05 below.

4.

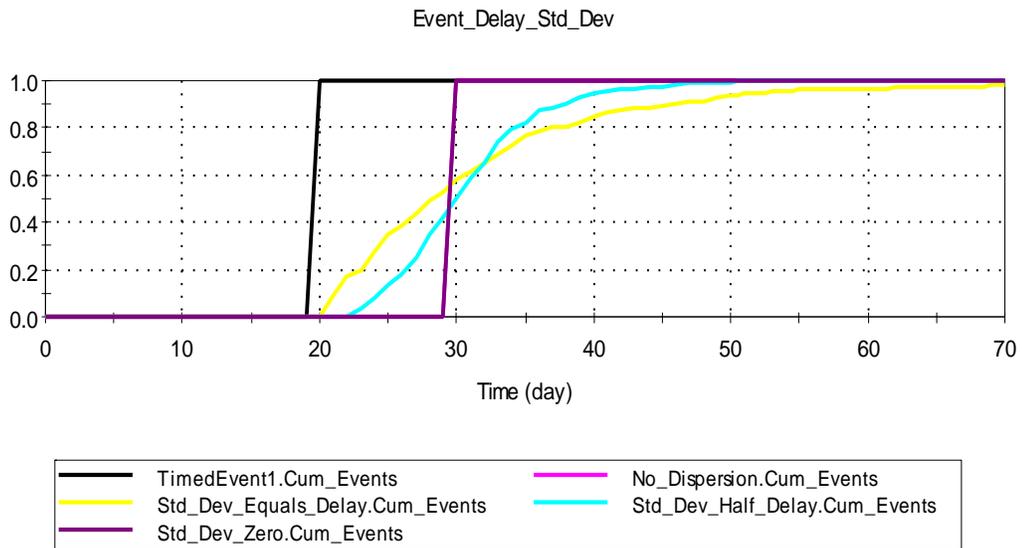


Figure GS16_04

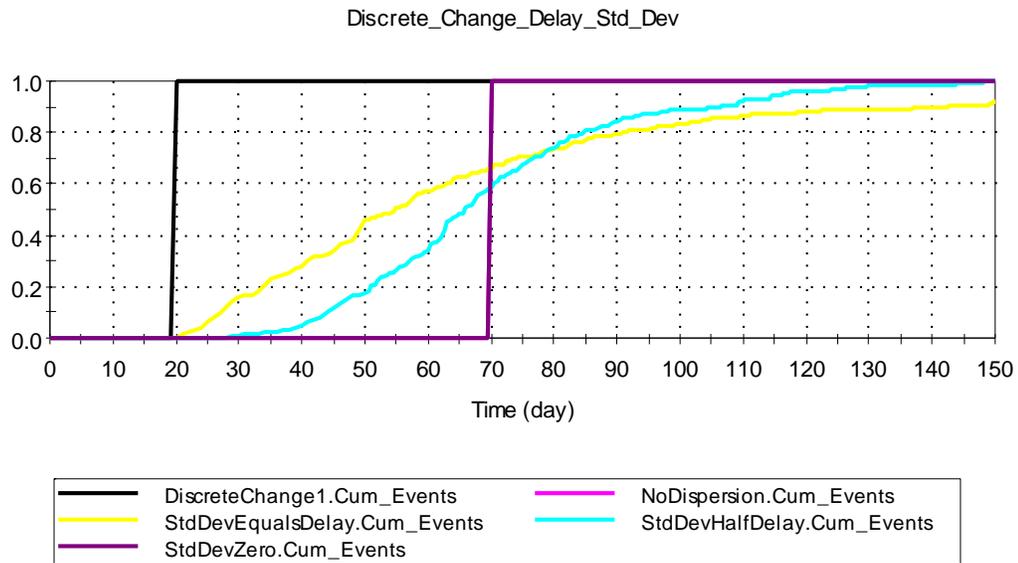


Figure GS16_05

5. Enter the Std_Dev_Dispersion_1 container. This container tests that conveyor and non-conveyor behavior both work correctly. In this test, the mean delay time is reduced to zero after the timed event enters the delay at 20d. This means that the conveyor delay should emit the event at 20d, while the non-conveyor element is not affected (and is emitted after a 10d delay with an Standard Deviation dispersion equal to half the delay (5d)). Compare the output for Event_Delay_Std_Dev and DC_Delay_Std_Dev to their expected output in Figure GS16_06 and GS16_06b below (also reproduced in the model).

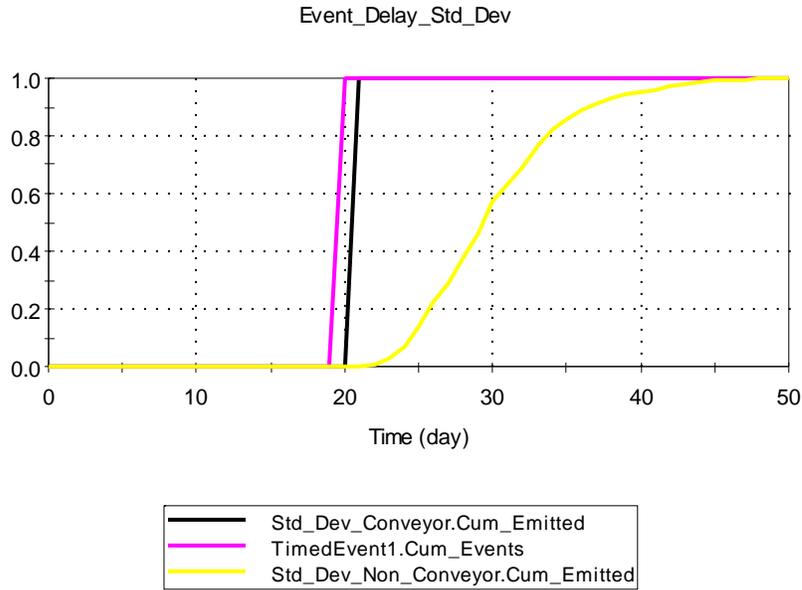


Figure GS16_06

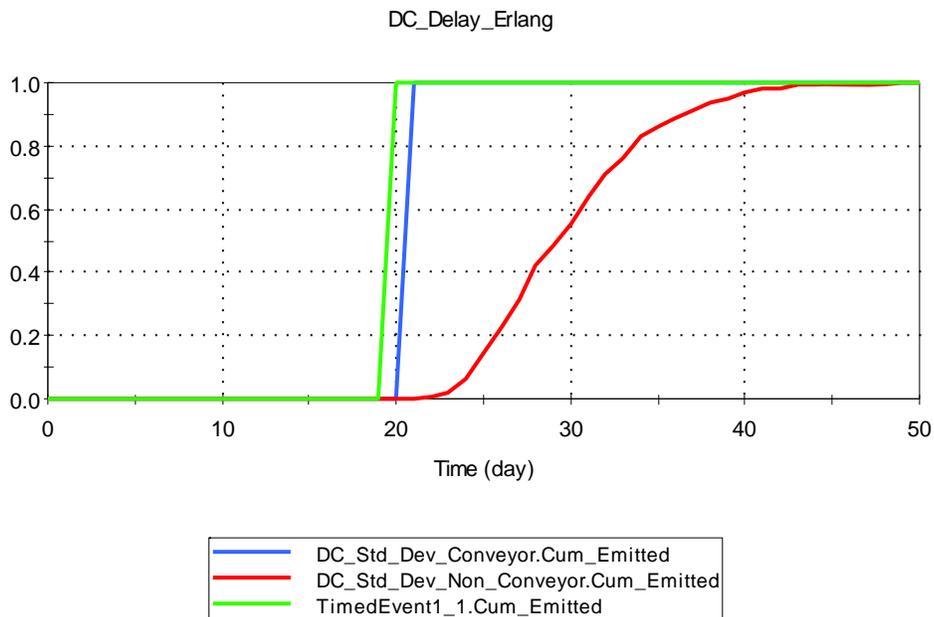


Figure GS16_06b

6. Enter the Variable_Delay_Time container. Confirm that the Conveyor element emits its first event at 25d (admitted at 10d, delay increased from 10 to 20d at 15d), and its second event at 35d (admitted at 15d, 20 d delay) and that the Non-Conveyor element releases its first event at 20d, and its second at 35d. Confirm that the initial discrete change is delayed by 15 days, and the second by 20 days (the first discrete change enters when the delay time is 10 days, and is halfway through the delay when the delay jumps to 20 days).

7. Enter the Zero_Delay_Time container. Confirm that both the Event and Discrete Change delays emit a single event at 10 days and three events at 15 days.
8. Enter the Stochastic container. This test generates an event within the Event_Delay1 element at the start of the simulation and delays it by a period determined by sampling the Normal(125,25) distribution. A second event is issued by TimedEvent1 at time = 100 days to ensure that the Event_Delay does not exhibit conveyor behaviour.

A successful test is indicated by the 5%/95% confidence bounds in the Result Array in the Milestone_Time CDF including the following values for the given percentiles:

5th percentile: 83.9 days
 25th percentile: 108.1 days
 50th percentile: 125 days
 75th percentile: 141.9 days
 95th percentile: 166.1 days

9. Enter the Statistics container. Confirm that the mean for the Milestone_Time approximately equals 30 days (i.e., the input delay time + time for TimedEvent1 to fire) and that the standard deviation of Milestone_Time approximately equals 5 days (i.e., the dispersion (standard deviation) for the delay).
10. Enter the Queueing_Behavior container. Perform the following checks:
 - a. Compare the tabular history for the following outputs of Simple_Queue:
 - i. Cum_Emitted = 0 for $t < 6$; 1 for $t = 6$; 2 for $7 \leq t \leq 10$
 - ii. Num_in_Transit = 0 for $t = 0$; 1 for $t = 1$; 2 for $t > 1$
 - iii. Num_in_Queue = 0 for $t < 3$; 1 for $t = 3$; 2 for $t = 4$; 3 for $5 \leq t \leq 7$
 - b. Compare the tabular history for the following outputs of Simple_Queue_DC:
 - i. Cum_Emitted = 0 for $t < 6$; 1 for $t = 6$; 2 for $7 \leq t \leq 10$
 - ii. Num_in_Transit = 0 for $t = 0$; 1 for $t = 1$; 2 for $t > 1$
 - iii. Num_in_Queue = 0 for $t < 3$; 1 for $t = 3$; 2 for $t = 4$; 3 for $5 \leq t \leq 7$
 - c. Compare the tabular history for the following outputs of Variable_Num_in_Transit and Variable_Num_in_Transit_DC:
 - i. Capacity increases to 125 at 125 days, then decreases back to 0.
 - ii. Num_in_Transit should grow to 125, then decline by 1 per day starting at 200 days
 - iii. Num_in_Queue decreases to 25 and remains there until the end of the simulation.
 - d. Compare the ServiceTimeResults plot to Figure GS16_7 below.

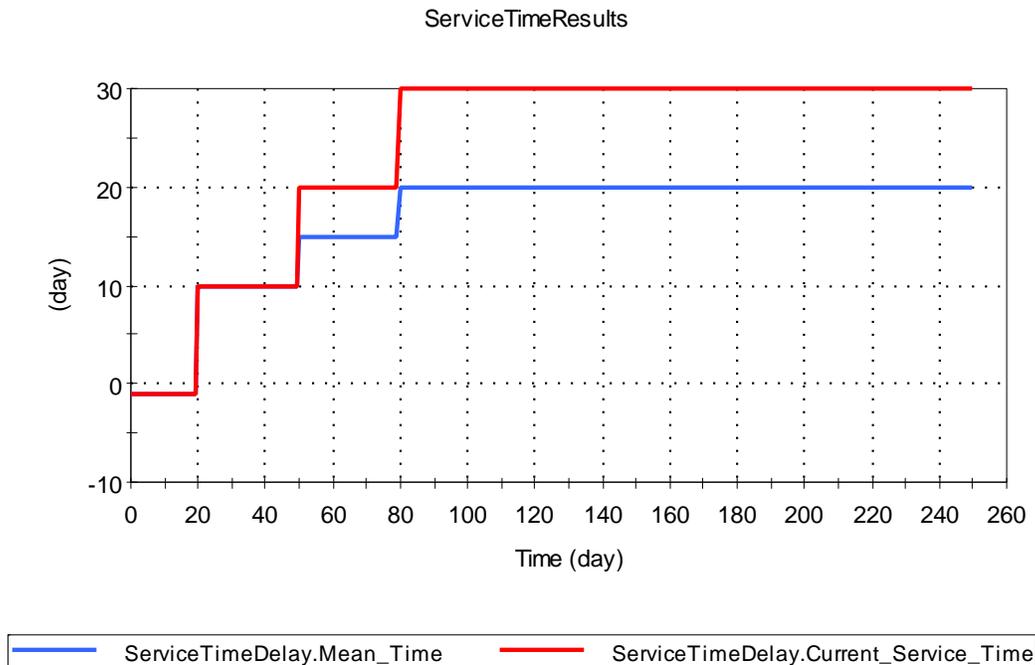


Figure GS16_7

11. Enter the Multiple_Inputs_Event_Delay container. Using Cum_Events, Confirm that Event_Count and Delay_Count end up with the same values (Delay_Count should lag Event_Count by 10 days; the 'value' is the total number of event outputs).
12. Enter the Multiple_Inputs_DiscreteChange container. Using the Cum_Events Result element, confirm that Event_Count and Delay_Count end up with the same values (Delay_Count should lag Event_Count by 10 days; the 'value' is the total number of event outputs). Using High_Dispersion, confirm that the sequence of discrete changes comes out dispersed and in random order (view the probability history to see this).
13. Enter the DC_Amount_Prop container. This container tests that the ~DC_Amount available property functions correctly. A discrete change is triggered at time zero and samples a distribution for its amount. The delay time in the Discrete Change Delay is equal to 1d/kg of material in the discrete change.

The discrete change triggers a Milestone when it exits the delay. The time to emerge can be compared to the sampled value and checked to ensure the available property is functioning correctly. This is done in the Check element.

The property is operating correctly if the value of the Check element in Result Mode is less than 1E-6 for all realizations.

GS16b_Information and Material Delays:

This file contains tests for the Information Delay and Material Delay. Expected results are described in the test Containers. This test requires running the model twice:

1. In Simulation Settings, set the model to have all timesteps the same length. Run the model. and compare output to the expected results.
2. In Simulations Settings, set the model to have phases with different timestep lengths. Run the model and view results in the containers named Info_Delays_and_Dispersion and Material_Delays_and_Dispersion.

GS17_Timed Events and Discrete Changes

This file contains all of the tests for verifying Timed Events and Discrete Changes. Tests include the following:

- 1) Single-event tests
 - a) Constant rate, recurring event
 - b) Constant rate, non-recurring event
 - c) Time-dependent rate (i.e., variable rate)
 - d) Multiple occurrences of an event within a single timestep
- 2) Multiple-event tests
 - a) Occurrence of Event 1 increases the rate of occurrence of Event 2
 - b) Occurrence of Event 1 “turns off” Event 2
 - c) Rate for Event 2 is a function of a parameter that is modified by the occurrence of Event 1
 - d) Rate is dynamic over the course of the simulation
- 3) Tests for Discrete Changes
 - a) Add constant discrete change
 - b) Replace with current time (i.e., a variable discrete change)
 - c) Realize a stochastic, then set discrete change to realized value
 - d) Multiple explicit triggers
 - e) Update of amount for discrete changes triggered more than once in a timestep
- 4) Checks to ensure that the Remaining Time to Event Timed Events function correctly.
- 5) Stochastic timed events tests.
- 6) Cumulative maximum number of events test.
- 7) Tests that remaining time to event functionality works properly.
- 8) Confirms the behavior of the occurs function.

The model must be in elapsed time mode and run to calculate results. The verifier should ensure that timed events can interrupt the simulation, and then proceed through the following steps:

1. Confirm that Integrator element outputs in the Single_Event_Tests, Mutliple_Events, and Discrete_Change elements correspond with the expected results shown in the tooltip window, and shown in Table GS17_1.

Table GS17_1

Element being tested	Test	Expected Output / Result (access either via Event or Consequence Elements directly, or via the Integrator Elements that follow the E/C elements)
Event_regular_1	1 a)	One occurrence every 100 days, for a total of 10 occurrences over 1,000 days.
Event_reg_cannot_recur	1 b)	Only one occurrence, and at a time of 100

		days.
Event_regular_2	1 c)	One occurrence at time 750 days (Sep. 18/2001).
Event_10_unchanged	2a)	One occurrence at time 667 days (Jun 26/01).
Event_10	2 a)	One occurrence at time 502 days (Jan 14/01)
Event_10_1	2 b)	No occurrences (value of 0 for all times)
Event_12	2 c)	One occurrence at time 503 days. (Jan 1514/01)
Result6	2d)	All curves should have the same shape and the final number of events should be within 1% of the integrated value.
Quantity_5a	3 a)	10 at a time of 1000 days; increases from 0 by 1 each 100 days.
Quantity_5b	3 b)	1,000 at a time of 1,000 days; increases from 0 by 100 each 100 days (same as Add_1)
Quantity_6	3 c)	time history of values equals the time history for Stoch_1 for all events which begin at 100 days.
Quantity_4	3 d)	6; start at 0 and add 1 at times 200, 400, 500, 600, 800, and 1,000 days.
Integrator1	3 e)	3; initial value of integrator is 5, discrete changes of 5, 10, and 20 added at time 0 for a total of 40.

4. Enter the container labeled “Stochastic_Timed_Events.” This test generates an event after a time interval sampled from a normal distribution with mean 20 days and a standard deviation of 5 days . A successful test is indicated by the 5%/95% confidence bounds on the Milestone_Time CDF including the following values for the given percentiles:
 - 5th percentile: 11.8 days/36414 date-time
 - 25th percentile: 16.6 days/36419 date-time
 - 50th percentile: 20 days/36423 date-time
 - 75th percentile: 23.4 days/36426 date-time
 - 95th percentile: 28.2 days/36431 date-time
2. Enter the container labeled “Cumulative_Max_Events.” Conduct the following tests:
 - a. TimedEvent2 is of the Defined cumulative event count type, with the event count equal to 1000 for the first 500 days, and equal to 2000 for the remainder of the simulation. Verify that the value of TimedEvent2.Cum_emitted is 1000 for ETime < 500 d and 2000 for ETime > 500 d.
 - b. TimedEvent3 is of the regular time interval type and emits an event once per day. However, it has a Maximum Number of Events of 500. Verify that the value of TimedEvent3.Cum_emitted increases by one per day, reaching a maximum of 500.
3. Enter the container labeled “Time_to_Event.” Ensure that the absolute value of Distance_to_Event is less than 1E-5 for all realizations (this can be viewed in the Result Distribution element). Also verify that only one event per realization is emitted by Time_to_Event2 at 500d.
4. Return to the Single_Events_Test container, and verify that the time-history element “Occurs” does not show the event occurring when events are allowed to occur between timesteps. Then turn off the option to allow timed events to interrupt the simulation. Run

the model for a single realization and ensure that the output of Occurrs1 is true whenever Event_regular_1 emits an event (once every hundred days).

All tests should be rerun with the model in date-time mode.

GS18_ RandomTimed Event

This file contains a test to verify the functionality of GoldSim's Timed Event Element. Run the model to see results. Compare the simulated mean value and standard deviation to the theoretical values in Table GS18_1. Next, compare the cumulative probabilities for various values of N to the theoretical values in Table GS18_1. To do this, enter the value of the cumulative probability from Table GS18_1 into the GoldSim result-statistic Calculator, and then read the resulting value of N from the Calculator. Compare this value of N to the value for N in Table GS18_1. Because the simulation only performs 10,000 realizations, results are approximate. Therefore, for purposes of verification, if the simulated results match the theoretical results to within about 1% (mean and standard deviation) and to within a probability of 0.01 (for the CDF), then the test is considered to have passed.

Table GS18_1

Mean = 10
Std Dev = 3.16

N	Cumulative Probability of N
1	4.540E-04
2	0.003
3	0.010
4	0.029
5	0.067
6	0.130
7	0.220
8	0.333
9	0.458
10	0.583
11	0.697
12	0.792
13	0.864
14	0.916
15	0.951
16	0.973
17	0.986
18	0.993
19	0.997
20	0.998
21	0.999

GS19_Reservoir: Reservoir Elements

This file contains all of the tests for the Reservoir Element. Tests include the following:

1. **Current_Value** tests: Scalar values and no specified reservoir bounds
 - a) Constant rates of addition and withdrawal where addition rate exceeds withdrawal rate;
 - b) Constant rates of addition and withdrawal where withdrawal rate exceeds addition rate;
 - c) Time-variable rate of addition, constant rate of withdrawal, where addition rate exceeds withdrawal rate;
 - d) Constant rate of addition and withdrawal where addition rate exceeds withdrawal rate; one discrete addition and one discrete withdrawal;
 - e) Same as d), except two discrete additions and no discrete withdrawals.
 - f) Same as e), with a replace discrete change
2. **Overflow_Rate** and **Withdrawal_Rate** tests: Scalar values and specified reservoir bounds
 - a) Constant rates of addition and withdrawal where addition rate exceeds withdrawal rate;
 - b) Constant rates of addition and withdrawal where withdrawal rate exceeds addition rate;
 - c) Time-variable rate of addition, constant rate of withdrawal, where addition rate exceeds withdrawal rate;
 - d) Constant rate of addition and withdrawal where addition rate exceeds withdrawal rate; one discrete addition and one discrete withdrawal;
 - e) Same as d), except two discrete additions and no discrete withdrawals.
 - f) Same as e), with a replace discrete change
3. Vector inputs with reservoir bounds (tests Reservoir Element vector capabilities) – 3 x 1 reservoir vector; constant rates of addition and withdrawal, no discrete changes.
4. Matrix inputs with reservoir bounds (tests Reservoir Element matrix capabilities) – 2 x 2 reservoirs matrix; constant rates of addition and withdrawal, no discrete changes.

The model must be run to calculate results. Expected results are shown in the tooltip window for the Reservoir Element or in plots in the file. The results are also shown in Table GS19_1 and Figures GS19.1 and GS19.2.

5. To test the requirement that discrete additions and withdrawals must be positive, enter the container **Positive_Tests** and do the following:
 - a. Run the model using the value of 100 for **Discrete_Addition** and 50 for **Discrete_Withdrawal**. Model should run to completion.
 - b. Change **Discrete_Addition** to -100. Run the model. An error message should appear that states that negative discrete additions are not allowed.
 - c. Abort, Change **Discrete_Addition** back to 100, and then change **Discrete_Withdrawal** to -50. Run the model. An error message should appear that states that negative discrete withdrawals are not allowed.
 - f. Abort, Change **Discrete_Withdrawal** back to 50 and save the model.
6. To test the **Discrete_Overflow** output, view the results in container **Discrete_OF**.
7. To test the ability to do matrix discrete changes, view the results in Container **MatrixChanges**. All results should increment at time 10, then return to zero at time 20.

Table GS19_1

Element Being Tested	Test	Expected Output (value of Reservoir Element):
Reservoir1	1 a)	Volume (Current_Value) increases linearly from 1,000 gal at 0 days to 6,000 gal at 100 days. Withdrawal_Rate is 50 gal/day for all times.

Reservoir2	1 b)	Volume decreases linearly from 1,000 gal at 0 days to -4,000 gal at 100 days. Withdrawal_Rate is 100 gal/day for all times.
Reservoir3	1 c)	see Figure GS19.1
Reservoir4	1 d)	see Figure GS19.1
Reservoir5	1 e)	see Figure GS19.1
Reservoir10	1f)	see Figure GS19.1 (replace reduces value to 6000 at 80 days, should then follow slope of Reservoir4 and 5)
Reservoir1a	2 a)	Current_Value increases linearly in volume from 1,000 gal at 0 days to 5,500 gal at 90 days; Overflow_rate of 50 gal/day from days 90 to 100; Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir 2a	2 b)	Volume (Current_value) decreases from 1000 gal to 500 by day 10; withdrawal rate is 100 gal/day from day 1 thru day 9, and 50 gal/day thereafter.
Reservoir 3a	2 c)	See Fig. GS19.2 for Current_Value; Overflow_Rate is a constant 0 gal/day; Withdrawal_Rate is a constant 50 gal/day.
Reservoir 4a	2 d)	See Fig GS19.2 for Current_Value; Overflow_Rate is 50 gal/day between days 70 and 75 and from day 95 on; Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir 5a	2 e)	See Fig GS19.2 for Current_Value; Overflow_Rate is zero until day 70, when it becomes 50 gal/day. Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir10a	2f)	See Fig GS19.2 for Current_Value; Overflow_Rate is zero until day 70, when it becomes 50 gal/day. Withdrawal_Rate is a constant 50 gal/day. See Fig. GS19_3 for Is_Full.
Reservoir6	3	Current_Values at day 100 for the three reservoirs are 2350 gal for the first reservoir; 2900 gal for the second; and 1000 gal for the third (the third reservoir should be 1000 gal starting at day 90). IsFullCheck should be zero.
Reservoir7	4	Current_Value starts at 2,000 gal for all four; final values at time 100 days are: 2500 gal for [1,1] and [2,2]; 3000 gal for [1,2]; and 1000 gal for [2,1]. IsFullCheck should be zero.
Reservoir8	6	Element Discrete_Overflow should be 0 until day 49, then jump to 50 at time 50 and remain there.

Reservoir9	7	Values increment at 10 days, decrement at 20 days.
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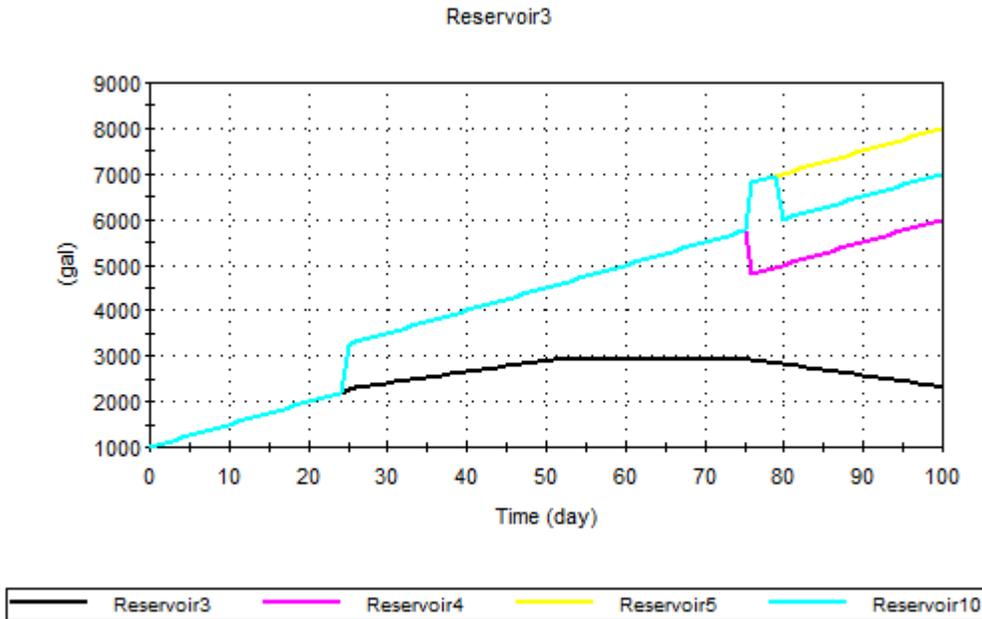


Figure GS19.1. Results for Reservoir-Element Tests.

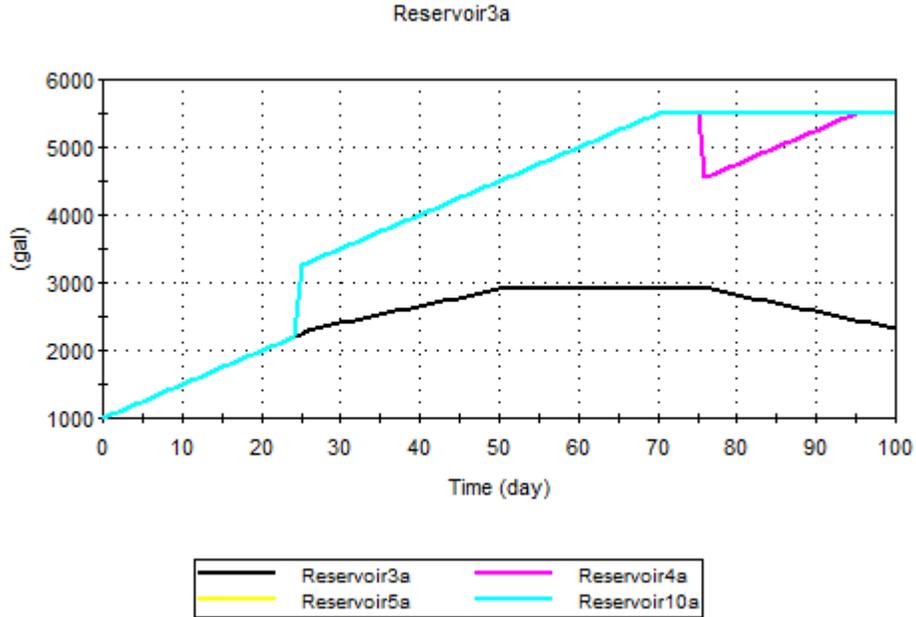


Figure GS19.2. Results for Reservoir-Element Tests

Note to verification plan writers: If the graphs above need to be updated, they are stored in a spreadsheet called vplancalculations.xls, stored in the same folder as the verification plan in Visual Source Safe.

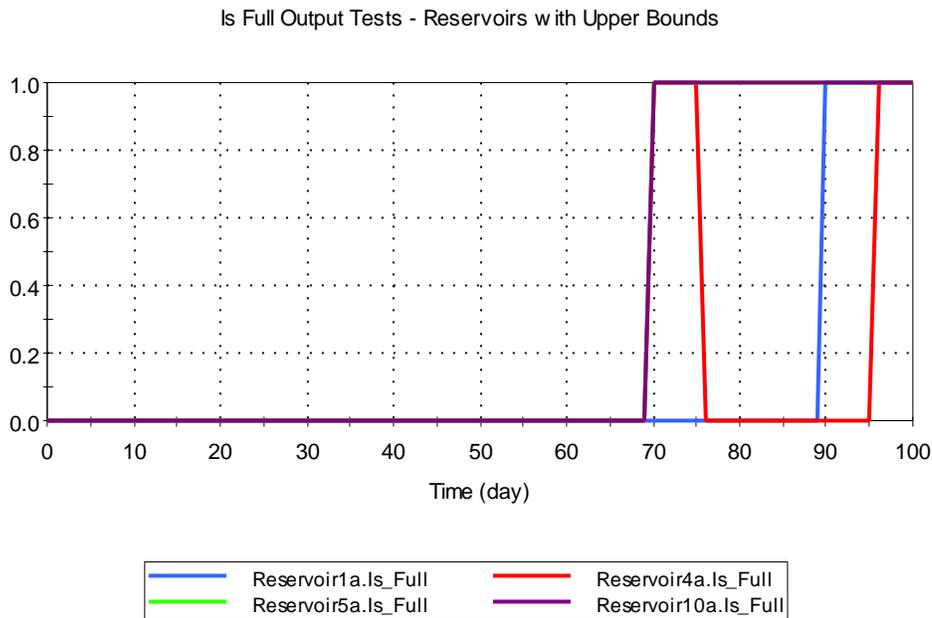


Figure GS19.3. Scalar IsFull Tests

GS19a_Reservoir_2: Reservoir Elements with Changing Bounds

This file tests the ability of Reservoir Elements to handle time-variable upper and/or lower bounds. The test consists of two parts: 1) running the model using multiple timesteps and checking results (to ensure that the time history of volume is calculated correctly); and 2) inducing run-time errors related to illegal bound/volume relationships. In all cases, the expected output for the test reservoir element is located in the tooltip window for the reservoir element.

1. **Multiple timesteps:** Enter the container named Multiple_Timesteps. Open the Model Simulation Settings dialog box and change the number of timesteps to 100 (i.e., a 0.1-day timestep) and click 'ok'. Run the model. Enter each "Case" container in turn and ensure that the simulation result for each reservoir element matches the expected result (especially the time history). Expected results are shown in Table GS19a_ below.

Table GS19a_

Test Case	Scenario	Expected Output from Reservoir Element
Case 1	Constant lower bound, increasing upper bound, volume increases faster than upper bound.	Final Reservoir Volume = 20 m ³ ; Total overflow = 15 m ³ ; volume should follow upper bound after time = 2.5 days. Since the upper bound is constantly increasing, the Is_Full output should almost always be false. (Due to rounding of floating points, the output may not be false at several timesteps.)
Case 2	Constant lower bound, increasing upper bound, volume increases slower than upper bound.	Final Reservoir Volume = 14.95 m ³ ; Total overflow = 0.05 m ³ ; volume is below upper bound. Is_Full should be true at time = 0.

Case 3	Constant lower bound, increasing upper bound, volume decreases.	Final Reservoir Volume = 5 m ³ ; Total overflow = 0 m ³ ; volume is below upper bound.
Case 4	Constant lower bound, decreasing upper bound, volume increases.	Final Reservoir Volume = 15 m ³ ; Total overflow = 15 m ³ ; volume should follow upper bound and Is_Full should be true after time = 4 days.
Case 5	Constant lower bound, decreasing upper bound, volume decreases faster than upper bound decreases.	Final Reservoir Volume = 0 m ³ ; Total overflow = 0 m ³ ; volume is below upper bound.
Case 6	Constant lower bound, decreasing upper bound, volume decreases more slowly than upper bound decreases.	Final Reservoir Volume = 7 m ³ ; Total overflow = 2 m ³ ; volume should follow upper bound and Is_Full should be true after time t = 5 days.
Case 7	Constant upper bound, increasing lower bound, volume increases faster than lower bound increases.	Final Reservoir Volume = 35 m ³ ; Total withdrawal = 5 m ³ ; volume is above the lower bound.
Case 8	Constant upper bound, decreasing lower bound, volume increases.	Final Reservoir Volume = 35 m ³ ; Total withdrawal = 5 m ³ ; volume is above the lower bound.
Case 9	Constant upper bound, decreasing lower bound, volume decreases faster than the lower bound decreases.	Final Reservoir Volume = 3.003 m ³ ; Total withdrawal = 11.99 m ³ ; volume should follow lower bound after time t = 4 days.
Case 10	Constant upper bound, decreasing lower bound, volume decreases faster than the lower bound decreases.	Final Reservoir Volume = 5 m ³ ; Total withdrawal = 5 m ³ ; Total overflow = 15 m ³ ; volume follows both bounds throughout the simulation. Is_Full true for the duration of the simulation.

2. **Failure Case:** Enter the container named Fail_Case. To activate this model, enter the following values: Net_Rate_Change= 0 {m³/day} and Initial_Volume=15 m³. Then, run the model. The expected result is a fatal error at day 5.1 (“The lower bound is increasing at a faster rate than the volume”). Change Net_Rate_Change back to 1 {m³/day}, Initial_Volume to 20 m³, and save model. The test is complete.

GS20_Element Activation

This file verifies that common elements activate correctly. Tests include:

1. A container that does not activate contains a number of elements that do not activate.
2. A container that activates, deactivates, then reactivates contains a number of elements that become active.

Run the model to calculate results. Expected results for each element are shown in the tooltip window for the element, and are shown in Table GS20_1. 2 run log warning should be generated.

Table GS20_1

Element being tested	Expected Output / Result
All elements in container 'Never_Active'	None of the elements in this container ever activate. All elements report a value of zero for all times, with the following exceptions: Data1, InfoTimeSeries1, MaterialTimeSeries1, Data2, InfoDelay1 and MaterialDelay1. These each report a value of 5 for all times (even though they are never activated). Stochastic 1 – reports a constant sampled value Reservoir1 – run log reports that material was received while the element was inactive
Elements in container 'Activate_Reactivate':	Container is active between days 100 and 1100, then inactive between days 1101 and 1200, then reactivates at day 1200.
Data1	Should report a value of 5 at all times, even while inactive.
InfoTimeSeries1	Should report a value of 5 at all times.
MaterialTimeSeries1	Should report a value of 5 kg at all times.
Data2	Should report a value of 5kg at all times.
Data4	Time history follows: 0 for time < 100 days; step to 100 at time = 100d; linear increase to 1100 between time 100 and 1100d; plateau at 1100 between 1100 and 1200d; step to 1200 at 1200d; linear increase to 2000 between 1200 and 2000d.
Integrator1	Time history follows: 0 for time < 100; linear increase from 100 to 1,100 between time 100 and 1100; linear increase from 1,200 to 2,000 from time 1200 to time 2000.
Reservoir1	Same time history as for Integrator1, except with units of kg.
Stochastic1	Expected output is 0 prior to time 100, then a new sampled value at time 100, then another new value at time 1200.
Expression1	Same time history as for Integrator1
Min1	Value is always 0
Max1	Same time history as for Integrator1
Sum1	Same time history as for 2 * Integrator1
Selector1	Time history follows: value is 0 prior to time 100, and value is 5 thereafter.
Event1	Time history for Cum_Emitted is 0 prior to time 100, and 1 thereafter.
DiscreteChange1	Time history for Cum_Emitted is 0 prior to time 100; 1 at time 100; and 2 at time 1200.
Decision1	Time history for Last_Decision is the same as for Event1.Cum_Emitted.
Milestone1	Time history for Completion_Status is the same as for Event1.Cum_Emitted.
EventDelay1	Time history for Cum_Emitted is 0 prior to time 200, and 1 thereafter.
ChangeDelay1	Time history for Cum_Emitted is 0 prior to time 200; 1 at time 200; and 2 at time 1300.
InfoDelay1	Should report a value of 5 at all times, even while inactive.
MaterialDelay1	Should report a value of 5kg except between time 1101 and 1200 when it should report a value of zero.
Random_Choice	Time history for Last_Choice is the same as for

Element being tested	Expected Output / Result
	Event1.Cum_Emitted.

GS21_ Conditional Containers

This file verifies that conditional containers perform properly. The test file evaluates container activation, deactivation with completion, and deactivation with termination. The tests are repeated for both unconditional and conditional parent containers.

Run the model to calculate results.

The first test checks that Conditional Containers activate and deactivate properly. The expected results for each test container are described in the tooltip window for the container, and are summarized in Table GS21 below. You will have to navigate the model to locate many of the test containers. The results in Table 21 apply to both the parent containers 'UnConditional' and 'Conditional'.

Table GS21

Test Container	Expected Results
Activation_Deactivation	Activity status: Changes to 1 at time 20; 0 at time 30; 1 at time 50; and 0 at time 60. Completion status: changes to 1 at time 30; 0 at time 50; and 1 at time 60. Num_Activations = 2. Duration (final stage) = 40.
Nested_Inside1	Should never activate (since parent is not active when the activation trigger fires)
Nested_Inside2	Activates at time 50

The verifier should then check to make sure that the Events and Duration plots in the 'UnConditional' and 'Conditional' container match the plots in Figure GS21_1 through GS21_4,

Unconditional Container Event and Condition Outputs

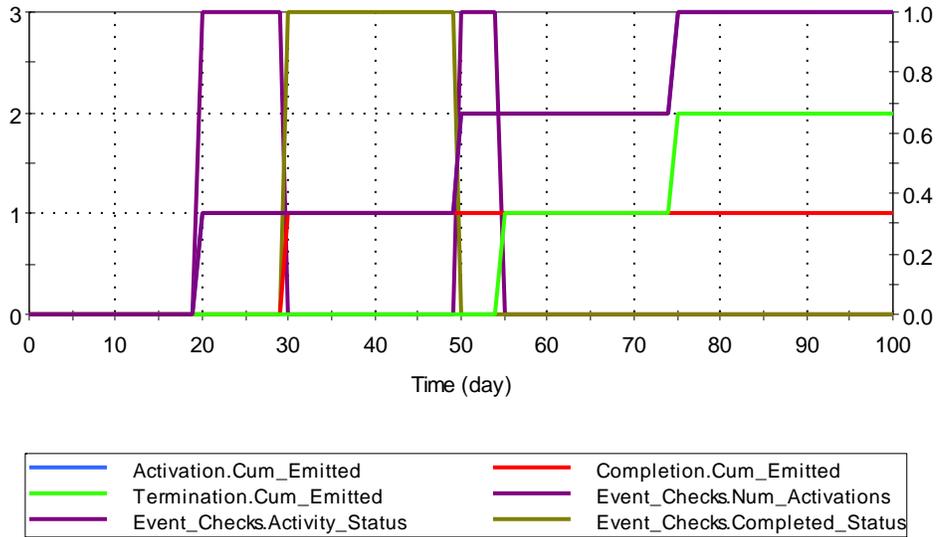


Figure GS21_1: Expected plot for Events Time History in the UnConditional Container

Unconditional Container Duration Output

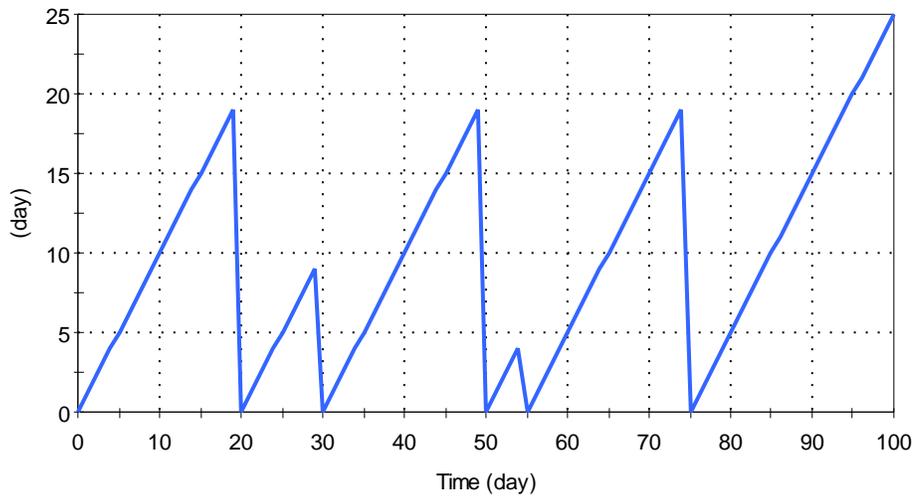


Figure GS21_2: Expected plot for Duration Time History in the UnConditional Container

Conditional Container Event and Condition Outputs

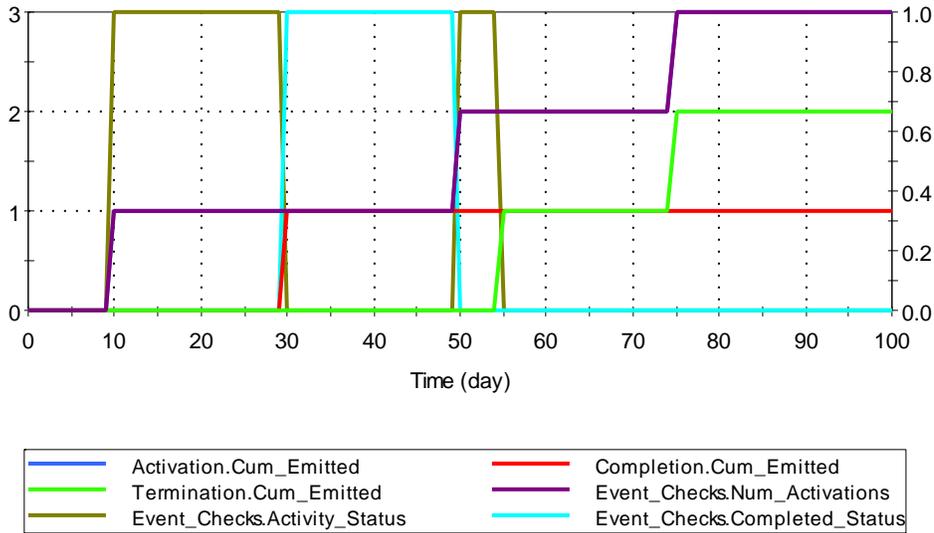


Figure GS21_3: Expected plot for Events Time History in the Conditional Container

Conditional Container Duration Output

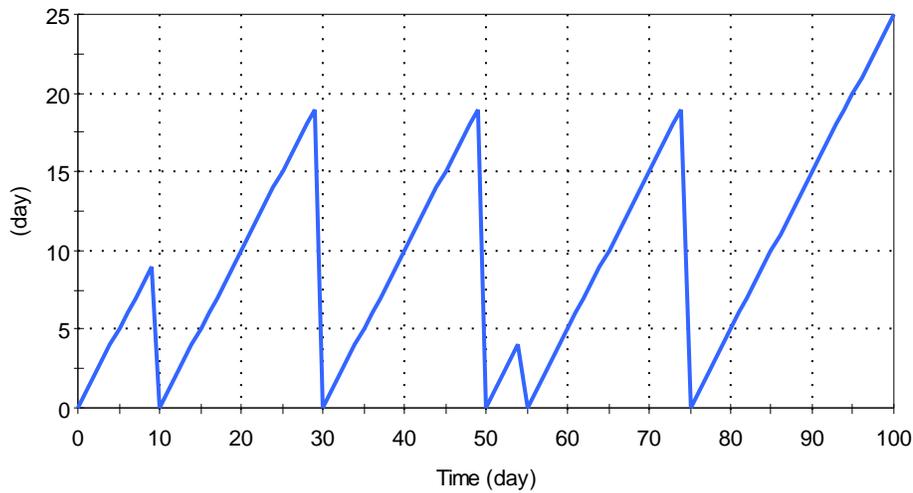


Figure GS21_4: Expected plot for Duration Time History in the Conditional Container

The verifier should also ensure that the value of the Time_at_Last_Update Expression element in Event_Checks is 75 days in both the UnConditional and Conditional containers. This check verifies that elements inside a Conditional Container that is activated and deactivated at the same timestep are properly updated.

GS22_Datetime: Track Serial Date and Time

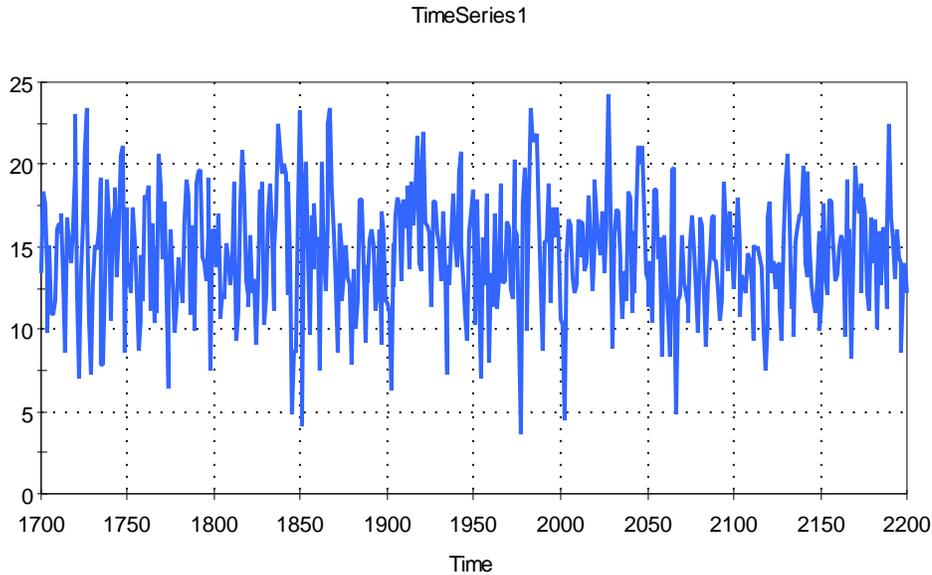
This first part of this test verifies that GoldSim correctly tracks simulation time when the simulation duration is specified in the Master Clock using the Date-Time option. The simulated timeframe is specified as 1/1/99, 12:00:20 AM to 12/31/99, 11:59:50 PM. Run the model to calculate results. Expected results are shown in a table in the file and are shown in Table GS22_DATETIME. The results are in terms of the Serial date system, as calculated by EXCEL, which starts a numeric count of days on December 30st, 1899 (e.g., Serial Day 3.00 = the end of Jan. 1, 1900).

Also, confirm that the date-axis for the history plot, are displayed in date-time format.

Table GS22_1

Serial Date Number for Year	
Date:	Serial
1-Jan	36161
31-Jan	36191
1-Feb	36192
28-Feb	36219
1-Mar	36220
31-Mar	36250
1-Apr	36251
30-Apr	36280
1-May	36281
31-May	36311
1-Jun	36312
30-Jun	36341
1-Jul	36342
31-Jul	36372
1-Aug	36373
31-Aug	36403
1-Sep	36404
30-Sep	36433
1-Oct	36434
31-Oct	36464
1-Nov	36465
30-Nov	36494
1-Dec	36495
31-Dec	36525

The second test checks GoldSim's ability to simulate models beginning in 1700 and ending after 2100. The tester should change the simulation settings to a model running from 1/1/1700 to 1/1/2200 in 500 steps. Then run the model and compare the graph in Result1 to the image pasted beside it and below this paragraph. Finally, reset the X axis limits in Result1 to show only 1/1/1700 to 1/1/1900. Confirm the plot shows the limited date range.



The third test checks GoldSim's ability to format times as datetimes and dates. Run the model to completion and confirm that Datetime_Check shows 1/1/2200 0:00:00 and Date_Check shows 1/1/2200 if the model is run from 1/1/1700 to 1/1/2200 in 500 steps.

GS23_Elapsetime: Track Elapsed Simulation Time

This file verifies that GoldSim correctly evaluates elapsed simulation time and correctly converts among various units of time. The file verifies GoldSim's calculation of Serial seconds, hours, days, months, and years for a simulation with a duration of 1 year. Run the model to calculate results. Expected results are shown in a table in the file and are shown in Table GS23_1. The results are in terms of the Serial date system, as calculated by EXCEL, which starts a numeric count of days on December 30st, 1899 (e.g., Serial Day 3.00 = the end of Jan. 1, 1900).

Table GS23_1

For Year 1999:	
Total Seconds:	3.1536E+07
Total Hours:	8760
Total Days:	365
Total Months:	12
Total Years:	1

GS24_Timestep: Variable Timesteps

This file verifies that GoldSim functions properly when variable timesteps are used. Run the model to calculate results. The tests are as follows:

- In the first test, values of a time-dependent function are generated using a variable timestep for a period of 10,000 days:
 - 0 - 1,000 days: timestep = 50 days
 - 1,001-2,000 days: 12.5 days
 - 2,001-10,000 days: 100 days
 Run the model to generate results. Ensure that the correct timestep was used in each phase. Expected results are as shown in the table below. Expected results are shown in a table in the file and in Table GS24_1. Expected results are the theoretical values of the time-dependent expression.

Table GS24_1

Time (days)	Function
0	0.000E+00
900	0.000E+00
1000	1.000E+00
2000	8.208E-02
3000	6.738E-03
4000	5.531E-04
5000	4.540E-05
6000	3.727E-06
7000	3.059E-07
8000	2.511E-08
9000	2.061E-09
10000	1.692E-10

- In this test, an Integrator element is tested to ensure that they correctly integrate their rate over time when variable timesteps are used. Expected result is a value of 10,000 at time equal to 10,000 days. In addition, the value of the Integrator element should be equal to time throughout the duration of the simulation.
- This test ensures that a timed event fires at the correct time when variable timesteps are used. Expected result is that the event fires every 50 days, for a total of 200 occurrences. View the time history of results to confirm.
- The final test verifies the correct functioning of the Timestep_Length local property. It should match the scheduled timestep for the first 2000 d (value of 50d from 0 -1000 days and a value of 12.5 days from 1001-2000 days) and then return to a value of 50 days for the remainder of the simulation (even though a 100 day timestep is being used, events issued by Event1 will cause the simulation to be updated once every 50 days).

GS25_Multiprocessor Networked Solution Tests

In order to verify the networked capability of GoldSim, the user has to run a GoldSim Master application and at least one Slave application. The slave application does not need to be on a different computer from the master application. The user can run more than one slave at the same time in one computer, which will be effective if it has multiple processors. Up to 20 slave applications can be run on each computer. The Master process assigns individual realizations of the GoldSim model to available slaves. Each slave makes a local copy of the model and any required auxiliary files (eg. DLL files used by External and External Pathway elements, XLS files

used by spreadsheet elements, and arbitrary files defined by File elements). At the completion of the simulation, the results of all of the realizations are re-assembled into the .GSM file.

The multiprocessor test consists of two GoldSim models: GS25a_Multiprocessor Dynamic.gsm tests the multiprocessor capability for dynamic models, while GS25b_Multiprocessor Static.gsm does the same for static models. These files and all supporting files are contained within a folder called GS25_Multiprocessor. Follow the steps outlined below for each test file.

GS25a_Multiprocessor Dynamic

File preparation: The user should load file GS25a_Multiprocessor Dynamic.gsm prior to doing the networked verification.

Setting up the test: The user needs to launch GoldSim on each Slave machine. The tester should launch a copy of both GoldSim and the Player in slave mode. To launch the player in slave mode, the tester types the following in the Run dialog for Windows (accessed from the Start button) on the appropriate Slave machine:

“path to GSPlayer.exe” –s

where *path to GSPlayer.exe* is the path to the GoldSim Player executable on the slave machine. The quotes must be included and the *–s* must go outside the quotes. Upon entering this run command, the GoldSim Network Client dialog will appear on the Slave machine, with a Client Status of “Client is ready to connect to Master”. The Slave machine is now ready to receive commands from the Master. GoldSim is started in slave mode the same way, with the path to GoldSim.exe being placed inside the quotes. The *–s* switch is still required.

Next, the user must specify the slaves’ addresses in the NetworkSettings dialog on the Master machine. This can be done by selecting “Run on Network...” from the Model menu. Slave address can be entered either as a computer name or as an IP address (e.g., obtained from browsing the Network Neighborhood). If one computer is to have more than one slave application running, the user should define the slave system multiple times, once per slave.

Next, the user should make connections from the master to all desired slaves. Pressing the “Update Slave Status” button will not only do this for the user, it also verifies that the specified computer has a GoldSim slave running. After the Master knows which slaves are active and which ones are not, it is ready to do the simulation. Pressing the “Run Simulation” button will start the networked simulation.

Performing the test: The Networked version of GoldSim has many features to speed up the simulation. The user will verify all of them according to the step-by-step instructions that are given in this section. Some of the features require the simulation to be run, and some do not.

1. Adding a new slave address.

To do this, user does not need to run the simulation. The user can add a new slave address by inputting it in the ‘New slave address’ edit box and pressing the ‘Add Slave’ button. The new slave address will be shown on the grid, which is located above the buttons.

2. Modifying a slave address

To do this, user does not need to run the simulation. The user can modify a slave’s

address by editing it directly from the grid. The user should click the slave address cell and input a modified slave address.

3. Removing a slave from the list

To do this, the user does not need to run the simulation. The user can remove a slave from the master list by first selecting the slave, and then pressing the “Remove Slave” button. The selected slave address will be removed from the grid.

4. Abort the simulation

If the ‘Abort’ button is clicked during a simulation, the simulation should terminate.

5. Rerun after Abort

The user should rerun the simulation using the runs completed prior to the abort.

6. Abort and Discard

The user should rerun the simulation, abort the run, rerun the simulation, and then discard the results.

The user should carry out all of the above tests, and confirm that the requested actions are performed, and for the simulations the final results for each element are identical to a normal simulation where no slaves are used.

GS25b_Multiprocessor Static

Open the file GS25b_Multiprocessor Static.gsm. Follow the steps listed above for GS25a under “setting up the test” and “performing the test”.

GS25c_Multiprocessor – Loading/Saving Slave Lists

Confirm that a list of slaves can be loaded and saved to a file by selecting the “Run on Network...” option in the Model menu and using the “Export” button to save the current list of slaves to a file (with extension .SLV) and using the “Import” button to load the list back in. During loading of a slave list, verify that the user is asked whether to remove the existing slaves in the list and whether to immediately update their status.

GS25d_Multiprocessor – Auto-Launching Slaves using Slave Manager

Preparation: The Slave Manager (NT service) – as well as GoldSim itself – must be installed on all client machines running GoldSim Slaves. Preferably this would be done on both the master station and one other networked PC. The Slave Manager can be installed during the main GoldSim install or by running the stand-alone install: GSSlaveMgr130.exe. You may verify that the Slave Manager is running by using Windows Control Panel to go into Administrative Tools and selecting “Services.” In the list of services, you should see “GoldSim Slave Manager” listed with a status of “started.” If a formal install is not provided for the verification, it is necessary to modify the registry key for the version in HKEY_LOCAL_MACHINE\SOFTWARE\GTG\GoldSim. A String value called “InstallPath” must be added to the key, and its value should be set equal to the path to the test version. After adding the value, the GoldSim Slave Manager service must be restarted.

Performing the Test: Open GS25a_Multiprocessor Dynamic.gsm . From the GoldSim master, with a model loaded, select “Run on Network...” from the Model menu. In the list of slaves, add 3 slaves for a networked PC running Windows XP. Verify on the networked PC that the slaves are not already running. Press the “Update Status” button in the dialog. Observe the results. The slaves should be automatically launched on the networked PC and run to completion successfully.

Open GS25d_Multiprocessor_WinVista.gsm . From the GoldSim master, with a model loaded, select “Run on Network...” from the Model menu. In the list of slaves, add 3 slaves for the local PC (client address should be “localhost”) and 3 slaves for a networked PC. At least one of the two PC’s should be running Windows Vista. Verify on both PCs that the slaves are not already running. Press the “Update Status” button in the dialog. Observe the results. The slaves should be automatically launched on both PCs. Run the model to completion. None of the slaves should crash, and all realizations should run successfully.

GS25e_Multiprocessor – 32/64-bit Slave Detection

Preparation: GoldSim should be installed and slaves manually started on a 32-bit PC and a 64-bit PC.

Performing the Test: Open GS25e_Multiprocessor64.gsm . From the GoldSim master, with a model loaded, select “Run on Network...” from the Model menu. In the list of slaves, list the machine name for the 32-bit and 64-bit slave machines.

Run the model. Only the 64-bit machine should process realizations. The 32-bit machine should report a fatal error, but the simulation should run successfully and the verifier should ensure that result values match the expected values listed in the GS25a test.

GS26_Event_Substep: Firing an Event Within a Timestep

This test verifies the proper functioning of the “Allow timed events to occur between timesteps” option and the Minimum timestep length field.

The Timed Event occurs once, at a minimum of 30.31 years.

For the first test, run the model without allowing timed events to occur between timesteps.

Event_Time should be equal to 200 years and the Quantity integrator should have a value of 0m^3 at the end of the simulation.

The model should then be run with the "Allow events to occur between timesteps" option selected. Run the model with the default minimum timestep of 0yr. The event should occur at 30.31 years, and the Quantity integrator should have a value of 1696.97 m^3 at the end of the simulation.

Run the model again with the following settings and confirm the following results:

Minimum Timestep Length	Event Time	Quantity Value at Simulation End
100 yr	100 yr	1000 m^3
50 yr	50 yr	1500 m^3
25 yr	30.31 yr	1696.97 m^3
10 yr	30.31 yr	1696.97 m^3

GS26b_MaximumTimestep_EditModeUpdates

This test verifies the proper functioning of the Maximum Timestep Length setting, and also verifies the proper function of the Edit Mode Update setting.

1. Run the model and ensure that 101 events are generated by the Triggered Event (the event is triggered each time that the simulation clock changes, meaning that an event is generated at each model update).
2. Return to edit mode. Set the Edit Mode Update time to 0s. Check that the predicted values correspond with the expected values listed in the tooltip.
3. Set the Edit Mode Update time to 50s. Check that the predicted values correspond with the expected values listed in the tooltip.

GS27_Triggering: Basic Trigger Functionality

This test verifies basic triggering functionality by exercising the triggering dialog common to all elements that can be triggered. The test evaluates the three triggering modes (automatic versus user-defined triggers, optional precedence completion, and optional go/no-go conditions) individually and in combinations.

To complete the test, run the model. Compare the model results to the expected result for each Triggered Event element shown in Table GS27.

Table GS27

Element Being Tested	Functionality Tested	Expected Output
Trigger1	Automatic trigger	Triggered once at time 0
Trigger2	Automatic trigger + precedence completion	Triggered once at time 25
Trigger3	Automatic trigger + go/no-go condition	Triggered once at time 0
Trigger3_Condition	Same as Trigger3, but with go/no-go condition as a precedence condition	Triggered once at time 0
Trigger4	Automatic + precedence + go/no-go condition	Triggered once at time 25
Trigger4_Condition	Same as Trigger4, but with go/no-go condition as a precedence condition	Triggered once at time 25
Trigger5	Automatic + precedence + go/no-go condition	Never triggered
Trigger5_Condition	Same as Trigger5, but with go/no-go condition as a precedence condition	Triggered once at time 50
Trigger6	Automatic inside conditional container	Triggered once at time 10
Trigger17	Automatic + precedence completion inside conditional container	Triggered once at time 25
Trigger18	Automatic + go/no-go condition inside conditional container	Triggered once at time 25
Trigger18_	Same as Trigger18, but with go/no-go	Triggered once at time 25

Condition	condition as a precedence condition	
Trigger19	Automatic + go/no-go condition inside conditional container	Never triggered
Trigger19_Condition	Same as Trigger19, but with go/no-go condition as a precedence condition	Triggered once at time 30
Trigger7	User-defined (on Event) inside conditional container	Triggered once at time 10
Trigger8	User-defined (on True) inside conditional container	Triggered once at time 20
Trigger9	User-defined (on Changed) inside conditional container	Triggered once at time 25
Trigger10	User-defined (on Event + on True + on Changed) inside conditional container	Triggered once each at times 10, 20, and 25
Trigger11	Same as for Trigger10 + on False	Triggered once each at times 10, 20, 25, and 50
Trigger12a	Act just once for simultaneous triggers	Triggered once at time 15.
Trigger12b	Act once for each simultaneous trigger option off.	Triggered three times at time 15.
Trigger13	Same as for Trigger11 + precedence completion	Triggered three times at time 25 and once at time 50.
Trigger13_ActOnce	Same as for Trigger11 + precedence completion + Act once option selected	Triggered once at time 25 and once at time 50.
Trigger14	Same as for Trigger11 + go/no-go condition	Triggered once each at times 20, 25, and 50.
Trigger14_Condition	Same as Trigger14, but with go/no-go condition as a precedence condition	Triggered once at time 15, 20, 25, and 50.
Trigger15	Same as for Trigger11 + precedence completion + go/no-go condition	Triggered three times at time 25 and once at time 50.
Trigger15_Condition	Same as Trigger15, but with go/no-go condition as a precedence condition	Triggered three times at time 25 and once at time 50.
Trigger15_ActOnce	Same as for Trigger11 + precedence completion + go/no-go condition + act once option selected	Triggered once at time 25 and once at time 50.
Trigger15_Condition	Same as Trigger15, but with go/no-go condition as a precedence condition + act once option selected	Triggered once at time 25 and once at time 50.
Trigger16	Same as for Trigger11 + precedence completion + go/no-go condition	Triggered once at time 50.
Trigger16_Condition	Same as Trigger16, but with go/no-go condition as a precedence condition	Triggered three times at time 26 and once at time 50.
Trigger16_ActOnce	Same as for Trigger11 + precedence completion + go/no-go condition + act once option selected	Triggered once at time 50.
Trigger16_Condition_ActOnce	Same as Trigger16, but with go/no-go condition as a precedence condition + act once option selected	Triggered once at time 26 and once at time 50.
Trigger20	User-defined inside inactive container	Triggered once at time 50.

Trigger21	*****Removed*****	If True trigger no longer supported.
Trigger22	OnFalse when time exceeds 50	Triggered once at time 51.
Trigger23	OnEvent with multiple required events	Triggered once at time 77.
Trigger24	OnEvent triggering using a discrete change	Triggered once at time 50.

GS28_Deterministic Options: Deterministic Simulation settings

This file tests the different Deterministic Simulation Settings. The test consists of two parts:

Part 1: Deterministic modes – enter the container named Deterministic_Modes.

1. Under the Monte Carlo Tab of the Simulation Settings Dialog(SS), select the "Run Deterministic" simulation mode, and then select the "Use Element's Deterministic Value" option.
2. Open one of the stochastic elements, click 'Define', then 'Use mean (expected) value', and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the expected value in the tooltip window for the element.
3. On the Monte Carlo tab of the SS dialog, select "Use Specified Quantile" option, enter a value of 0.5, and then click 'OK'. Run the model. Compare the result for each stochastic with the median value in the tooltip window for the element.
4. On the Monte Carlo tab of the SS dialog, select "Use Mean" and then click 'OK'. Run the model. Compare the result for each stochastic with the expected value in the tooltip window for the element. Under MSS, select "Use Element's Deterministic Value" option.
5. Open one of the stochastic elements, click 'Define', then 'Use median value', and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the median value in the tooltip window for the element.
6. Open one of the stochastic elements, click 'Define', 'Use quantile', enter a value of 0.5, and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the median (0.5 quantile) value in the tooltip window for the element.
8. Open one of the stochastic elements, click 'Define', 'Use specified value', and enter a value for the variate (may be outside the range for the defined distribution). Close the dialog, run the model, and ensure that the specified value was produced by that stochastic.
9. Repeat step 8, but this time specify the value by inserting a link to element Data1 in the 'specified value' field for the stochastic.
10. Open one of the stochastic elements for which a value was not specified in steps 8 and 9. Click 'Define', 'Use quantile', enter a value of 0.5, and then click 'Apply to all stochastic elements'. Run the model. Compare the result for each stochastic element with the median (0.5 quantile) value in the tooltip window for the element.

11. Open one of the elements for which a value was specified in Steps 8 or 9. This element should show a deterministic input of Quantile = 0.5. Next, check the "Use Specified Value" radio button. The value that was previously specified for this element in Step 8 or 9 should re-appear (i.e. GoldSim remembers this value).

Table GS28_1

Element being tested	Median value and 0.5 Quantile [-]	Expected value [-]
Uniform	50.5	50.5
Log_Uniform	10.0	21.5
Normal	10.0	10.0
Log_Normal	0.894	1.0
Triangular	5.257	5.333
Log_Triangular	1.853	1.863
Cumulative	34.0	35.0
Discrete	3.0	3.0
Poisson	5	5
Binomial	1	1.25
Beta	4.61	5.0
Gamma	4.74	5.0
Weibull	3.76	4.0

Part2: Random Timed Events in deterministic mode: Enter container Event_Checks.

1. In the Model Simulations Settings dialog, select 'Run All Realizations' from the Simulation Run Mode list box.
2. Run the model. The value of the Integrator element should change from 0 to 1 at sometime between 0 and 100 days (an average rate of occurrence for the random timed event Event1 of 0.1/day was specified).
3. In the Model Simulations Settings dialog, select the 'Run Deterministic' option and then 'Use Element's Deterministic Value'.
4. Run the model. The value of the Integrator element should change from 0 to 1 at a time of 10 days (i.e., GoldSim now treats the random timed event as a regular timed event).

GS29_External2: External-Element Table and Time Series Definition Output

This test verifies that the Table and Time Series Definition outputs of the External Element work correctly. The Table-Definition output allows the user to create a lookup table externally and import it into GoldSim. The file cfstubs.dll contains the test data tables and is called by the External Elements in this test file, while the TS_Proc.dll is used by the Time Series elements. The test proceeds as follows:

1. Enter the container labeled "Table_Def_1D", which houses the tests for the 1D Table-Definition output. These tests verify the functionality of the 1D Table Definition

output, including unit conversions made in the transfer from the External Element to the Table Element. It also verifies that the Table definition output type can be transmitted to a SubModel.

- a. Run the model. Verify that the output of Expression1 and SubModel_Result1 is 102160 (for Element A = 0.6 m/s).
- b. Change the value of Element A to 1.2 m/s. Run the model. Verify that the value of both Expression elements has changed to 104320 {m}.
- c. Change the value of Element A to 12 m/s. Run the model. Verify that both Expression elements now have a value of 143200 m.

2. Enter the container labeled “Table_Def_2D”, which houses the tests for the 2D Table-Definition output. These tests verify the functionality of the 2D Table Definition output, including unit conversions made in the transfer from the External Element to the Table Element. It also verifies that the Table definition output type can be transmitted to a SubModel.

- a. Run the model. Verify that Expression2 and SubModel_Result2 both have a value of 115000 m (for Speed = 0.5555 m/s = 2 km/hr and Fuel = 101 gal).
- b. Change the value of Speed to 1.11111 m/s. Run the model. Verify that the output of both Expression elements is now 116500 m.
- c. Change the value of Fuel to 107 gal. Run the model. Verify that the output of both Expression elements have changed to 122000 m.

3. Enter the container labeled “Table_Def_3D”, which houses the tests for the 3D Table-Definition output. These tests verify the functionality of the 3D Table Definition output, including unit conversions made in the transfer from the External Element to the Table Element. It also verifies that the Table definition output type can be transmitted to a SubModel.

- a. Run the model. Verify that the value of Expression 3 and SubModel_Result3 is 1150000 m (for Speed1 = 0.5555 m/s = 2 km/hr, Fuel1 = 101 gal, and Engine_displacement = 1000 cc).
- b. Change the value of Speed1 to 1.11111 m/s. Run the model. Verify that the value of both Expression elements has changed to 1165000 {m}.
- c. Change the value of Speed1 back to 0.55555 m/s, and then change the value of Engine_displacement to 2000. Run the model. Verify that the value of both Expression elements has changed to 2115000 m.

4. Enter the container labeled “Time_Series.” Enter the Instantaneous, Constant_Over_Next, Constant_Over_Previous, Change_Over_Previous, and Change_Over_Next_Interval containers and ensure that the values for TimeSeries 1 and TimeSeries2[1] are identical. The verifier should then enter the Discrete_Change container and confirm that Integrator1 and Integrator2[1] produce identical histories. Finally the tester should enter the Instantaneous, Constant_Over_Next, Constant_Over_Previous, Change_Over_Previous, and Change_Over_Next containers and change TimeSeries1 from elapsed time to calendar basis. The tester should then run the model and re-verify all of the time series result graphs in these containers.

Repeat the test using the 64-bit version of the test file and DLLs (GS29_External264.gsm, cfstubs_x64.dll, and TS_Proc_x64.dll)

GS30_Table Function: Using a Table Element Like a Function

<REVISED LOOKUP TABLES WERE INTRODUCED IN VERSION 9 –SUPPORT FOR OLD STYLE TABLES WAS DISCONTINUED IN VERSION 9.60>

<THIS TEST SUPERCEDED BY GS50 FOR VERSION 9.60 AND LATER>

GS31_Param Import Samp: Parameter Importance Sampling

This file verifies that GoldSim's stochastic-parameter importance-sampling algorithm functions properly. The tests in this file evaluate GoldSim's output for a single uniformly-distributed random variable, U(0,1). Each test case must be run in succession. To run a test case, adjust the location for sampling enhancement (low, high, none) in the properties dialog box for the element 'Uniform'. Then run the model and view the Results Distribution and Results Array (**this is a button below the plot in the Result Distribution dialog**) to evaluate the model output against the expected results shown in Table GS31_ 1 below. Note that all tests should report the same mean value and standard deviation because GoldSim corrects for the sampling weights before reporting results.

Table GS31_ 1

For n=10000 realizations, Random Number Seed = 1 and Latin Hypercube Sampling Disabled

Test Case	Enhancement Location	Mean Value	Standard Deviation	Weight of sorted sample (n = 1 or n = 10000) ¹	Visual measure of confidence bounds on sampled values	# of Realizations in Enhanced Zone ²
1	none	0.50 +/-	0.29 +/-	0.0001 (for all)	equal for all samples	NA
2	lower	0.50 +/-	0.29 +/-	Approx. 1E-8	tighter near lower end	on the order of 1000
3	upper	0.50 +/-	0.29 +/-	Approx. 1E-8	tighter near upper end	on the order of 1000

Notes:

1. For lower enhancement, use n = 1 in the sorted list shown in the Results Array; for upper enhancement, use n = 10,000.
2. For this test, the enhanced zone is taken as between 0 and 0.01 for the "low end" and 0.99 and 1.0 for the "high end". Thus, count the number of values realized between these values when sampling from the corresponding "end". The values specified in the table are approximate.
3. Because GoldSim results are stored in single precision, the high-end of the results when run with the upper end enhanced contains a number of results that round to 1.0 in single precision. As a result, the results array display will show a count of several results and their combined weight, rather than the 1E-8 weight of the highest result.

GS31b_ImportanceSampling:

This test verifies that Importance Sampling features in the Timed Event, Random Choice and Reliability elements function properly.

As part of the test the verifier will run the model three times. The first time the model should be run with importance sampling enabled only for the Timed Event. The verifier should confirm that the probability of an event in a given realization is approximately 0.00995, and then they should check the Result Array to ensure that there are on the order of 500 realizations in the enhanced zone.

The model should be run a second time with importance sampling enabled only for the Random Choice element. The verifier should confirm that Result3 shows a probability for the

LowProbEvent of approximately 0.00100, and that GoldSim reports approximately 150 observations in the enhanced zone.

The model should be run a final time with importance sampling enabled only for the Function element. The verifier should confirm that Result1 shows that the probability of the failure mode occurring during a given realization is approximately 0.00140 and that there are on the order of 50 realizations in the enhanced zone.

GS32_Save_Results

This file is used to verify that result-saving for multiple user-defined time phases works correctly. For each realization, the result X equals the realization number multiplied by the time. Run this problem a total of eight times (i.e., in the following $2 \times 2 \times 2 = 8$ scenarios):

1. (If the player version is available to perform network runs) Do each run once as a normal run, and once using two Slave processes running on your system (launch these by entering "goldsim.exe -s" from the Start/Run Windows input, as described in GS25_MULTIPROCESSOR earlier).
2. Save 1 and 100 histories.
3. Run with and without 'Save results at the end of each Phase' set in the simulation settings/customize timesteps dialog.

Ensure that all appropriate results are correctly saved for each scenario (e.g., for 100 realizations, saving results at end of each phase, and for element "Stats", the mean value at time 10 days should be approximately 500; at 50 days, 2,500; and at 100 days, 5,000).

GS33_Previous_Value

This file tests the Previous Value element, which delays a value, condition, event or discrete change input by one timestep. Tests are stored in three containers, and the test is run with the "Allow events to occur between timesteps" option turned off. To conduct the test, the verifier should run the model and verify the specified results in each container.

Scalar Container

Open Result1 and ensure that:

1. Previous_Timestep_Value has a value that lags one day behind that of SIN_Function;
2. Difference and Difference2 are evaluated correctly (see their formulas); and
3. On day 75, Integrator1 should assume a value equal to Previous_Timestep_Value.

These results may best be seen by viewing Result1 in Table mode.

Vector_Matrix Container

1. The value of elements in the PreviousValue1 vector should lag the values in the Stochastic1 vector by one timestep.

2. The output of members of the Condition_Matrix and the Value_Matrix should be True and 1 respectively at day 50. Members of the previous value matrices should lag their respective inputs by one day.
3. Expression 1 tests the Previous Value element's Rate of Change output. It should be 1 1/d on day 50 and -1 1/d on day 51. (The increase to 1 on day 50 is an average rate of change of 1 1/d and the decrease back to 0 -1 1/d).

Events_Discrete_Changes_Container

1. The time output of Milestone1 should take on a value of 1 at time = 1 day, and a value of 101 at time = 101 days, as TriggeredEvent1 is activated at time = 0 d and at time = 100d.
2. Integrator2 should take on a value of 442 at time = 1 day, and a value of 884 at time = 101 days, as DiscreteChange1 (with a value of 442) is activated at time = 0 d and at time = 100d.

Initial_Values_Container

1. Verify that the value of X in the Initial_Values container is 502. This is because the Previous Value element has an Initial Value of 100, and 2 is added to the previous value at each update (200 timesteps = 201 updates = 402 added).
2. Enter the Cond_Initial_Values container and verify that the value of X is 482. This is because the Previous Value element has an Initial Value of 100, and 2 is added to the previous value at each update (the container is activated at 10 days, so it receives 191 updates = 382 added).

Static_Submodel

Enter the looping container inside the static submodel and confirm that the script element inside has recorded the values 0,1,2,3,4,5,6,7,8,9 as a vector of 10 items.

GS34_Modify_Units_and_Sets

This file verifies that 1) members of an array-label can be added or deleted without causing elements based on that set to "crash"; and 2) user-defined units (that are currently used by the model) cannot be deleted.

- 1) The test for adding/removing members of an ordinal set proceeds as follows:
 - a. Open the elements IQ and Cooperation_Factor to view their current values. Next, open the Array Labels dialog box (under the pull-down menu Model, select Array Labels). Then select the "People" array labels, and then "Edit Set".
 - b. Add one or more entries to the set and click "OK" and "Close" to exit the Array Labels dialog.
 - c. Open the element IQ and ensure that a new member (row) has been added to the vector for each new set member. Likewise, open Cooperation_Factor and ensure that a new row and column has been added for each new set member. The values in all new cells should be 0.0.

- d. Finally, open the Array Label dialog and delete one or more entries from the People set. Ensure that the corresponding rows and/or columns are removed from IQ and Cooperation_Factor.

Also ensure that no other "problems" result from these operations.

2) The test for removing a user-defined unit that is currently in use is as follows. Enter the container User_Defined_Unit_Test. From the Model menu, select Units. Then, scroll to the "Math Constants" folder, highlight the unit with name "Trho", and then select the "Remove" button on the right side of the dialog box. You should get a message that the unit cannot be deleted because it is in use. Click the "Show References" button to make sure that Data1 is listed. Click the "Close" button to complete the test.

GS34b_Units_Wizard

This file tests the units wizard. Open the model and go to the units wizard. Create a unit abbreviated dmgl and define it as 1 day * 1 mg/L. Put it in the category of WeightedConcentration. After closing the units wizard, go to the element Integrated_Concentration and give it units of dmgl.

Create another unit for langleys and abbreviate it as lang. Define it as 41840 kg/s². Put it in the Solar_Radiation category of units. Close the units dialog and make sure the element Solar_Radiation is defined as 1 lang/day and it has display units of kW/m². Run the model and confirm the element True_if_everything_works is true.

GS35_Dynamic_Export

This test verifies that the Export feature correctly exports results to an ASCII file, binary file and a database. This particular test file represents a dynamic model. The model must be run to calculate the results.

Structured ASCII Text File Format

1. After running the model, select File from the menu bar, then Export, and then Results.
2. First, select the "ASCII Text" export option. Next, select one or two reservoir elements to be exported. Then select one or more time points, but not all of the time points. Next, select one or more realizations, but not all of the realizations. Next, enter a file name and path where you would like the text file to be saved. Click Finish. Open the text file and compare the results with the results for the output Data Element "Reservoir1", "Reservoir1_1", and "Reservoir1_2".

Repeat the steps above, however, this time select all elements, all time points and all realizations. Open both text files and compare the results with the results for "Reservoir1", "Reservoir1_1", and "Reservoir1_2" in the model.

Binary File – MayDay Format:

1. After running the model, select File from the menu bar, then Export, and then Results.

2. First, select one or two reservoir elements to be exported. Then select one or select one or more time points, but not all of the time points. Next, select one or more realizations, but not all of the realizations. Next, enter a file name and path where you would like the binary file to be saved. Click Finish. Use Mayday Reader to view the binary file and compare the results with the results for the output Data Element "Reservoir1", "Reservoir1_1", and "Reservoir1_2".7.

Repeat the steps above, however, this time select all time points and all realizations. Use Mayday Reader to view the binary file and compare the results with the results for "Reservoir1", "Reservoir1_1", and "Reservoir1_2" in the model.

Results Database (MS-Access-MDB file)

1. After running the model, select File from the menu bar, then Export, and then Results.
2. First, select one or two reservoir elements to be exported. Then select one or more time points, but not all of the time points. Next, select one or more realizations, but not all of the realizations. Next, enter a file name and path where you would like the database to be saved. Click Finish. Open the database and compare the results in tblResults with the results in the output Data Elements "Reservoir1", "Reservoir1_1", and "Reservoir1_2".. Also, compare the results in tblUserDistribution with tables GS35_5 and GS35_Cumulative and - Discrete.

Repeat the steps above, however, this time select all elements, all time points and all realizations. Open the database and compare the results in tblResults with the results for "Reservoir1", "Reservoir1_1", and "Reservoir1_2" in the model.

GS36_Static_export

This test verifies that the Export Feature correctly exports results to an ASCII file, binary file and a database. This particular test file represents a static model.

Structured ASCII Text File Format

1. After running the model, select File from the menu bar, then Export, and then Results.
2. Select one or two reservoirs and one or more realizations for export. Next, enter a file name and path where you would like the text file to be saved. Click Finish. Open the text file and compare the results with those for "Reservoir1", "Reservoir1_1", and "Reservoir1_2" in the model.
3. Repeat the steps above, however, this time select all elements and realizations. Open the text file and compare the results with those for "Reservoir1", "Reservoir1_1", and "Reservoir1_2" in the model.

Binary File – MayDay Format:

1. After running the model, select File from the menu bar, then Export, and then Results.
2. Select one or two reservoir elements and one or more realizations, but not all of the realizations for export. Next, enter a file name and path where you would like the binary

file to be saved. Click Finish. Use Mayday Reader to view the binary file and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.

3. Repeat the steps above, however, this time select all elements and all realizations. Use the Mayday Reader to view the binary and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.
- 4. Results Database (MS-Access-MDB file)**
1. After running the model, select File from the menu bar, then Export, and then Results.
 2. Select one or two reservoirs and one or more realizations, but not all of the realizations for export. Next, enter a file name and path where you would like the database to be saved. Click Finish. Open the database and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model.
 3. Repeat the steps above, however, this time select all elements and all realizations. Open the database and compare the results with those for "Resveroir1", "Reservoir1_1", and "Reservoir1_2" in the model. Also, compare the results in tblUserDistribution with table GS36_Static_Export – Cumulative and –Discrete..

Table GS36_Static_Export - Cumulative - User Distribution

Probability	Value
0	0
0.2	1
0.3	7
1	8

Table GS36_Static_Export - Discrete - User Distribution

Probability	Value
0.1	1
0.4	2
0.5	3

GS37_Initial Values and Previous-Value Elements

This file verifies the functionality of initial values and previous-value links for GoldSim elements. Follow the tests below. Expected results are listed in the appropriate sub-sections.

Initial Values and Activation

Enter the container Initial_Values. This container activates at time = 10 days. Run the model and compare model results to the following:

- a. The results for all elements should be 0.5 except for Stochastic1 and Selector 1. Stochastic1 should be a sampled stochastic value between 0 and 1. Selector1 should be 0 before time = 10 days and 0.5 thereafter.

Return to the main model window.

Previous-Value Links

The Previous_Value_Links container contains tests to verify that only certain elements can originate a previous-value link. No action is necessary in this container; if the model has been run successfully for the previously-described tests in this file, then all tests in this container have been completed.

‘Function of’ and ‘Affects’ with Previous-Value Links

Enter the container Function_of. This container verifies that the 'Function of' and 'Affects' dialogs work properly when previous value links are present. The test proceeds as follows:

1. Check the 'Function of' dialog for Expression8. It should show that Expression8 is a function of Expression7, Integrator3_1, PV_Expression8 and Expression8 (forming a loop).
2. Check the 'Affects' dialog for Integrator3_1. It should show that Integrator3_1 affects Expression7, Expression8, PV_Expression8 and Integrator3_1 (forming a loop).

Illegal Initial Values

Enter the container named Failed_Initial_Values. Tests in this container verify that initial values for certain elements cannot contain previous-value links. The test proceeds as follows:

- a. Place GoldSim in edit mode and enter the element Previous as the initial value for Integrator2. Run the model. You should get a message stating that initial values cannot contain previous value links. Return to edit mode and change the initial value back to 0.0.
- b. Enter the element Previous as the initial value for Reservoir2. Run the model. You should get a message stating that initial values cannot contain previous value links. Change the initial value back to 0.0.

GS38_Changed and Occurs

This file verifies that the functions *changed()* and *occurs()* operate correctly. Run the model. For each element listed in Table GS38, compare the model output with the expected results shown in the table.

TABLE GS38

Test Element	Expected Result	Purpose of Test
Changed1	Value spikes to 1 at time 10, and is zero for all other times	Event occurrences are recorded by changed()
Changed2	Number of events changes from 0 to 1 at time 10 days	Changed() can be used as a condition in the trigger dialog
Changed3	Value spikes to 1 at time 10, and is zero for all other times	Container status changes are recorded by changed()
Changed4	Value changes from 0 to 1 at time	Ensures that changed()

Test Element	Expected Result	Purpose of Test
	10 days, and then remains at a value of 1	behaves properly for continuously-varying input parameter
Changed5	Value spikes to 1 at time 10, and is zero for all other times	Repeats Changed1 test with a Data element.
Occurs1	Value spikes to 1 at time 10, and is zero for all other times	Triggered Event transaction recorded by occurs()
Occurs2	Value spikes to 1 at time 10, and is zero for all other times	Timed Event transaction recorded by occurs()
Occurs3	Value spikes to 1 at time 11, and is zero for all other times	Event Delay transaction recorded by occurs()

GS39_Decision_Milestone_Status

This file verifies that the Decision, Milestone, and Status elements operate correctly. Run the model. For each element listed in Table GS39_1, compare the model output with the expected results shown in the table.

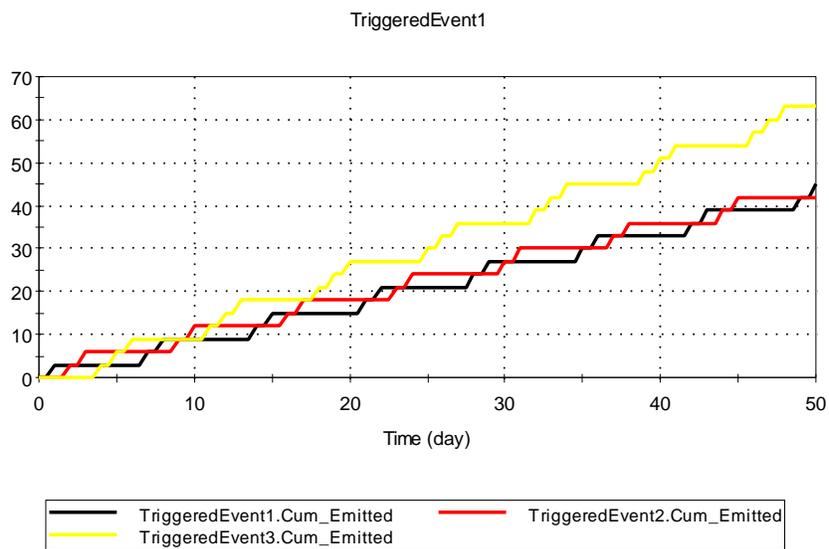
Table GS39_1

Test Element	Expected Result	Purpose of Test
Milestone1	Time = 10 days. The following warning message is also generated: "Ignoring attempt to achieve Milestone Milestone1, which was already achieved at time 10 day."	Ensures that GoldSim produces a warning message when the "Event may only occur once" option is selected
Milestone2	Time = 15 day.	Tests Automatic Triggering
Milestone3	Time = 15 day.	Tests User-defined Triggering with onTrue trigger type.
Milestone4	Time = 1.5 day.	Tests User-defined triggering with onEvent trigger type.
Milestone5	Time = 15 day.	Tests User-defined triggering with onChanged trigger type.
Milestone6	Time = 10 days	Tests the "Event may occur multiple times/Store time of first occurrence" option (milestone triggered at 10 and 20 days).
Milestone7	Time = 40 days	Tests the "Event may occur multiple times/Store time of latest occurrence" option (milestone triggered at 10, 25 and 40 days).
Milestone8	Never activated	Tests the "Record a warning message if this milestone is never achieved" option. Should generate a run log warning when the model is run.

Test Element	Expected Result	Purpose of Test
Decision1	Value will change from 0 to 3 at time 10 days.	Tests Automatic triggering with two outputs.
Decision2	Value will change from 0 to 2 at time 10 days.	Tests Automatic triggering with three outputs.
Decision3	Value will change from 0 to 1 at time 12 days.	Tests User-defined triggering with two outputs.
Decision4	Value will change from 0 to 2 at time 12 days.	Tests User-defined triggering with three outputs.
Decision6	Value of LastDecision output should jump to 1 at time 1 day and then oscillate between 1 and 3 for the remainder of the simulation	Tests the ability of the decision element to reference its LastDecision output.
Status1	Value changes from 0 to 1 at 5 days, from 1 to 0 at 10 days, from 0 to 1 at 20 days, and from 1 to 0 at 25 days	Test that User-defined triggering sets the Status output to true or false when the triggers fire.
Status2	Value changes from 0 to 1 at time 25 days	Test User-defined triggering.
Status3	Value changes from 1 to 0 at time 20 days	Test User-defined triggering.
References_Itself	Value starts at true, and then oscillates between true and false for the rest of the simulation (changes value once per timestep).	Tests dynamic features of status elements (initialization and ability to reference itself).

Then enter the container called “Decisions\Multiple_Simultaneous_Events” and ensure that both the shape and values in the Result1 graph correspond with Figure GS39_1 below (also pasted in the model).

Figure GS39_1



GS40_Information Time Series

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS40b_InformationTimeSeriesExcelSupport

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS41_Material Time Series

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS41b_InformationTimeSeriesExcelSupport

<REVISED TIME SERIES ELEMENTS WERE INTRODUCED IN VERSION 9.60 WITH EXISTING ELEMENTS AUTOMATICALLY CONVERTED>

<THIS TEST SUPERCEDED BY GS60 FOR VERSION 9.60 AND LATER>

GS42_Date Time Series

This file verifies that Information and Material Time Series elements function correctly in date/time mode. The tester should perform the following steps:

1. With the model in date/time mode:
 - a. Switch each history table between elapsed and date-time modes, and confirm that the contents do not change. The start date of Jan 15, 2001 10:00 AM should convert to 15 days of elapsed time relative to a start date of January 1, 2001 10:00 AM.
 - b. Run the model with the tables in each mode, and confirm that the results do not change.
2. With the model in elapsed-time mode:
 - a. Switch each history table between elapsed and date-time modes, and confirm that the contents do not change. The start date of Jan 15, 2001 10:00 AM should convert to 15 days of elapsed time relative to a start date of January 1, 2001 8:00 AM.
 - b. Run the model with the tables in each mode, and confirm that the results do not change.

GS43_Versioning

There is no predefined test file for this case. Start with a new GoldSim file, and carry out the following steps:

1. Enable all modules that have elements (i.e. the RT, FN, RL modules).
2. Add a new Container, “C”.
3. Use the Model/Versioning menu, enable versioning, add a first version titled “one”, and from the Version Manager dialog select the first version as the ‘Show’ version. Exit the Version Manager.
4. Add a Data element into the root Container. Then add one of every other type of element (except SubModel) into Container C.
5. Enable the browser and confirm that all elements are flagged in red except for those existing prior to enabling versioning. Display the element context-menu option “Show Changes...” for several elements and Containers, and confirm that the appropriate logging messages are present: element added (for normal elements), and a summary of the elements added for the Containers.
6. Delete one or more of the elements. Move one or more elements to a different container.
7. Add a Version Change Note using its context menu to one of the elements. Confirm that the note is accessible from that element’s change log.
8. Add a new version; “two”, and make it the reference version by clicking the “Show” checkbox next to it in the versioning dialog.
9. Randomly change different properties of a number of elements, and confirm that their change logs are updated correctly:
 - a. Element ID
 - b. Element description
 - c. A normal input field
 - d. A setting such as a check-box
10. Select one element and change all its available properties. Switch to version “one” as the reference version, and confirm that appropriate log messages are displayed for this element. Test the ‘Show History’ and ‘Show Global Changes’ options and confirm that the changes are reported. Test using either “one” or “two” as the reference version.
11. Move several elements between the root and “C” folders. Confirm that their change logs and the Container change logs report the moves.
12. Delete several elements. Confirm that their (previous) Containers indicate they were deleted.
13. Return to the Version Manager dialog and generate a report. Print the report. Confirm for several elements that the report correctly reflects their change logs.

14. In the Version Manager, delete version “one”. Test several elements and confirm that their change logs reflect their changes since version “two”. Confirm that the elements that were added and then deleted prior to version “two” are not present in the change logs. Confirm that the elements that were moved prior to version “two” are no longer shown as moved.
15. To test serializing of the change logs, save the test file. Open a new file. Reopen the test file, and confirm that the change logs for several elements are identical to their contents prior to saving and reopening the file.

GS44_External File Locking

This test checks the external file locking capability of the Spreadsheet, File, External, and External Pathway elements. There are four test files, each containing one of the above elements linked to an external file. Each file is first run to ensure that the simulation can be conducted without error using the original locked files. Next, each of the locked files is replaced with a different file of the same name, and the model files are re-run. Each should issue an error message stating that the locked external file has been modified, and the simulation should be terminated.

- 1) Open GS44_CRC_Spreadsheet and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
- 2) Rename the external file GS44.xls to GS44_old.xls, then copy GS44_Modified.xls and rename the copy to match the original filename (GS44.xls). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
- 3) Open GS44_CRC_File and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
- 4) Rename the external file GS44.txt to GS44_old.txt, then copy GS44_Modified.txt and rename the copy to match the original filename (GS44.txt). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
- 5) Open GS44_CRC_External and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
- 6) Rename the external file GS44.dll to GS44_old.dll, then copy GS44_Modified.dll and rename the copy to match the original filename (GS44.dll). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
- 7) Open GS44_CRC_ExternalPath and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).
- 8) Rename the external file GS44_Pathway.dll to GS44_Pathway_old.dll, then copy GS44_Pathway_Modified.dll and rename the copy to match the original filename (GS44_Pathway.dll). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.
- 9) Open GS44_CRC_Lookup and run the model. The simulation should execute successfully. (If an error message is presented, un-check and then re-check the “Lock External File” checkbox and re-run the simulation).Rename the external files

GS44_LookupTable.txt and GS44_lookupTable.xlsx to GS44_LookupTable_old.txt and GS44_lookupTable_old.xlsx respectively, then copy GS44_LookupTable_Modified.txt and GS44_lookupTable_Modified.xlsx and rename the copies to match the original filenames (GS44_LookupTable.txt and GS44_lookupTable.xlsx). Re-run the model. You should receive an error message stating that the locked external file has been modified, and the simulation should terminate.

GS45_Command-Line Arguments

These tests verify that the various command-line arguments are functioning properly. Open a command line window and navigate to the directory containing the GoldSim executable file. For those tests that require a model file, you will need to either copy the model file into the GoldSim root directory, or specify the full path (in quotes) to the model file. Type the following commands into the command line window. You should exit GoldSim after conducting each test:

1. `goldsim -show Container1 "{path}GS45_Command.gsm"` - GoldSim should open and show the contents of Container1.
2. `goldsim -d "InitialValue = 10d" -r -sv "{path} GS45_Command2.gsm" -x "{path}GS45_Command.gsm"` - GoldSim should open and immediately run the simulation, then save it as GS_Command2.gsm and close. Confirm that the Integrator in Container1 has a value of 101 at the end of the simulation.
3. `goldsim -data "Integrator1.Initial Value = 20d" -r -sv "{path} GS45_Command3.gsm" -x "{path}GS45_Command.gsm"` - GoldSim should open and immediately run the simulation, then save it as GS_Command3.gsm and close. Confirm that the Integrator in Container1 has a value of 120 at the end of the simulation and that the Initial Value field in the Integrator shows 20d instead of being linked to InitialValue.
4. `goldsim -s` - GoldSim should launch in slave mode.
5. `goldsim -slave` - GoldSim should launch in slave mode.

GS46_Dashboard and Player

The dashboard and player test consists of four separate sub-tests. The first is designed to verify the proper functionality of each of the dashboard elements, including inputs, outputs, and buttons. The second sub-test exercises the linkages between dashboard elements and the underlying model elements. The third test verifies the creation of a player file, and the fourth test verifies the proper functionality of the GoldSim Player.

1. Open file GS46_Dashboard1.gsm and go into Dashboard1. Place the Model in Edit Mode and Activate the Dashboard.
 - a. Change the values of each of the four input controls. Try entering values less than 0 and greater than 2 into the text box (these values should not be allowed and an error message will result). Flip to Design Mode, and then change the smallest allowed increment for the controls for Data1 through 4. Activate the dashboard and ensure that GoldSim warns if a prohibited value is entered or automatically adjusts the value to the nearest permitted value. During these tests

- confirm that the value reported by each of the output controls equals $\text{Data1} + \text{Data2} + (\text{Data3} * \text{Data4}) + \text{Data5} + \text{Data6} + \text{ETime}$. Make sure the reported values are correct. Check and uncheck the checkbox and make sure the results are correctly updated. (Etime should have a value of 0 before the simulation is run). Verify that the value of Data 7 changes when different dates are selected.
- b. Click the Run Model button to run the simulation. Make sure the results are still correct. Etime should now have a value of 10, so the displayed results should have been incremented by this amount.
 - c. Check (or uncheck) the checkbox (Data3) and re-run the model. Again, verify the results.
 - d. Click the Reset Values button. Ensure all controls return to their defaults.
 - e. Click the button labeled “Go To Data1”. The model container should be shown in the graphics pane, and element Data1 should be selected.
 - f. Return to the dashboard and click the button labeled “Open Data1”. The property page for element Data1 should be displayed. Also, the value displayed in the definition field should match that shown in the dashboard control labeled Data1.
 - g. Click the button “Show Container1”. The graphical pane should display the contents of Container1. Use the Back arrow on the graphics pane to return to the dashboard.
 - h. Repeat the previous test, this time using the hyperlink in Container1 to return to the dashboard.
 - i. Return to the dashboard and click the “Execute Application” button. A new copy of GoldSim should be launched. (If this doesn’t work, first edit the properties of that button and make sure the path represents the correct path to the GoldSim executable on your machine).
 - j. Click the button labeled “Open File.txt”. A text file should appear in notepad. (If this doesn’t work, first make sure the test file of that name is present in the same directory as the verification test file).
 - k. Click the button labeled “Open URL”. The GoldSim website should open in a web browser.
 - l. Click the button labeled “Open Dashboard2”. Dashboard2 should open be opened. Click the button labeled “Open Dashboard1” to return.
 - m. Click the button labeled “Show Result”. A chart of Data5 should be displayed. (Note that you will need to be in results mode to view actual results).
 - n. Click the button labeled “Database Download”. The database download dialogs should appear. Check element Data1 in the Simple_Database container to make sure the download took place by inspecting the date/time label in the Database tab. (In order to complete this step, you will need to have set up the connection to the Simple Database test file as outlined in test GS09_DBAS).
 - o. Click the button labeled Open TimeSettings – the time page of the Simulation Settings dialog should open.
 - p. Click the button labeled OpenMonteCarlo – the time page of the Simulation Settings dialog should open.
 - q. Click the Edit Time Series button. Ensure that a value of 0 is specified at 0d and a value of 100 is specified for 100d.
 - r. Click the Edit Lookup Table button. Ensure that a value of 0 is specified for an independent variable value of 0d and a value of 50 is specified for an independent variable value of 10d.
 - s. Click the Change Spreadsheet button. Ensure that GS46DashboardA.xlsx is selected.

- t. Run the model and click the Show TS/Table/SS Values button. The TimeSeries should change from 0 to 100 linearly over the course of the simulation, while Expression1 (linked to a Lookup Table) should linearly increase from 0 to 50 over the course of the simulation. The Spreadsheet output should show a constant value equal to Data1.
 - u. Return to Edit/Ready Mode. Click the Edit Time Series button and make changes to the Time Series data (add an extra time point, change the starting and ending values).
 - v. Click the Edit Lookup Table button. Add additional data points and edit the existing dependent values.
 - w. Click the Change Spreadsheet button. Select GS46DashboardB.xlsx.
 - x. Re-run the model and click the Show TS/Table/SS Values button. The outputs from the TimeSeries and the Expression that uses the LookupTable should reflect the changes made in step u) and v). The output of the Spreadsheet element should now be equal to $5 * \text{Data1}$.
2. Open file GS46_Dashboard2.
 - a. Move each of the four data elements from the root container into Container2. Go into the dashboard and place the model in run mode. Change each of the input values and make sure the output values display the correct result ($\text{Data1} + \text{Data2} + \text{Data3} * \text{Data4} + \text{Data5} + \text{Data6}$). Run the model and re-check the results.
 - b. Rename each of the four data elements and then repeat checks in Step a.
 - c. Delete one of the input data elements. Go back into the dashboard and try to place the file into Run Mode. You should receive an error message referring to the deleted element not being found. You should not be able to run the model or interact with the dashboard in run mode.
 3. Re-open file GS46_Dashboard1. Make sure the model is in Result mode. From the File menu, select "Save Player File". (Note that you must be running GoldSim Pro, and have the "Dashboard Publishing" option checked in the Extension Modules dialog.)
 - a. In the second step of the wizard, fill in the author name, model title, and model description. Click Next.
 - b. Accept the defaults in Step 3 and click Finish to save the player file as GS46_Player1.gsp.
 - c. Next, re-enter the wizard and save a new player file. This time, select the "Show Top Level Container when model opens" and "Allow User to Run Model" options. Under the "Allow User to Run Model" entry, check the boxes to allow the user to change both the Time and Monte Carlo simulation settings. Save the file as GS46_Player2.gsp.
 - d. Look in the directory you specified and make sure that the two player files were created.
 4. Launch the GoldSim Player.
 - a. Open file GS46_Player1.gsp. Repeat steps a) through m) in Part 1 of this test. You should observe the following differences in behavior (because running the model was disabled for this player file):
 - i. The dashboard inputs will not be editable because the file is in results mode (steps a, c)
 - ii. The "Run Model" will do nothing (step b);
 - iii. The "Database Download" button will issue a message that database downloads cannot be conducted in Results mode (step m).

-
- b. Click the “Show Container1” button again to browse the model. Click through the menu items and toolbar buttons. Refer to the user interface steps listed in GS_00_User_Interface. For each of the individual checks listed in the User Interface test, the appropriate behavior in the Player is described below.
 - i. Extension Modules – should not be available in the Model|Options dialog
 - ii. Send to – should not be available in the File Menu
 - iii. Property Dialogs – the property dialog for an element should be available on double-click, but all input fields should be grayed out.
 - iv. Search and Synchronization – The Search tool should function in the same manner as GoldSim, and the graphical and browser panes should synchronize correctly.
 - v. Navigation Buttons - The navigation buttons should function in the same manner as in GoldSim.
 - vi. Filter – the Filter should not be available.
 - vii. Graphics – the Graphics menu should not be available, nor should the right-click graphics options.
 - viii. Simulation Settings – the simulation settings dialog should be available by going to Model|Simulation Settings.
 - ix. Editing – editing of element properties should be disabled.
 - x. Moving, Copying, Deleting – moving, copying, and deleting of elements should not be available.
 - xi. ToolTips – tooltips should function in the same manner as in GoldSim.
 - xii. Input/Output Windows – the input and output popup windows should function in the same manner as in GoldSim.
 - xiii. Zooming – the zoom, zoom to fit, and pan options should be available on the toolbar, but not from the right-click context menu.
 - xiv. Appearance – the appearance options in the context menu should all be unavailable.
 - xv. Drawing Tools – the drawing tools (text, shapes, links, etc.) should all be disabled.
 - xvi. Run Mode – the Model menu option should not be available, the Run button on the toolbar should be disabled, and F5 should do nothing.
 - xvii. Result Mode – the model should be in Result mode by default. All behaviors should be the same as in GoldSim.
 - xviii. Export Graphics – this feature should not be available.
 - xix. Inserting Elements – Inserting elements should not be possible.
 - xx. Link Cursor – the link cursor should be disabled.
 - c. Open file GS46_Player2.gsp. Repeat steps a), and b) in Part 1 of this test. You should observe the same behavior as described in that test (i.e., the model should run successfully). Save the model in the Player, and then close the Player and reopen GS46_Player2.gsp. Ensure that changes to Dashboard elements are retained and no errors occur when the model is loaded.
 - d. Click the “Show Container1” button again to browse the model. Check the following behaviors specific to running the model:
 - i. Simulation Settings – the simulation settings dialog should be available from the Model menu. Duration, timesteps and Monte Carlo options (with the exception of those in the Advanced dialog) should be editable.

- ii. Run Mode – run mode should be available from the Model menu, the toolbar button, and by hitting F5. All of the standard run mode functionality (run, pause, abort, resume, reset) should be available.
 - iii. View Run Log – the run log should be accessible from the Model menu.
 - iv. Options Dialog – the options dialog should be accessible from the Model menu, but only the Results tab should be visible.
- e. Return to Dashboard1. Change the values for Data1 through Data7 and record the changes. Click the Go to Data1 button. Ensure that Data1, through Data7 show the appropriate values in their tool tips. Return to Dashboard 1 and ensure that the controls for Data1 through Data7 continue to display the changed values.
- f. Change the values for Data1, Data2, Data3, and Data4 a second time and record the changes. Run the model, then click the Go to Data1 button. Verify that the data elements show the correct values when you view their tooltips. Return to Dashboard1 and ensure that the dashboard continues to display the changed values.

GS46a_Dynamic_Dashboard

This test verifies that dashboard editing is prohibited during the simulation unless authorized by the model creator. It also ensures that if the dashboard controls can be edited during a run that the linked elements update their values correctly.

To run the test, open GS46a_Dynamic_Dashboard.gsm and follow these steps:

1. Enter the dashboard and ensure all controls are set to their default value and that editing of the controls is not permitted during the simulation run (the “Allow value to be changed during simulation” option should not be checked).
2. Run the model and pause it midway through the simulation (it may be necessary to reduce the speed of the simulation using the slider in the run controller).
3. Attempt to edit all of the controls in the dashboard. They should not be editable. Allow the simulation to run to completion and view the Result time history. The values of all outputs should be 1 over the course of the simulation except for the Condition type Data element’s value, which should be 0 and the DateTime control, which should show its default value.
4. Return to Edit Mode and make the Dashboard controls editable during the simulation by checking the “Allow value to be changed during simulation” box on each control’s property dialog.
5. Run the model and pause it midway through the simulation (it may be necessary to reduce the speed of the simulation using the slider in the run controller).
6. Change the value of the Input Field and Sliders to 2, check both Checkboxes, select option B in the Combo and List Boxes, and specify a value of two for both items in the Grid Control. Select a different date in the DateTime Control. Run the model to completion and view the Result time histories by clicking the Dashboard buttons. Values should be 1 until the point at which the simulation was paused and 2 for the

remainder of the simulation. The Condition output should be false until the point the simulation was paused and true for the remainder of the simulation. The DateTime graph should show the default value up until the time the simulation was paused and the user-selected value after that.

GS46b_DB_Grid_Controls

This test verifies the correct functioning of the Grid Controls added in GoldSim Version 10. It consists of a dashboard and a series of data elements.

To complete the test the user should enter each of the containers (Scalar, Vector and Matrix). They should ensure that the values in the controlled data elements update when changes are made in the grid control, and they should also ensure that the grid controls return to their defaults when the Reset to Defaults button is selected. The verifier should also ensure the controlled elements also change to the default values.

GS46c_Status_Control

This test verifies the correct functioning of the Status dashboard output control added in GoldSim Version 10.

To run the verification test simply enter each dashboard in the test file and confirm the Status controls change their appearance in the manner described as the value of the input control is varied.

GS47_Run Properties

This test checks that the Run Properties produce the correct values. This test consists of two parts: the first (file GS47_RunProperties a) tests a calendar date/time simulation which runs from January 1, 2002 to December 31, 2002. The second (GS47_RunPropertiesb) tests an elapsed time simulation, which runs for 365 days. The verification files GS47_RunPropertiesa and GS47_RunPropertiesb must first be run. For expected results, see tables GS47_RunPropertiesa and GS47_RunProperties

Table GS47_RunPropertiesa

Output	Expected Result
Year_1	2002
Day_1	31
Month_1	12
Hour_1	23
Minute_1	59
Second_1	59
DayOfWeek_1	3
WeekOfYear_1	53
DayOfYear_1	365
Quarter_1	4
Realization_1	1
Timestep_Length_1	1 day
Start_Time_1	1/1/2002 12:00:00AM
Time_1	37622 day
Etime_1	365 day

Table GS47_RunPropertiesb

Output	Expected Result
Year_1	1
Day_1	31
Month_1	12
Hour_1	0
Minute_1	0
Second_1	0
DayOfWeek_1	2
WeekOfYear_1	53
DayOfYear_1	366
Quarter_1	4
Realization_1	1
Timestep_Length_1	1 day
Start_Time_1	Dec. 30, 1999
Time_1	365 day
Etime_1	365 day

GS48_Convolution

This test verifies the performance of the Convolution element. The test evaluates both scalar and vector inputs, and both Transfer function and Integrated Transfer function inputs.

The input function is a step that starts at 1.0 at time 0, and becomes equal to -1.0 at time 50.

The transfer function is a normal distribution with mean 20 seconds and standard deviation 5 seconds, which produces a delayed, 'smeared' response to the input function.

The integral of the transfer function is a cumulative normal distribution. This is input to those elements defined to have an integrated function.

The transformed result is calculated analytically using Expression elements.

The user should run the model, and then compare the curves in each of the three time-history result elements to ensure that the analytical and computed results are closely similar. Because the Convolution element uses a numerical integration, small discrepancies are acceptable.

GS48b_Truncated_Convolution

This test verifies the proper functioning of the truncation features in the Convolution element. It takes a constant signal (1) and feeds it through a Convolution element with a step transfer function (0.05 between 10 and 30s, 0 otherwise).

Run the model and compare Result1 to the Figure GS48b-01 below.

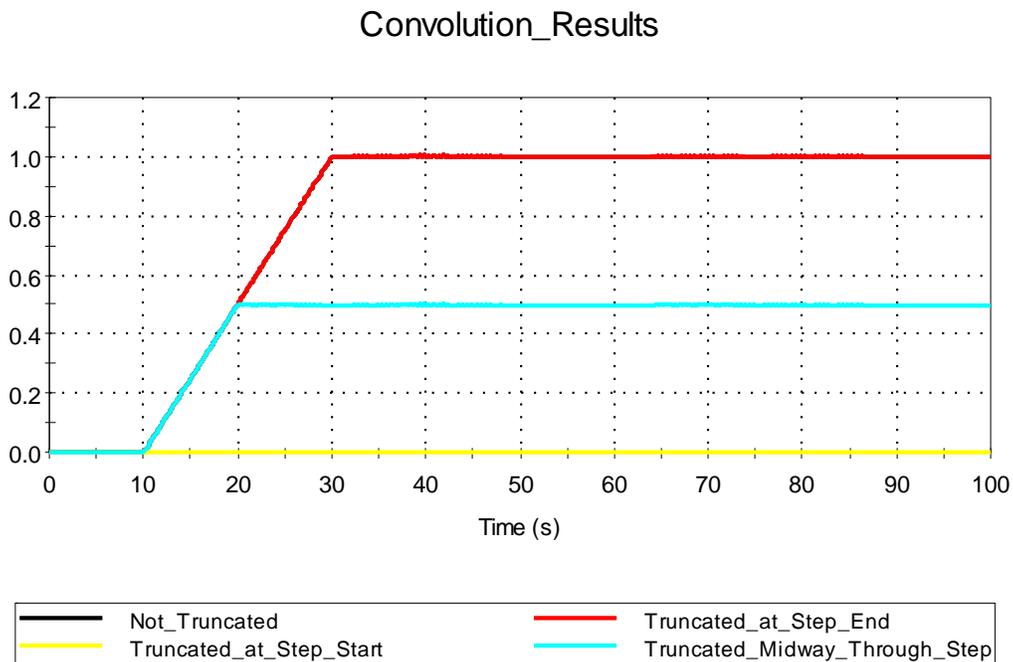


Figure GS48b-01

Verify that the final values of the convolution elements are as follows:

Not_Truncated = 1

Truncated_at_Step_End = 0.9975

Truncated_Midway_Through_Step = 0.4975

Truncated_at_Step_Start = 0

GS49_RandomChoice

This test verifies the proper functioning of the Random Choice element. A timed event element generates 1000 events at the start of the first and second timestep, and these events should be divided according to the proportions defined in the random choice element. These proportions are:

Event1 - 0.15 first timestep, 0.25 second timestep

Event2 - 0.35 first timestep, 0.5 second timestep
Event3 - 0.25 first timestep, 0.05 second timestep
LastEvent - 0.25 first timestep, 0.2 second timestep

Instructions/Expected Results: Run the model and check that the cumulative emitted values for each of the "Random" timed events corresponds with the expected value below.

Random_1 - 400
Random_2 - 850
Random_3 - 300
Random_4 - 450

GS50_LookupTables

This file contains tests for Look-up tables that are defined locally (i.e., either defined within the element or read in from a text file using the "Import Table" feature) as opposed to defined externally. The test consists of six parts:

1. Pasting data into Tables
2. General testing of lookup, extrapolation and interpolation features.
3. Importing Tables
4. Call tests
5. Miscellaneous features
6. Verifying that the user is warned properly when a table receives a query that is outside its bounds

1. Pasting data into Tables. In order to test the ability to paste copied data into Table elements, the user should execute the following procedure. First, in the file GS50_look.gsm, enter the container Pasting_Tests.

- a. Open the Excel spreadsheet that is linked to GS50_look.gsm (double-click on the hyperlink titled "Data to Paste", which is found next to the container Pasting_Tests) and enter the worksheet named "GS50".
- b. 1D Table: Open the 1D Table, and click "Edit Data". Click in the upper left cell in the table grid (there should only be two cells available). Go to the spreadsheet, highlight the 2 column x 51 row data set indicated by the text, and copy it (CTRL C). Return to GoldSim and paste the data (CTRL V). The 1D Table grid should expand to encompass the data, and all data should appear as in the spreadsheet. Verify that the paste was completed successfully by scrolling through the table. Click "OK" twice to exit the 1D Table's dialog boxes.
- c. 2D Table: Open the 2D Table, and click "Edit Data". Click in the upper left cell in the table grid (this cell is above the row heading and to the left of the column heading for the single existing data cell). Go to the spreadsheet, highlight the 51 column x 51 row data set indicated by the text, and copy it (CTRL C). Return to GoldSim and paste the data (CTRL V). The 2D Table grid should expand to encompass the data (all 2500 entries), and all data should appear as in the spreadsheet. Verify that the paste was completed successfully by scrolling through the table. Click "OK" twice to exit the 2D Table's dialog boxes.
- d. 3D Table. First, click "Edit Data" and then add a new layer (Layer 1). Then switch current the layer back to 0. Next, follow the same instructions as for the 2D Table for

Layer0. Then, switch to Layer 1 and ensure that Layer 1 is now a 50 x 50 cell grid. Add a new layer (Layer 2) and ensure that it is added as a 50 x 50 grid. Close and re-open the 3-D table element and ensure that the pasted data remains correct.

- e. Run the model and open the Result element called “Time History”. All three time histories should be identical with the exception of the 3d table at the first two timepoints. Because the 3d table does not permit extrapolation it will show its minimum value of 2 at 0s and 0.5s.

2. General testing of lookup, extrapolation and interpolation features. Look-up table functionality is verified by comparing model results with known results. The expected results for each non-time dependent output are presented either in a note or in the tool tip window for each element for easy comparison with the current value output. The look-up table tests checked in this section include:

1D Table

- look-up data point at, between, and outside table data points, linear interpolation and extrapolation
- look-up data point at, between, and outside table data points, linear interpolation and no extrapolation
- look-up data point at, between, and outside table data points, linear interpolation and extrapolation on the dependent variable axis, log interpolation and extrapolation on the independent axis
- look-up data point at, between, and outside table data points, log interpolation and extrapolation on the dependent variable axis, linear interpolation and extrapolation on the independent axis

2D Table

- look-up data point at table data point
- look-up data point between table data points with linear interpolation on the dependent and independent variables
- look-up data point with logarithmic dependent variable interpolation and linear independent variable interpolation
- look-up data point with linear dependent variable interpolation and linear independent variable interpolation

3D Table

- look-up data point at table data point
- look-up data point between table data points with linear interpolation on the dependent and independent variables
- look-up data point with logarithmic dependent variable interpolation and linear independent variable interpolation

- look-up data point with linear dependent variable interpolation and linear independent variable interpolation

The verification results are presented in Table GS50_01. It is not necessary for the user to enter any data but it is necessary to run the model to verify the above tests.

TABLE GS50_1

Tests Element	Result Type	Expected Values
Table_1D_1	Element time histories	time = 0s, value = 0 time = 10s, value = 1 time = 20s, value = 2 time = 30s, value = 3 time = 40s, value = 4 time = 50s, value = 5
Table_1D_2	Element time histories	time <= 10s, value = 1 time = 20s, value = 2 time = 30s, value = 3 time >= 40s, value = 4
Table_1D_3	Element time histories	time = 0s, value = 1 time = 10s, value = 10 time = 20s, value = 100 time = 30s, value = 1000 time = 40s, value = 10000 time = 50s, value = 100000
Table_1D_4	Element time histories	time = 0.5s, value = 10 time = 1s, value = 10 time = 10s, value = 20 time = 40s, value = 26.021
Table_1D_5	Element time histories	time = 0 – 19.5, value = 1 time = 20-29.5, value = 2 time = 30-39.5, value = 3 time = 40-50, value = 4
Table_1D_6	Element time histories	time in seconds = value
Table_2D_1	Element tool tip	Table_2D_1 = 3

TABLE GS50_1

Tests Element	Result Type	Expected Values
Table_2D_2	Element tool tip	Table_2D_2 = 3
Table_2D_3	Element tool tip	Table_2D_3 = 1000
Table_2D_4	Element tool tip	Table_2D_4 = 3
Table_2D_5	Element tool tip	Table_2D_5 = 3
Table_3D_1	Element tool tip	Table_3D_1 = 7
Table_3D_2	Element tool tip	Table_3D_2 = 4
Table_3D_3	Element tool tip	Table_3D_3 = 10000
Table_3D_4	Element tool tip	Table_3D_4 = 4

TABLE GS50_1

Tests Element	Result Type	Expected Values
Table_3D_5	Element tool tip	Table_3D_4 = 3.48
Table_1D_Import	Element edit data, Import file Lookup1d.txt	col row 1.5 10 2.5 20 3.5 30 4.5 40
Table_2D_import	Element edit data, Import file Lookup2d.txt	col 1 2 3 row 10 1 2 3 20 4 5 6 30 7 8 9 40 10 11 12
Table_3D_import	Element edit data, To import a table: Import file Lookup3d.txt	col row 1 2 10 1 2 20 3 4 30 5 6 10 10 20 20 30 40 30 50 60 10 100 200 20 300 400 30 500 600
Table_3D_import_layer	Element edit data, To import a layer: Import file Lookup2d.txt	col 1 2 3 row 10 1 2 3 20 4 5 6 30 7 8 9 40 10 11 12

3. Importing Tables. Verifying the table import capabilities requires some user interaction. It is necessary to test importing data using both text files and spreadsheets.

File import tests:

- import 1D table
- import 2D table
- import 3D table
- import a table layer (2D table) into a 3D table

File import is tested using elements inside the “Import_Tables” container. The verifier should open each test element, click the “Edit Data” button, then click the “Import Table” or “Import Layer” button, and choose the desired import file (this should be done from the import table button that is accessible after pushing the Edit Data button). The import file names and verification results are presented in Table GS50_1. Then the tester should change the data source for the tables, so that each is reading an ASCII text file at run time. The filenames should be entered, and then the tester should run the model and confirm the values are imported at run time.

Spreadsheet import tests:

- import 1D table
- import 2D table
- import 3D table

Spreadsheet import is tested using elements inside the “Spreadsheet_Import” container. The verifier should open each test element, switch to the Excel tab, and click the “Import Data” button. The verifier should also create two additional table elements:

1. Create a new 3D table (call it Created_3D), selecting Excel as the data source, and referencing 3dtable.xls as the source file. The user should use the Location button to select the row and layer variables, and should type in the appropriate cell reference for the starting column variable.
2. Create a new 1D table (call it Created_1D), selecting Excel as the data source. Use the “Create and select new spreadsheet” option, call the new spreadsheet GS50_created.xls (if this file already exists from a prior verification, it should be deleted), and use the open option to view the new spreadsheet. Create a simple data set (e.g., {1,2,3,4,5} as the independent variable and {10,20,30,40,50} as the dependent variable). Save the Excel file and specify the appropriate starting cell using the location button. Click the “Import Data” button and ensure that data is successfully imported.

After the user has completed the tests, the model should be run to ensure the spreadsheets can be successfully imported at runtime.

4. Call tests. This portion of the test verifies that a Table Element can be accessed by referencing the table’s name (i.e., a function-like call to a specified value in the desired table from within an Expression Element). The file tests valid and invalid calls to 1D, 2D, and 3D tables. Run the model to verify the results of the valid calls.

Table GS50_ 2: Valid Calls

Element Being Tested	Expected Result	Comment (base case: Depth = 5m, Position =

		50ft, Layer = 4)
Sat1D_const_2	0.2	constant argument = 2m
Sat1D_const_5	0.4	constant argument = 5m
Sat1D_variable	0.4	variable argument = 'Depth'
Sat1D_expression	0.2	expression argument = $\max(0 \text{ m}, \text{Depth} - 2 \text{ m}) = 3\text{m}$
Sat1D_sum	0.8	Saturation_1D(Depth) + Saturation_1D(Depth)
Sat2D_const_5_50	0.4	constant arguments = (5m, 50ft)
Sat2D_const_3_40	0	constant argument = (3m, 40ft)
Sat2D_variable	0.4	variable argument = (Depth, Position)
Sat2D_expression	0.2	expression arguments = $(\max(0 \text{ m}, \text{Depth} - 2 \text{ m}), 2 * \text{Position} / 2)$
Sat2D_sum12	0.8	= Saturation_1D(Depth) + Saturation_2D(Depth, Position)
Sat2D_sum22	-0.4	Saturation_2D(Depth, Position) - $2 * \text{Saturation}_2\text{D}(\text{Depth}, \text{Position})$
Sat3D_const_5_50_4	0.4	
Sat3D_5_50_3	0.3	
Sat3D_variable	0.4	arguments = (Depth, Position, Layer)
Sat3D_expression	0.2	expression arguments = $(\max(0 \text{ m}, \text{Depth} - 2 \text{ m}), 2 * \text{Position} / 2,$ Layer)
Sat3D_sum33	0.8	Saturation_3D(Depth, Position, Layer) + Saturation_3D(Depth, Position, Layer)
Sat3D_sum123	1.2	Saturation_1D(Depth) + Saturation_2D(Depth, Position) + Saturation_3D(Depth, Position, Layer)

Once the expected results of the valid calls have been verified, return to edit mode and ensure that the following invalid calls are not permitted by GoldSim.

Table GS50_3: Invalid Calls

Element	Changes that should result in errors while editing the element's properties; cancel without making changes before moving on to next case.
Sat1D_1	Base case: argument = Depth (valid state)
	Case 1: change arg to 5 gal
	Case 2: change arg to 5 (no units)
	Case 3: change arg to argument = Layer
Sat2D_1	Base case: arguments = (Depth, Position)
	Case 1: change arg1 to 5 gal
	Case 2: change arg2 to 50 gal
	Case 3: change arg1 to 5 (no units)
Sat3D_1	Base case: args = (Depth, Position, Layer)
	Case 1: change arg1 to 5 gal
	Case 2: change arg2 to 50 gal
	Case 3: change arg1 to 5 (no units)
	Case 4: switch argument positions: (Layer, Depth, Position)

5. Miscellaneous tests. These tests verify the functionality of some of the user-interface features of Table elements. To execute these tests, use the Table elements created in Part 3. above:

- a. Ensure that in all of the following tests that the row and column headings in the Table are always visible (i.e., while scrolling through a large table grid).
- b. Resizing: Open the Edit Data dialogs for several tables and re-size the dialogs by dragging on a corner of the dialog box (as for any standard Windows window). Ensure that the dialog re-sizes as intended and that all pertinent information (text, buttons) remains fully visible.
- c. Removing: After clicking into a cell in the table, click on the “remove” class of buttons (rows, columns) and ensure that the appropriate row or column is removed. A row or column can be removed either by placing the cursor in a single cell and then selecting “remove”, or by highlighting the headings (except for the first column or row, which cannot be deleted). Click on “Cancel” to exit the dialog without making any changes. Remove buttons should not be available in tables linked to Excel spreadsheets.
- d. Adding: After clicking into a cell in the table, click on the “add” class of buttons (rows, columns) and ensure that a new row or column is added below (for rows) or to the right (for columns) of the current location. Next, click CTRL + Add (row or column). A dialog should pop up requesting the number of rows or columns to add. Ensure that the appropriate numbers are added below (for rows) or to the right (for columns) of the current location. Click on “Cancel” to exit the dialog without making any changes. Add buttons should not be available in tables linked to Excel spreadsheets.
- e. Sorting: Add a new 1D Table element and call it “Sorting”. Enter the following values into the table in the order shown:

Independent	Dependent
1	5
3	3
2	4
5	1
4	2

Click “OK”. Ensure that the Table does not sort the values into ascending order (with respect to the independent variable) before clicking “OK”. Re-open the Edit Data dialog box and ensure that the table is sorted into ascending order by the independent variable (1,2,3,4,5). Ensure that the dependent variable is sorted properly as well (5,4,3,2,1)

6. Verifying that a fatal error is generated when a table receives a query that is outside its bounds. Open the file called “GS50_lookb.gsm”. Enter the container called “Bounds Check” and run the model.

- a. The first error will be caused by the 1-D table at t=40.5s. Go into the table element and select extrapolate in the Handling of Data Section.
- b. Rerun the model - it should now have an error at 41.5s (caused by the 2D table). Change the 2D table so that the data extends to the end of the simulation (change the column independent label from 41s to 50s).

- c. Rerun the model - it should now have an error at 42.5s (caused by the 3D table). Change the 3D table so that the data extends to the end of the simulation (change the second layer's independent variable from 42s to 50s).
- d. Rerun the model. It should run until 45s, at which point the Lookup Table in the Exact_Only container will generate a fatal error when it is queried with a value that does not exist in its lookup table.

GS51_Looping

This model verifies the proper functioning of looping containers by using them to do an iterative solution of a nonlinear equation.

At each time step, the model iterates to solve the equation: $X + X^2 = \text{Time}$ (in days).

It uses Newton's method to make successive adjustments to the value X, until the solution converges or ten iterations have been completed.

To run the test, open and run GS51_Looping.gsm

The verifier should run the model and ensure that the constraints are respected (error less than $1E-6$ and loops <10 , or error $>1E-6$ and loops = 10). Error can be viewed in the History plots, and Loops in the Number of Loops plots. It should also be verified that on the TestPlot graphs that Y increases in direct proportion to time throughout the simulation.

A second test is included in the Stock_Test container. This test ensures that GoldSim only applies Rate of Change inputs when the timestep changes and not each time a loop occurs. At the end of the simulation the Integrator and Reservoir elements inside the container should both report a value of 100d.

GS52_InternalClocks

This test verifies the proper functioning of Internal Clock Submodels. It consists of two parts. The first test verifies the functioning of the maximum timestep length setting, while the second test verifies the functioning of the minimum timestep length option/setting.

In the first test, there is an integrator with a rate that increases by $1/s$ each timestep inside an internal clock container (Container 1). The internal clock maximum timestep length changes from 20s (greater than the model timestep) to 1s after a triggered event occurs at 20s. This means that the Rate element should be equal to $1/s$ at 0s, $2/s$ at 10s, $3/s$ at 20s, $4/s$ at 21s, $5/s$ at 22/s and so on. The Integrator1 element should increase by 20 between 0 and 20s ($1/s * 10s + 2/s * 10s$), and then by the rate multiplied by 1s for every timestep after that (this is equivalent to the Sum(all n between 3 and 82)). This means that the Integrator1 element has an expected final value of 3430.

To run the test, the verifier should run the model and confirm that the Rate Integrator inside Container1 is equal to $83 1/s$ at 100s, and that Integrator1 is equal to 3430 at 100s.

In the second test, both Container2 and Container2_1 have a Timed Event that issues an event regularly once per second. In addition, each container has a second TriggeredEvent element,

which has an On Changed Etime trigger (in effect, the TriggeredEvent counts the number of timesteps in the container). Container2 does not permit events to occur between timesteps, while Container2_1 allows events to occur with a 5s minimum timestep.

To run the test, the verifier should run the model and confirm that the cumulative emitted output of the TriggeredEvent inside each container. The TriggeredEvent element inside Container2 should show a cumulative emitted value of 11, while the TriggeredEvent element inside Container2_1 should show a cumulative emitted value of 21.

GS53_Sensitivity

This test verifies the proper functioning of the Sensitivity Analysis features in GoldSim.

The tester should open the Sensitivity Analysis dialog by selecting Run|Sensitivity Analysis. The user should turn off the use quantiles option and set up the sensitivity analysis with the following values:

Variable	Lower Bound	Center Value	Upper Bound
A	-2	-2	-2
B	-3	5	87
C	-10	0	20
D	25	45	100

E is the result to be analyzed.

Ensure that the result data matches the expected values on the Numbers worksheet in the GS53_Sensitivity.xls spreadsheet.

Ensure that the individual, global and tornado plots correspond with the result data values.

Select the "use quantiles" option and rerun the sensitivity analysis. Ensure that the result data matches the expected values on the Quantiles worksheet in the GS53_Sensitivity.xls spreadsheet.

Again, ensure that the individual, global and tornado plots correspond with the result data values.

GS54_Splitter

This test verifies that the Splitter element functions correctly for values and discrete changes. It includes tests of the element when the sum of fractions must equal one and where the sum of fractions can take on any value. Inputs to all test elements vary dynamically, and a test is included to ensure the correct functioning of the ~Amount local property.

Instructions/Expected Results: The verifier should run the model and ensure the Max_Deviation element has a value of 0 at the end of the simulation. If the Max_Deviation element is nonzero, the subcontainers in the Values and Discrete_Changes containers each have a Container_Check Extrema element that can be used to narrow down the source of the problem.

GS55_Allocator

This test verifies that the Allocator element functions correctly. It has a number of containers that test the functions of the Allocator element for Value and Discrete change inputs.

Dynamic_Demand_Values:

This test checks the value of the ~Total and ~Remainder local properties and also verifies that the element reacts correctly to dynamic changes in demand for value inputs. The Output1 demand (which has the highest priority) has a demand of ~Total - ~Remainder and so should be zero for the duration of the simulation. Output three is dynamic – it only demands 30 after 50 days and is zero for the remainder of the simulation. The verifier should ensure that the following values are shown in the Results_Dynamic_Demand Time History element:

Time	Output1	Output2	Output3	Output4	Unused
0-50	0	65	0	15	20
60-100	0	65	30	5	0

Values_Dyn_Neg_0:

This test checks that GoldSim correctly handles Allocator elements with value inputs where the priorities are editable. When priorities are editable, negative, zero and dynamic priorities can be specified. To confirm the correct functioning of the element, the verifier should ensure that the values in the Result_Dyn_Neg_0 Time History are as follows:

Time	Output1	Output2	Output3	Output4	Unused
0-20	0	70	0	30	0
30-40	0	70	30	0	0
50	15	70	15	0	0

Values_Equal_Priorities:

This test ensures that GoldSim correctly handles Allocator elements with equal priorities but different demands. To ensure the correct functioning of the element under these conditions, the verifier should ensure that the values in the Values_Equal_Priorities container are as follows:

Equal Share:

Time	Output1	Output2	Output3	Output4	Unused
0-50	40	25	25	10	0
60-100	40	20	20	10	0

Proportional:

Time	Output1	Output2	Output3	Output4	Unused
0-50	40	25.7	25.7	8.57	0
60-100	40	20.8	20.8	8.33	0

Value_Dynamic_Amount:

In this container, the response of an allocator element to a dynamic value input is tested. The output of the allocator is recreated using basic Goldsim elements and compared with the output

from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

Single_Output:

In this container, the response of an Allocator element with a single output is tested. The expected output of the Allocator is recreated using basic Goldsim elements and compared with the output from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

Dynamic_Demand_DC:

This test checks the value of the ~Total and ~Remainder local properties and also verifies that the element correctly handles dynamic changes in demand for discrete change inputs. The Output1 demand (which has the highest priority) has a demand of ~Total - ~Remainder and so should be zero for the duration of the simulation. Output three is dynamic – it only demands 30 after 50 days and is zero for the remainder of the simulation. The verifier should ensure that the following values are shown in the Results_Dynamic_Demand Time History element:

Time	Output1	Output2	Output3	Output4	Unused
30	0	65	0	15	20
70	0	130	30	20	20

DC_Dyn_Neg_0:

This test checks that GoldSim correctly handles Discrete Change Allocator elements where the priorities are editable. When priorities are editable, negative, zero and dynamic priorities can be specified. To confirm the correct functioning of the element, the verifier should ensure that the values in the Result_Dyn_Neg_0 Time History are as follows:

Time	Output1	Output2	Output3	Output4	Unused
30	0	70	30	0	0
50	15	140	45	0	0
70	45	210	45	0	0

DC_Equal_Priorities:

This test ensures that GoldSim correctly handles Allocator elements with equal priorities but different demands when processing discrete changes. To ensure the correct functioning of the element under these conditions, the verifier should ensure that the values in the DC_Equal_Priorities container are as follows:

Equal Share:

Time	Output1	Output2	Output3	Output4	Unused
0	40	25	25	10	0
60	80	45	45	20	0

Proportional:

Time	Output1	Output2	Output3	Output4	Unused
0	40	25.7	25.7	8.57	0

60	80	46.5	46.5	16.9	0
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DC_Amount_Add:

In this container, the response of an Allocator element to a dynamic Discrete Change input is tested. The output of the Allocator is recreated using basic Goldsim elements and compared with the output from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

DC_Amount_Replace:

In this container, the response of an Allocator element to a dynamic Discrete Change input is tested. The output of the Allocator is recreated using basic Goldsim elements and compared with the output from the Allocator element. The verifier should check that the Max_Deviation Extrema element has a value of 0.

GS56_History_Generator

This test verifies the correct functioning of the HistoryGenerator element. Individual settings are primarily tested using scalar History Generators, with correlations tested using Vector-type history generators.

To run the test, the verifier should run the model. They should then confirm that the results generated by the model are as follows:

Scalar_HistGen Container:

Element	Test	Expected Result
Geometric_Scalar	Tests the Geometric Growth setting	Result1 should show the final result has a mean of 0.5 and a standard deviation of 0.447
Geometric_Scalar_Reversion	Tests geometric growth with reversion	Result2 should show the final result has a mean of 0.5 and a standard deviation of 0.215.
Random_Scalar	Tests the Random Walk setting	Result3 should show a mean of 50\$ and a standard deviation of 33.54\$
Random_Scalar_Reversion	Tests reversion in the random walk case	Result4 should show a mean of 50\$ and a standard deviation of 16.13\$.
Random_Scalar_No_Neg	Tests the allow negative values setting	Result5 and Result6 should show identical means and standard deviations.
Difference_Lag	Tests that median reverts to previous timestep value with high reversion rates.	Difference_Lag should be negligible (<0.01\$)
Difference_No_Lag	Tests the do not lag target option	Difference_No_Lag should be negligible (<0.01\$)

Vector_HistGen Container:

All of the multivariate result elements should show the following correlations (these are shown in the `_Correlations Multivariate Result` elements):

	1	2	3	4	5
1	1	0	0.75	0	0
2	0	1	0	0.1	0.35
3	0.75	0	1	0	0
4	0	0.1	0	1	0.93
5	0	0.35	0	0.93	1

The verifier should note that the correlations predicted by the Multivariate Result elements may not exactly agree with the matrix specified in the History Generator elements, especially for the t-distribution copula with one degree of freedom.

The verifier should also check that the correlation between variables agrees with the correlation type specified. To do this, the verifier should check the `_2_Variables Multivariate Result` elements. The Gaussian correlations should show a stronger correlation in the middle than at the tails. The 1 degree of freedom t-distribution copula should show a stronger correlation at the tails than in the middle. The 25 degree of freedom t-distribution copula should resemble the Gaussian copula (as the number of degrees of freedom increases, the t-distribution copula begins to approximate the Gaussian copula).

GS56a_History_Generator_Iman_Conover

This test confirms the proper functioning of the Iman and Conover correlation algorithm. This algorithm is actually designed for static models, so the test model only runs a single timestep (after the first timestep the algorithm behaves like a Gaussian copula). To conduct the test, run the model and ensure that the correlation matrix generated by the Multivariate result elements in each container agrees with the correlation matrix pasted in the GS56 test. The verifier should also ensure that the 2D plots approximate the 2D plots for the Gaussian distribution in the GS56 test.

GS57_Interrupt

This test verifies that the Interrupt element functions correctly. It starts with a base file where the interrupt is triggered when an Expression element reaches a value of 50.

To run the test, do the following:

1. Run the model – an interrupt should occur after 50 days in Realization 1. Check the “Ignore interrupt for this simulation” option. The simulation should run to completion. Open the run log and ensure no messages have been added by the Interrupt.
2. Run the model again. This time click **Pause** on the dialog that appears. This stops the run partway through the causality sequence, so Expression2 should show its previous timestep’s value ($49 + 2 = 51$) and the Triggered Event element (triggered when Expression1 becomes

- 50) should show a Cum_Emitted value of 0. The verifier should then abort the model and discard results. The model should automatically return to edit mode.
3. Run the model again but this time log the message as a run log message. Continue the model when prompted until realization 5. Then choose the ignore option and run the simulation model to completion. Open the run log and ensure that messages are added for the 5 interrupts that were not ignored.
 4. Run the model again but log the message as a warning. Continue the model when prompted until realization 5. Then choose the ignore option and run the simulation model to completion. A message saying that 5 warnings occurred should be displayed. Open the run log and ensure that the five warnings were added.
 5. Disable the interrupt element and rerun the model. It should run to completion and no warnings should be added to the run log.
 6. Open the Interrupt's dialog , and enable the element. Disable the message, turn off the addition of warnings to the run log and select continue in the drop-down list for the element's action when the message is disabled or off. Run the model – it should run to completion with no interrupts.
 7. Open the Interrupt's dialog and select “Skip remainder of current realization and continue” in the drop-down list for the element's action when the message is disabled or off. Run the model – it should run to completion with no interrupts. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. Check that these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update).
 8. Open the Interrupt's dialog and select “Skip remainder of current realization and abort” in the drop-down list for the element's action when the message is disabled or off. Run the model – the simulation should be aborted after realization 1 and the model should be in Result Mode. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. Check that these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update).
 9. Open the Interrupt's dialog and select “Discard this realization and abort” in the drop-down list for the element's action when the message is disabled or off. Run the model – the simulation should return to Edit Mode after 50 days.
 10. Open the Interrupt's dialog and select “Abort and return to Edit Mode” in the drop-down list for the element's action when the message is disabled or off. Run the model – the simulation should return to Edit Mode after 50 days
 11. Open the Interrupt element's property dialog, click More and then activate the “Check if this condition is true” option. Specify a condition of Realization = 5.
 12. Open the Interrupt's dialog and select “Skip remainder of current realization and continue” in the drop-down list for the element's action when the message is disabled or off. Run the model – it should run to completion with no interrupts. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. In realization 5, check that

these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update). The other realizations should show a final Expression2 value of 102 and a TriggeredEvent1.Cum_Emitted value of 1.

13. Open the Interrupt's dialog and select "Skip remainder of current realization and abort" in the drop-down list for the element's action when the message is disabled or off. Run the model – it should stop after the fifth realization and the model should be in Result Mode. Check the time history for Expression2 and TriggeredEvent1.Cum_Emitted in Result 1. In realization 5, check that these values are 52 and 1 from 50 days on (even though the interrupt occurs midway through the causality sequence, skipping the remainder of the realization completes the current update). The first four realizations should show a final Expression2 value of 102 and a TriggeredEvent1.Cum_Emitted value of 1.
14. Open the Interrupt's dialog and select "Discard current Realization and abort" in the drop-down list for the element's action when the message is disabled or off. Run the model – it should stop after the fifth realization and the model should be in Result Mode. Only four realizations should be available and each should show a final Expression2 value of 102 and a TriggeredEvent1.Cum_Emitted value of 1.

GS58_Currencies

This test verifies that currency unit conversion features work properly. It contains 20 data elements (one for each built in currency in GoldSim). These elements are equal to 1 unit of their particular currency (with fictional rates), but are set to display results in US dollars.

Run the model – the expected values of the data element tool-tips are as follows:

Element	Expected Value
Dollar	1\$
Euro	2\$
Pound	3\$
Yen	4\$
AUD	5\$
BRL	6\$
CAD	7\$
CNY	8\$
CZK	9\$
DKK	10\$
HKD	11\$
HUF	12\$
MXN	13\$
NZD	14\$
NOK	15\$
RUB	16\$
SGD	17\$
SEK	18\$
CHF	19\$
ZAR	20\$

The verifier should then flip to Edit Mode, open the currencies dialog and then change the base currency. After closing the Currencies dialog, the verifier should run the model and ensure that all of the element values are the same for the new default currency as for the old default currency.

The verifier should reopen the Currencies dialog and set the newly selected base currency as the default. They should then insert a number of Financial Module elements and ensure that they have the new default unit selected.

After that, the verifier should reopen the Currencies dialog and switch the base currency back to US dollars. Again, the verifier should run the model and check that the values of the data elements are as listed in the table above. The verifier should then switch the default currency to US dollars and insert a number of Financial Module elements – these elements should have US dollars selected in the currency drop-down.

GS59_Submodels

The GS59 test for Submodels is actually a suite of several different tests, each of which is described in detail below.

GS59a_Submodel_Run_Properties

This test ensures that Submodels with externally controlled run properties behave appropriately. The model file contains six SubModels, each of which has a different run property controlled by the outer simulation. The difference elements check that the value passed to the Submodel is the same value used by the inner simulation.

To run the test, the verifier should run the model. They should then confirm that the Diff elements had a negligible value for all outer loops by checking the Final Value Distribution elements in the model.

GS59b_Submodel_Statistics

This test ensures the proper functioning of the final value statistics generated by the Submodel. It includes two Submodels, one with a continuous stochastic input and another with a discrete stochastic input. These are fed into an expression element, and the final value of the expression element is exported to the outer loop using all appropriate methodologies.

To conduct the test, the verifier simply needs to run the model. They should then confirm the following Submodel outputs:

SubModel	Output	Value
Continuous	Cond_Tail	114 kg
	Mean	100 kg
	Prob_Less_115	0.933
	Result_08	108.416 kg
	SD	10
Discrete	Cond_Tail	2 m
	Mean	50
	Prob_Equal	0.2
	Prob_Less_60	0.983

Result_08	54
SD	5 (values between 4.99 and 5.01 are acceptable)
Prob_True	0.8

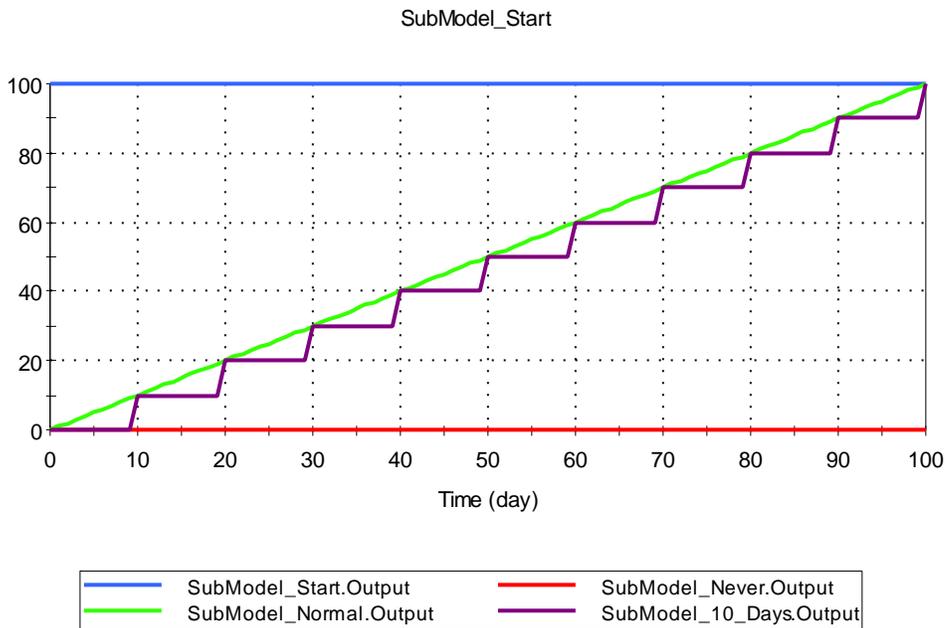
GS59c_Submodel_Triggering

This test ensures that SubModel triggering functions properly.

To conduct the test, the verifier should run the model. Expected results are as follows:

Element	Expected Result
SubModel_Start	100 for the duration of the simulation
SubModel_Never	0 for the duration of the simulation
SubModel_Normal	Increases linearly from 0 to 100 over the course of the simulation
SubModel_10_Days	Increases by 10 every 10 days

The Result time history should look like this:



GS59d_Submodel_Protection

This test ensures that Protection features work correctly in a Submodel.

The verifier should first test sealing the SubModel. Once the SubModel is sealed, the verifier should attempt to change settings and inputs on the property pages of the elements contained within the SubModel. Any changes should result in a warning that this will break the seal. If the seal is not broken, any changes should be reversed.

The verifier should unseal the SubModel and ensure changes can now be made to the SubModel's property dialog and to the elements inside. The SubModel should then be locked. GoldSim should prevent any changes to the elements inside the SubModel.

Then the verifier should unlock the model and ensure changes can be made to elements inside the SubModel.

GS59e_Submodel_Static_Outer_Model

This test ensures the proper functioning of SubModels contained within an outer static model. Three Submodels are included: one static, one dynamic and one optimization.

Results should be as follows:

SubModel_Static.Output: Mean value = 100
SubModel_Dynamic.Output : Mean value = 200
SubModel_Optimization.Output: Mean value = 0

The verifier should also pause the model midway through the simulation and ensure that the abort options work correctly. Discarding results should return the model to edit mode, while keeping results should place the model in Result mode and make results available for all realizations prior to the abort (and including the abort if that option is selected).

GS59f_Submodel_Dynamic_Outer_Model

This test ensures the proper functioning of SubModels contained within an outer static model. This test involves two separate test files: GS59f_Submodel_Dynamic_Outer_Model_1.gsm, which tests a dynamic outer model with a static and dynamic SubModel, and GS59f_Submodel_Dynamic_Outer_Model_2.gsm which tests a dynamic outer model with an Optimization SubModel.

Results for GS59f_Submodel_Dynamic_Outer_Model_1.gsm should be as follows:

SubModel_Static.Output: Mean value = 200
SubModel_Dynamic.Output : Mean value = 300

The verifier should also pause the model midway through the simulation and ensure that abort functionality works correctly. Discarding results should return the model to edit mode, while keeping results should place the model in Result mode and make results available for all realizations prior to the abort (and including the abort if that option is selected).

Results for GS59f_Submodel_Dynamic_Outer_Model_2.gsm should be as follows:

SubModel_Optimization.Output: Mean value = 0 (a mean value less than 0.05 is acceptable)

The verifier should also pause the model midway through the simulation and ensure that the three abort options work correctly. Discarding results should return the model to edit mode, while keeping results should place the model in Result mode and make results available for all realizations prior to the abort (and including the abort if that option is selected).

GS59g_Submodel_Import

This test ensures that SubModels correctly import Currency settings, custom Units, and Array Labels.

To run the test, open the outer model file, GS59g_Submodel_Import_Outer. Perform the following checks to ensure the test file is ready.

1. View the Currency dialog. Ensure that their default exchange rates are 1. The Bermudian Dollar (BMD) should not be shown in the Currency dialog.
2. View the units dialog - there should not be a Flux (Volume) unit defined called meters cubed per minute (MCPM) and there should not be a user defined unit category called Created.
3. View the array labels dialog. Only the default array labels of Days and Months should be shown.

The verifier should then insert a new Submodel element and import GS59g_Submodel_Import_Inner. The following checks should be performed:

1. Check that the Edit Mode values of Expression 1 and Expression 2 are still [1 GS, 2 GS, 3 GS] and 0.5 \$-MCPM for all elements of Expression 2.
2. Verify that the following Units and Unit Category have been added to the model:
 - New Unit Category called Created, with dimension M3L2T.
 - New Unit in the Created category called GoldSims, abbreviated GS and equal to 334.45094 kg3-m2-s
 - New Unit in the Flux (Volume) category called meters cubed per minute (abbreviated MCPM) that is equal to 1 m3/min.
3. Verify that the following Array Label sets have been added to the outer model:
 - New Array Label Set called Named, with labels Rick, Stefan and Ian
 - New Array Label Set called Indexed, with labels 1 through 5

GS59h_Submodel_Import_Error_Conditions

This test ensures that GoldSim does not crash if the user tries to import models that have Units, Currencies and Array Label sets that conflict with those in the outer simulation model. First, open and save three Mismatch models (GS59h_Array_Index_Mismatch.gsm, GS59h_Array_Named_Mismatch.gsm and GS59h_CurrencyMismatch.gsm) in the test build.

1. Open the outer model file, GS59h_Submodel_Import_Error_Conditions. Attempt to import GS59h_Currency_Mismatch as a SubModel. A message should be displayed stating that the conversion rates in the two models do not match for US dollars, Euros, Pounds and Yen and that the rate from the outer model should be used. The verifier should also check that the default currency remains as US Dollars, and that the exchange rates in the outer model are all ones. The verifier should then enter the imported model and insert a data element equal to 1 Euro, but display the value in US dollars. They should then hit F9 and ensure that the element's tooltip shows a value of 1\$.

2. Attempt to import GS59h_Unit_Conversion_Mismatch as a SubModel. A message should be displayed stating that there is a discrepancy in the conversion rate for GoldSims. The unit in the outer model should not change (it should retain its initial value of 334.45094 kg3-m2-s). GoldSims can be found in the Created unit category. The verifier should then enter the imported model and insert a data element equal to 1 GS, but display the value in kg3-m2-s. They should then hit F9 and ensure that the element's tooltip shows a value of 334.45094 kg3-m2-s.
3. Next try to import GS59h_Unit_Dimension_Mismatch as a SubModel. The import should fail due to a discrepancy in the dimension of the GoldSims unit. The dimension in the outer model should not change from M3L2T.
4. Attempt to import GS59h_Array_Index_Mismatch as a SubModel. The import should fail because the two array label sets called Indexed have a different dimension. The Indexed array label set in the outer model should not be changed during the attempted import (labels should be 1 to 5).
5. Finally, try to import GS59h_Array_Named_Mismatch as a SubModel. The import should fail because of a difference in one of the elements of the Named array label set in both models. The Named array label set in the outer model should not be changed during the attempted import (it should remain as Rick, Stefan, and Ian).

GS59i_Submodel_Export_Versioning

This test ensures that GoldSim correctly exports Globals, Output Interfaces, Array Labels, Units and Currency Information.

1. To run the test, simply export the Submodel inside the test model file (GS59i_SubModel_Export_Versioning) to a standalone GoldSim file (call it ExportedSubmodel.gsm). Confirm the following information in the exported file:
 - The following custom currencies should be available and have the following conversions:
 - Bermudan Dollar (BMD) equal to 0.5 \$
 - Canadian Tire Money (CTM) equal to 2 \$
 - The following array label sets should be available:
 - Indexed [1 to 5]
 - Named [Rick, Stefan, Ian]
 - The following custom units should be listed in the Units dialog:
 - In the Flux(Volume) category, a meters cubed per minute (MCPM) unit equal to 1 m3/min should be listed.
 - In the Created category, a unit called GoldSims should be listed. It should be equal to 334.45094 kg3-m2-s.

- The verifier should also confirm that three versions of the model are listed in the Versioning dialog (A through C).
2. The Input Interface expressions in the Globals tab should be changed to static values. Run the model – it should run without errors.
 3. A new version (Version D) should be added to the exported model and the model saved as ExportedSubmodel2.gsm.
 4. The verifier should then open the original model file (GS59i_SubModel_Export_Versioning) and import the ExportedSubmodel.gsm into a second SubModel container. The Interface should be identical to the original SubModel. Versioning information for elements contained in the SubModel elements should also be identical on an element and global level.
 5. Next the verifier should import ExportedSubModel2.gsm into a new SubModel container. There should be no record of changes made prior to importation for elements brought in from the ExportedSubModel2.gsm file, but this should not affect the versioning information for the remainder of the model.

GS59j_Submodel_Monte_Carlo_Repeated_Sampling

This test verifies that the “Use a different random seed for each realization of the parent model” option works correctly. The model consists of a SubModel with a uniform stochastic inside (0,10). The SubModel is run for 10 Monte Carlo realizations and returns the 95th percentile of the values sampled from the stochastic over the ten realizations.

The verifier should ensure that the parent model selects random points in each LHS stratum and then run the model with the SubModel’s option to “Use a different random seed for each realization of the parent model” disabled. The model should return the same value for all ten realizations. This can be confirmed by viewing the result array in the Result Distribution. The model should then be re-run with the option enabled. All 10 realizations should return different values. In all cases result from the SubModel should be between 9 and 10 (as LHS is enabled).

GS60_Time_Series

<Supercedes GS40_Information Time Series and GS41_Material Time Series>

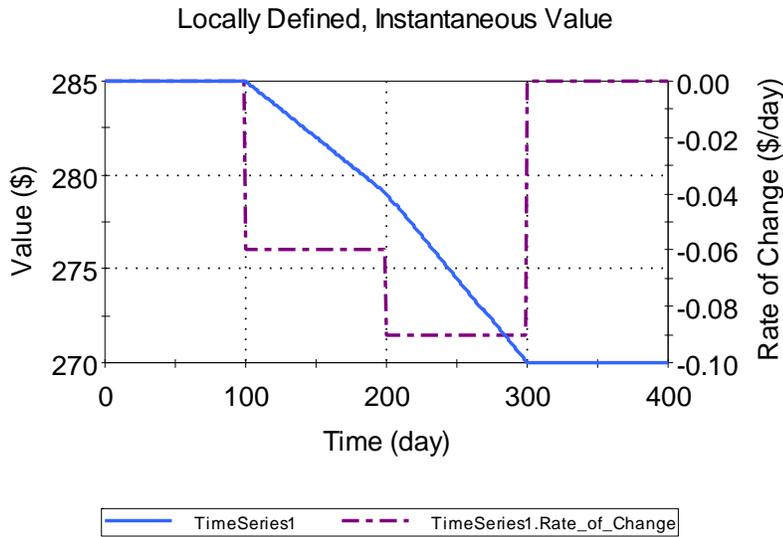
This test ensures the proper functioning of the second generation Time Series elements (introduced in GoldSim 9.60). Excel functionality is tested separately in the GS60b_Time_Series.gsm test.

The test should be run and then the verifier should enter each of the top level containers and perform the tests prescribed inside.

Basic_Functionality Container

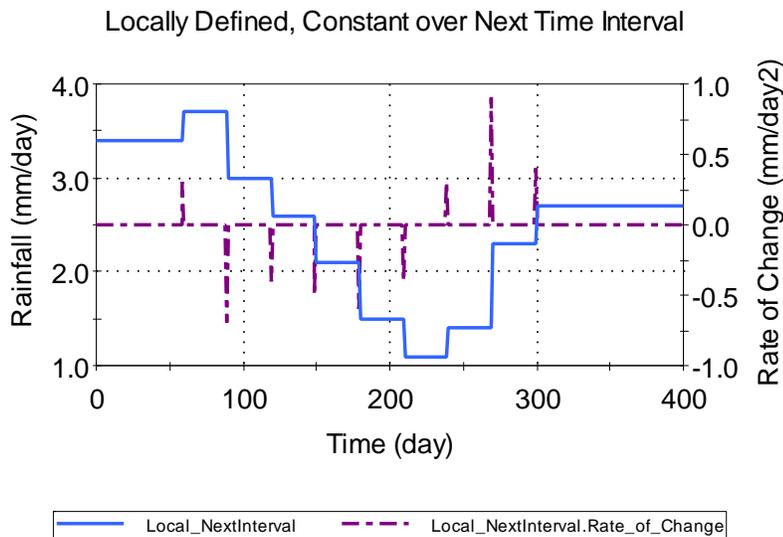
These tests ensure the proper behavior of the Time Series elements for locally defined data. Tests cover all source data types, the rate of change output, and the two main output settings for Value-type data.

1. Locally Defined Instantaneous – The verifier should check that the graph of `Locally_Defined_Results` matches the following graph:



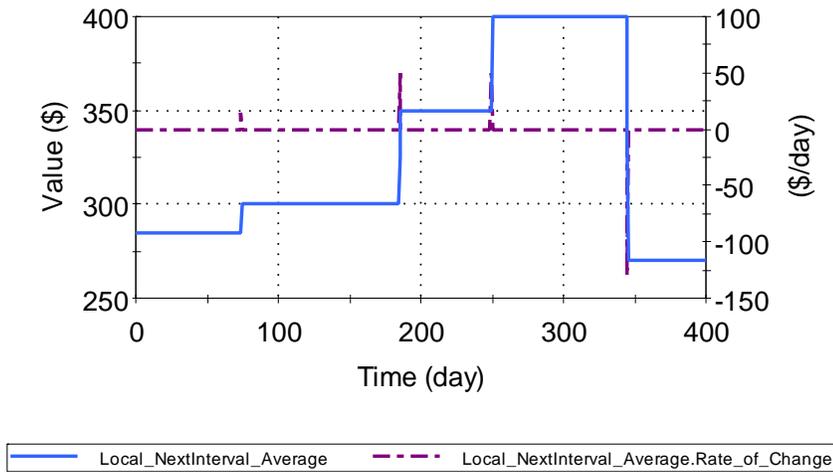
The verifier should also ensure that the value of `Max_Deviation` is negligible.

2. Locally Defined Next Interval – The verifier should check that the graph of `Local_Next_Interval_Results` matches the following graph:



It should also be confirmed that `Local_Constan_Avg` matches this graph:

Locally Defined, Constant Value, Average over Next Interval

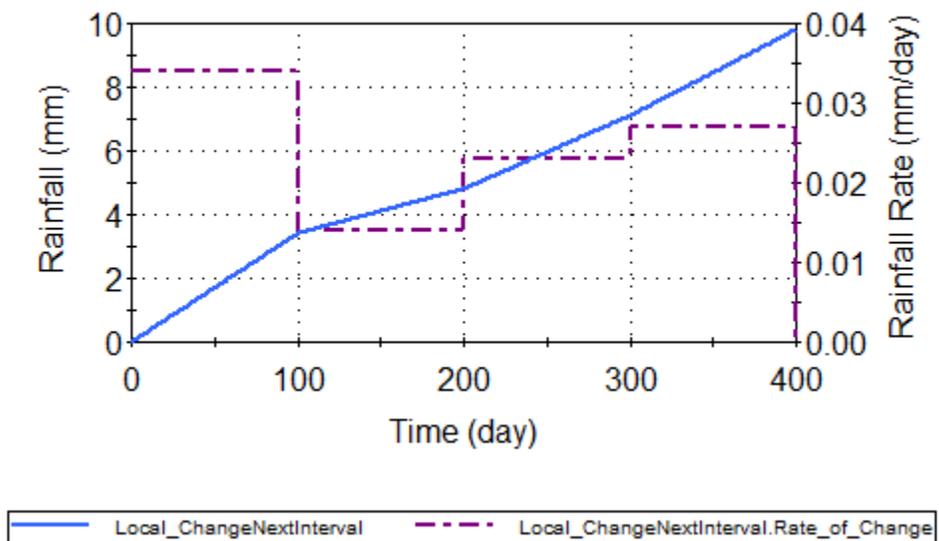


The verifier should also ensure that that the value of Local_NextInterval_Average and Local_NextInterval_Average.Rate_of_Change have the following values at the specified times (this tests the average value over next timestep calculation):

Time (days)	Value (\$)	Rate of Change (\$/day)
185	325	50
345	335	-130

3. Locally Defined Change – The verifier should check that the graph of Local_ChangeInterval_Results matches the following graph:

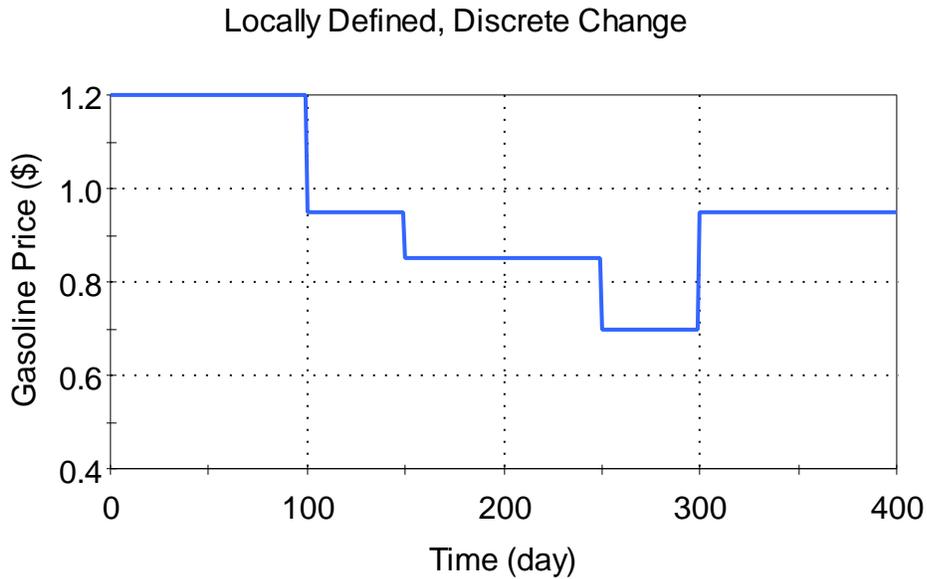
Locally Defined, Change over Next Time Interval



The verifier should also ensure that that the value of `Local_ChangeNextInterval_Avg` and `Local_ChangeNextInterval_Avg.Rate_of_Change` have the following values at the specified times (this tests the average value over next timestep calculation):

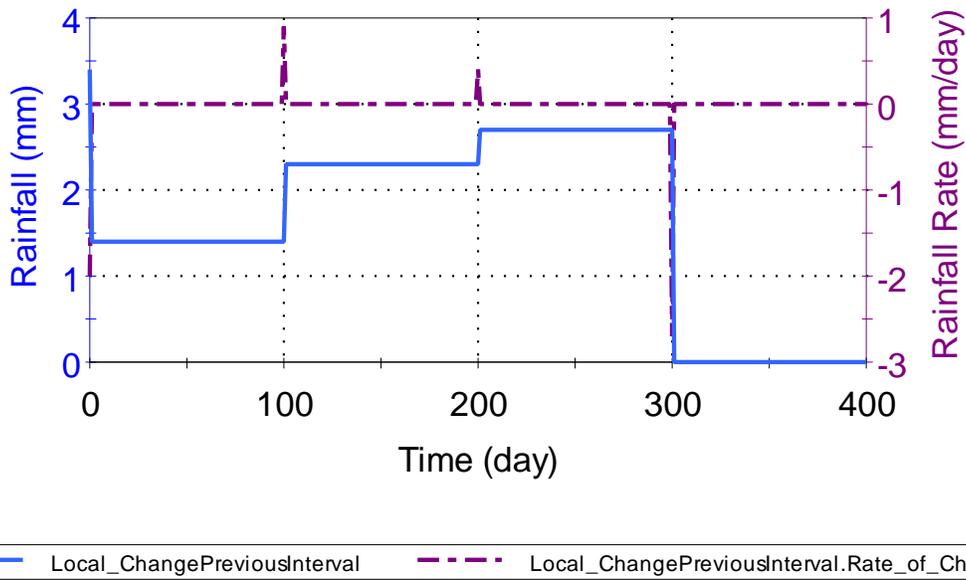
Time (days)	Value (mm)	Rate of Change (mm/day)
100	3.3975	0.023915
200	4.8011	0.0185
300	7.1005	0.025

4. Locally Defined DC – The verifier should check that the graph of `Local_DC_Results` matches the following graph:



5. Locally defined Previous Change. The verifier should enter this container and confirm that the result element, `Local_Change_Interval_Results`, shows the following graph:

Locally Defined, Change over Next Time Interval

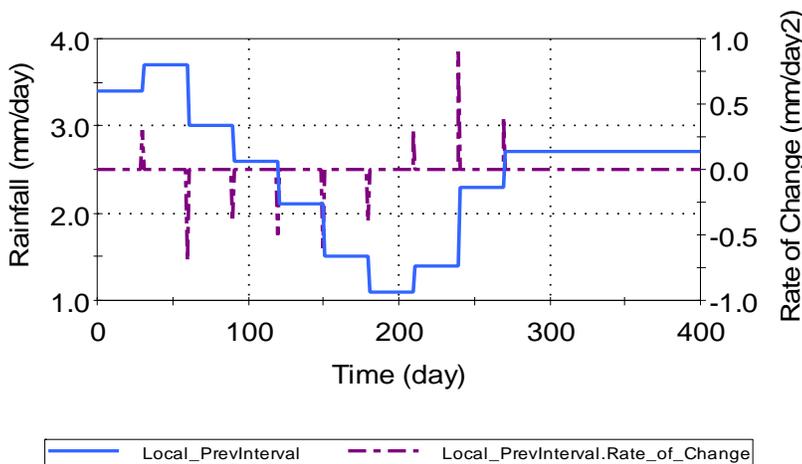


In addition the tester should enter the Local_Constant_Avg element and open its table to confirm the following three data points:

- T = 100 days Expected Value = 1.85 mm Expected Rate of Change: 0.9 mm/day
- T = 200 days Expected Value = 2.5 mm Expected Rate of Change: 0.4 mm/day
- T = 300 days Expected Value = 1.35 mm Expected Rate of Change: -2.7 mm/day

6. Locally Defined Previous Interval- The tester should enter this container and confirm the result element Local_Prev_Interval_Results has a graph like the one pictured below:

Locally Defined, Constant over Previous Time Interval



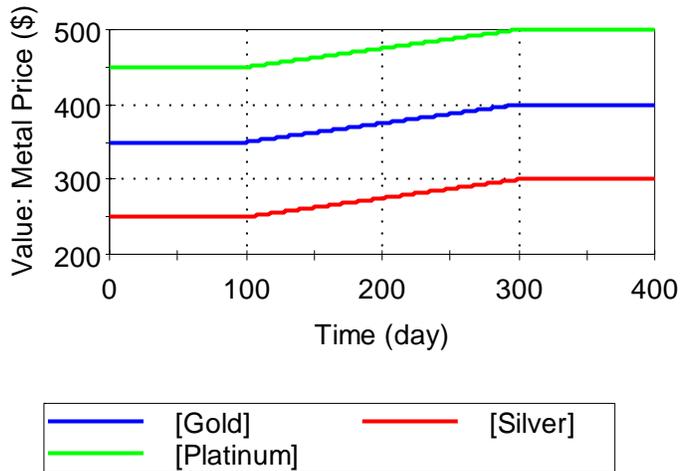
In addition, the tester should open the table for the result element Local_Prev_Constant_Avg and confirm the following two data points:

- T = 185 days Expected Value = \$375 Expected Rate of Change \$50/day

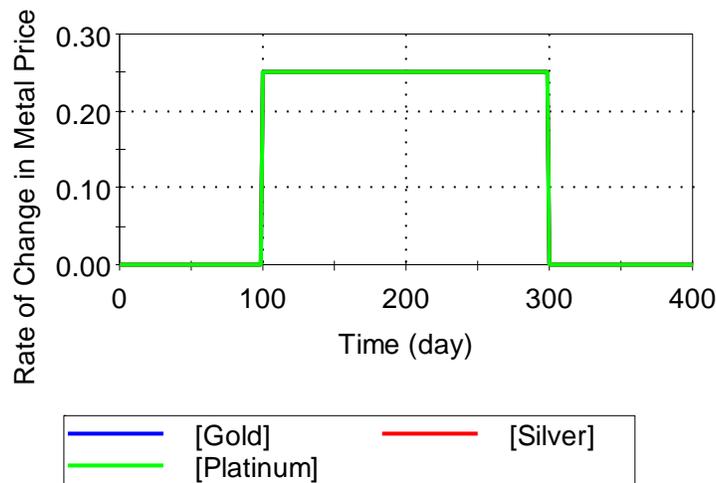
T = 345 days Expected Value = \$275 Expected Rate of Change -\$10/day

7. Vector Input – The verifier should check that Result6 and Result7 match the graphs pasted below:

Result 6: Vector of Values

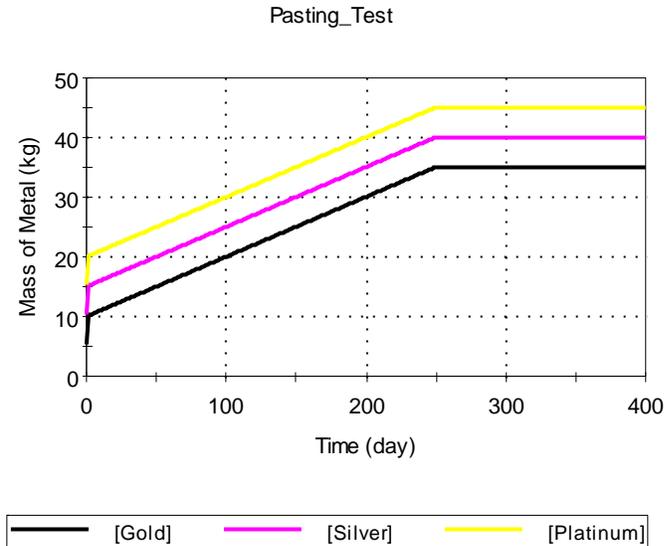


Result 7: Rates of Change



8. Pasting Tests – The verifier should follow these steps:
- Open Pasting_Test, Edit Data. If data exists, remove it.
 - Open the Excel file "Pasted Cells keep GS Tests.xls" (located in the directory containing this test file), and go to the tab labeled "GS40".
 - Copy the indicated array of values (inside the bold border) from GS40.
 - In GoldSim, click into the upper left cell in the 'Edit Data' field of Pasting_Test.
 - Click CTRL + V to paste the copied array of values into Pasting_Test.

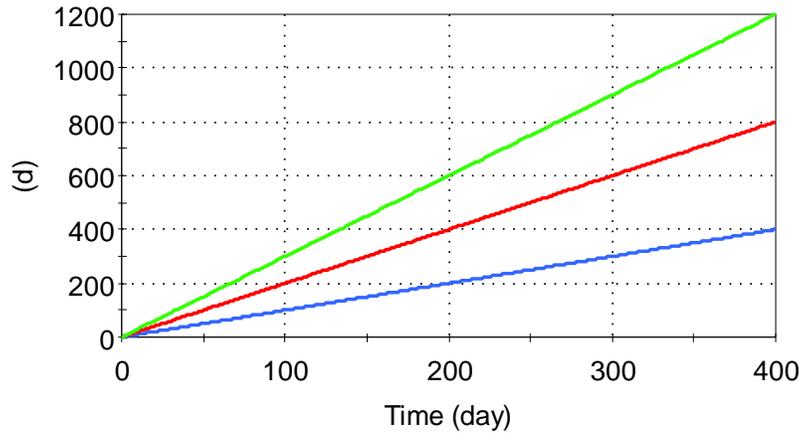
- f) The copied data should be inserted into the 'Edit Data' field, and the field should automatically re-size to accommodate the pasted data.
- g) Click 'OK' twice to accept the pasting operation.
- h) Run the model file and ensure that Result8 (i.e., mass of metal) matches the following graph:



- i) Repeat the test using calendar time data from the GS40datetime worksheet in "Pasted Cells keep GS Tests.xls" - ensure that the model start date is 9/13/1999 at 9:32 am
9. Matrix Tests – The verifier should enter the Matrix_Tests container and follow these steps:
- a) Delete the data in the TimeSeries1 element and turn it into a recording element. Link it to Expression1.
 - b) Run the Model. Verify that the Column1 and 2 Time Histories correspond with the graphs pasted below.
 - c) Change TimeSeries1 to Locally defined and run the model.
 - d) Verify that the Column1 and 2 Time Histories correspond with the graphs pasted below:

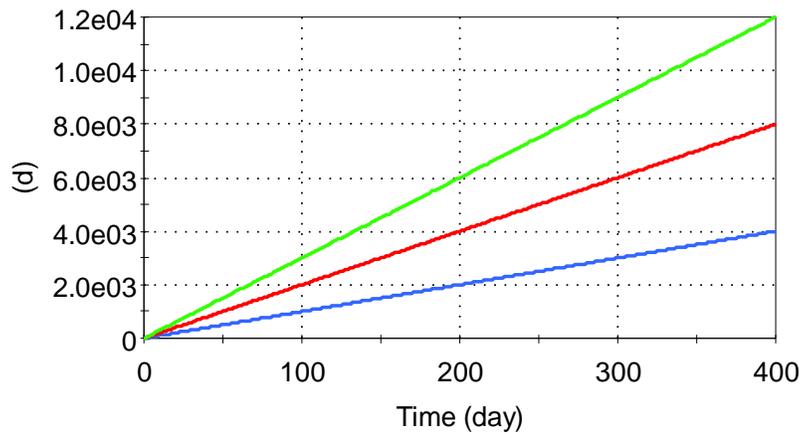
Column1:

Column1 of the Time Series



Column2:

Column 2 of the Time Series



Timestep_Interruption Container

These tests ensure the proper behavior of the Value and Rate of Change Outputs for Value Type Data when events can occur between timesteps. This test also ensures that Discrete Change time series correctly interrupt the clock when a discrete change occurs between timesteps.

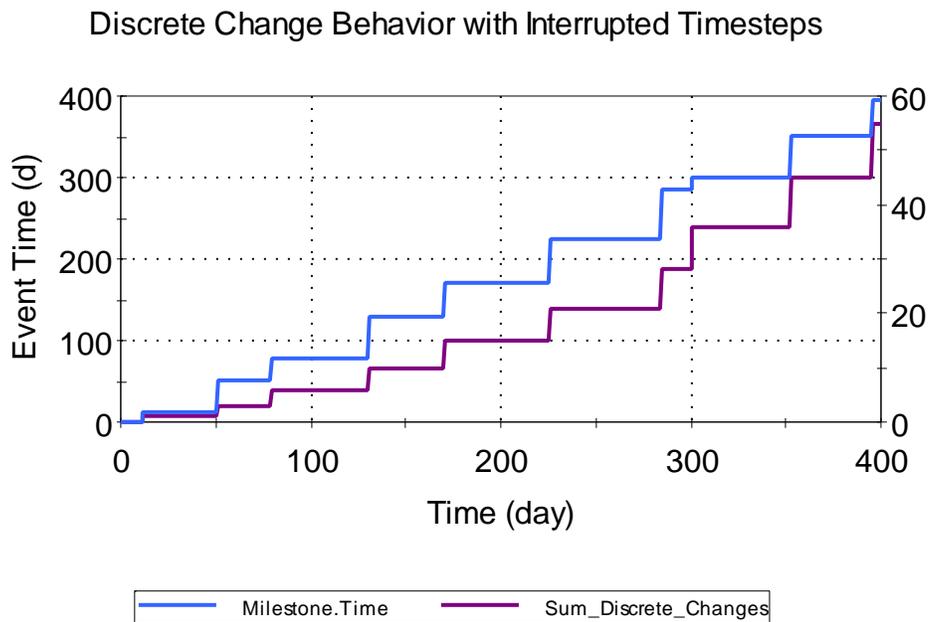
The verifier should ensure that Extrema elements inside the `Locally_Defined_Instantaneous_1`, `Locally_Defined_Next_Int_1`, and `Locally_Defined_Change_1` containers have a negligible value at the end of the simulation.

Note that due to a timestep inserted at 24.5 d, `Local_ChangeNextAverage` in the `Locally_Defined_Change_1` container outputs a slightly different value from the theoretical value

at 25d. Therefore, the output for Max_Deviation_Avg_2 may not be negligible. If this is the case, look at the time history of Check_Ang_1 and confirm that it is in fact negligible everywhere except at 25d.

Timestep interruption is also tested with time series elements that are constant over previous interval and change over previous interval. Interrupt elements will be triggered if these tests fail and the message will point the tester to the type of calculation that is failing.

They should also confirm that the graph of Discrete_Change_Interrupted in the Discrete_Change_Interrupt is as follows:



Links Container

These tests ensure that Time Series links to and from SubModels function correctly. The verifier should enter the container and confirm that the final value for all four Extrema elements is negligible.

Recording Container

These tests ensure that the Time Series element correctly records source data, and that all recording options function correctly. To complete the test the verifier should enter the four subcontainers and ensure that the recorded values match the expected values described for each element.

Instantaneous

Element	Records	Expected # of Values
Record_Fixed_Change_Only	ETime at all fixed timesteps	401
Record_All_Timesteps	ETime at all timesteps	801
Record_Fixed_All	\$100 at each fixed timestep	401
Record_All	\$100 at all timesteps	801

Constant Over Next Interval

The following data points should be recorded:

	Elapsed Time [day]	Value
1	0	2
2	100	2.995
3	200	4.49
4	300	5.995
5	400	6

Constant Over Previous Interval

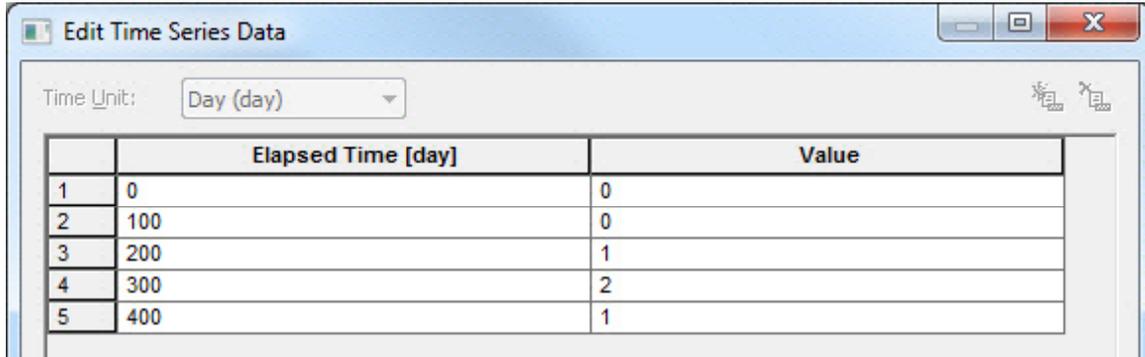
	Elapsed Time [day]	Value
1	0	0
2	100	2
3	200	2.995
4	300	4.49
5	400	5.995

Change over Previous Interval

The following data points should be recorded:

	Elapsed Time [day]	Value
1	0	0
2	100	0
3	200	1
4	300	2
5	400	1

Change Over Next Interval



	Elapsed Time [day]	Value
1	0	0
2	100	0
3	200	1
4	300	2
5	400	1

Discrete Change

Element	Records	Expected # of Values
Record	Discrete change equal to record number in table for all fixed timesteps	800
Zeroes_Not_Recorded	Records a discrete change at every fixed timestep before 200d. The discrete change's value should be equal to the elapsed time for each entry	399
Record_Multiple_and_Zeroes	records two discrete changes at every timestep. The value of each discrete change value should be equal to the elapsed time for each entry until 200 days, at which point all further entries should have a value of zero.	1600
Record_and_Combine	Records a discrete change at every timestep. The discrete change's value should be equal to the twice the elapsed time for each entry until 200 days, at which point all further entries should have a value of zero.	800

Data Wrapping Elapsed Container

These tests ensure the proper behavior of the Time Series elements when start year synchronization is enabled and when periodicity is specified in an Elapsed time model.

Tests in the Instantaneous and Average Value containers check to ensure that wrapping functionality and shifts are handled correctly for Instantaneous value and Constant over next time interval Time Series elements. This is done by comparing the output of an automatically wrapped time series with a manually wrapped time series. Shifting for Change over next time

interval and Discrete change time series is confirmed by checking a graph of the outputs of the two time series. This test is only done in the instantaneous value container.

Element	Tests	Expected Result
Calendar_Shift\ Instantaneous_Value\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligible (<1E-4)
Calendar_Shift\ Instantaneous_Value\ Diff_Wrap	Tests calendar shifting and wrapping for constant over next time interval time series elements.	Negligible (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligible (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Wrap	Tests calendar shifting and wrapping for constant over next time interval time series elements.	Negligible (<1E-4)
Random_Starting_Point\ No_Periodicity\ Random_Result	Tests random selection of start point within data set.	Result array should show real values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_2
Random_Starting_Point\ Annual_Periodicity\ Annual_Result	Tests random selection of start point with annual periodicity.	Result array should show observations at 0,365 and 730.
Random_Starting_Point\ Daily_Periodicity\ Daily_Result	Tests random selection of start point with daily periodicity.	Result array should show integer values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_4

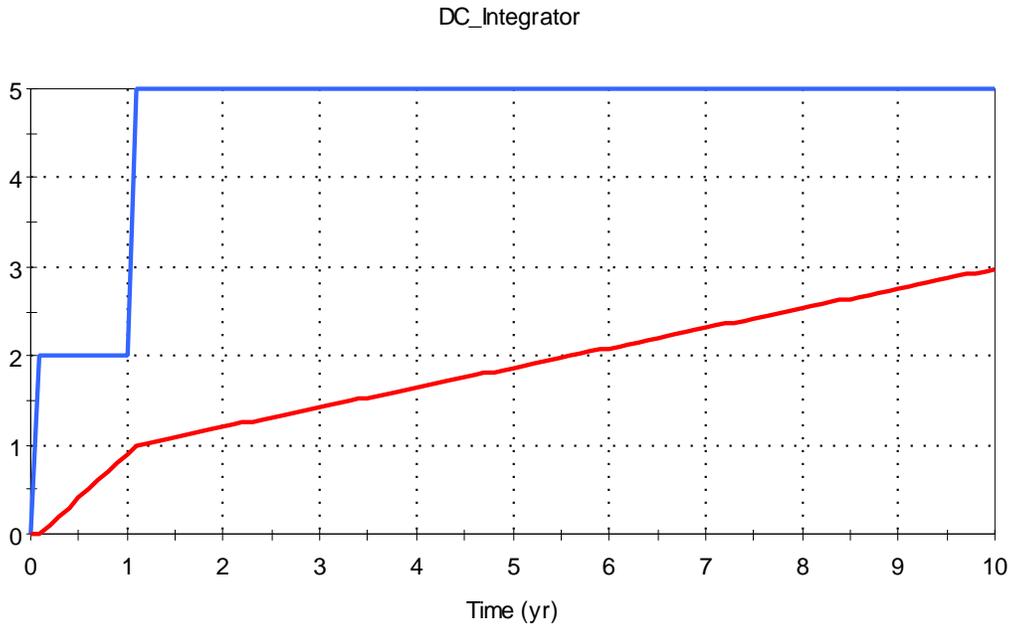


Fig. GS60_Wrap_Elapsed_1

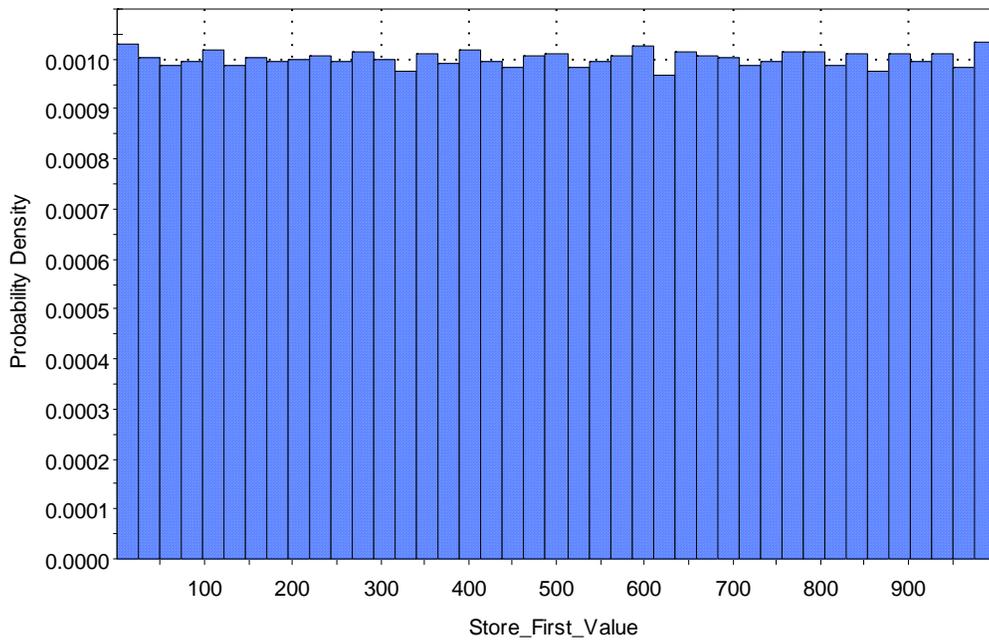


Fig. GS60_Wrap_Elapsed_2

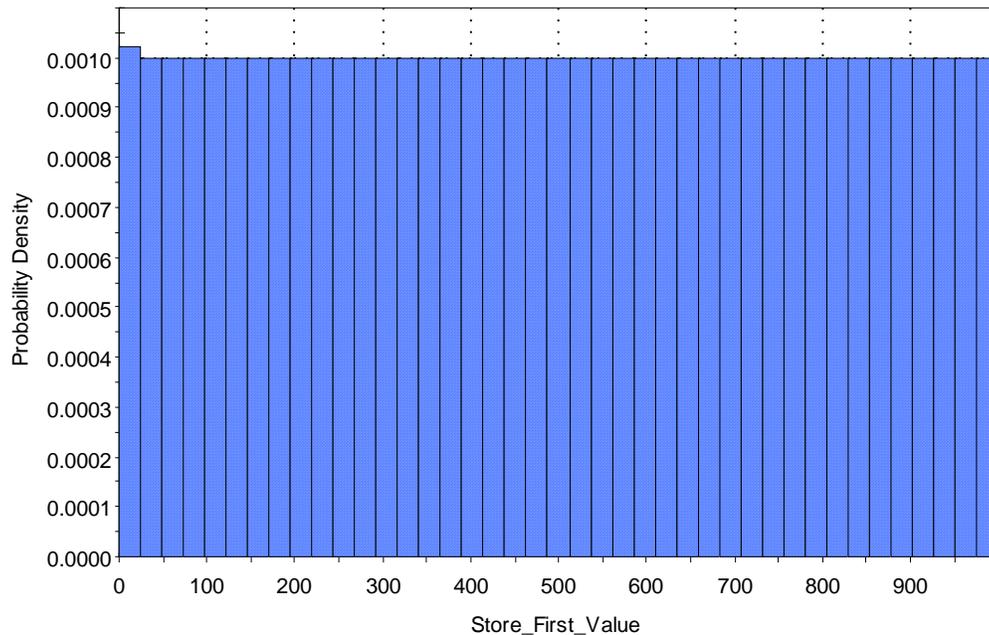


Fig. GS60_Wrap_Elapsed_4

Data Wrapping Cal Container

These tests ensure the proper behavior of the Time Series elements when start year synchronization is enabled and when periodicity is specified in an Calendar time model.

Tests in the Instantaneous and Average Value containers check to ensure that wrapping functionality and shifts are handled correctly for Instantaneous value and Constant over next time interval Time Series elements. This is done by comparing the output of an automatically wrapped time series with a manually wrapped time series. Shifting for Change over next time interval and Discrete change time series is confirmed by checking a graph of the outputs of the two time series. This test is only done in the instantaneous value container.

Element	Tests	Expected Result
Calendar_Shift\ Instantaneous_Value\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligable (<1E-4)
Calendar_Shift\ Instantaneous_Value\ Diff_Constant	Tests calendar shifting and wrapping for constant over next time interval time series elements.	Negligable (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Instant	Tests calendar shifting and wrapping for instantaneous time series elements.	Negligable (<1E-4)
Calendar_Shift\ Average_Value_Over_Timestep\ Diff_Constant	Tests calendar shifting and wrapping for constant over next time interval time series	Negligable (<1E-4)

Random_Starting_Point\ No_Periodicity\ Random_Result	elements. Tests random selection of start point within data set.	Result array should show real values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_2
Random_Starting_Point\ Annual_Periodicity\ Annual_Result	Tests random selection of start point with annual periodicity.	Result array should show observations at 0, 365 and 730. Plot should appear as shown in Fig. GS60_Wrap_Elapsed_3
Random_Starting_Point\ Daily_Periodicity\ Daily_Result	Tests random selection of start point with daily periodicity.	Result array should show integer values. Plot should appear uniform as shown in Fig. GS60_Wrap_Elapsed_4

Multiple Series Container

These tests ensure the proper behavior of the Time Series elements with multiple data sets and Time History input from other GoldSim models. It also checks that multi-set data can be sent and returned from SubModel elements.

Open the Retrieved_from_Other_File element. Delete any existing data, then download Time History result data from GS60_TimeSeries_Source (the Result element). Run the model and ensure the two Extrema elements show a negligible value ($<1E-4$).

Element	Tests	Expected Result
Multiple_Series\ Diff_SubModel	Tests multi-set export to SubModels, multi-set recording and linking, and export from SubModels	Negligible ($<1E-4$)
Multiple_Series\ Diff_OtherModel	Tests multi-set import from other GoldSim models.	Negligible ($<1E-4$)

GS60b_Time_Series

<Supercedes GS40b_Information Time SeriesExcelSupport and GS41b_Material Time SeriesExcelSupport>

This test ensures the proper functioning of Excel functionality in the second generation Time Series elements (introduced in GoldSim 9.60).

The first part of the test checks error handling – enter the container called Errors. Enter each property page and click the View Data button on the definition tab and Import data now option on the Excel tab. In both cases, you should receive identical error messages. The problems, and the expected error message with each Time Series element are listed below.

Element	Problem	Error Message
Columns_Extra_Row	Number of rows to read > number in Excel file	Empty spreadsheet cell found at A11

Rows_Extra_Column	Number of columns to read > number in Excel file	Empty spreadsheet cell found at K1
Missing_Dependent_Variable_Row	Missing dependent variable entry – 5 th data point	Empty spreadsheet cell found at B5.
Missing_Dependent_Variable_Cmn	Missing dependent variable entry – 5 th data point	Empty spreadsheet cell found at E2.
No_Cell_Specified	No starting cell specified	Column position is not specified for cell.
No_Excel_File_Specified	No Excel file specified	No spreadsheet specified.

Now enter the Too_Many_Cells container. In this container, there are two time series elements that check that the user is warned if they attempt to import a number of data points larger than the number available in an Excel sheet. The tester should enter the Extra_Rows element, and attempt to specify a number of rows to be read in greater than the Excel maximum (this is 65536 for Excel versions after Excel97). A warning should be generated. Clicking OK in the dialog should redisplay the warning (and the dialog should remain open).

Repeat the procedure for the Extra_Columns element – in this case, the tester should attempt to change the number of columns to be read in to a number greater than the maximum number of columns supported by Excel (256 for Excel versions after Excel97). A warning should be generated, and data should not be imported. Clicking OK in the dialog should redisplay the warning (and the dialog should remain open).

The second part of the test checks that the Excel import works correctly under normal conditions. Enter the container called Normal.

Open the property dialog for each of the four elements, click the Import data from MS-Excel file now option, and then return to the Definition page and click the View Data button. The expected results are as follows:

For Columns_Till_Empty and Rows_Till_Empty:

Time (d)	Value
1	10
2	20
3	30
4	40
5	50
6	60
7	70
8	80
9	90
10	100

For Columns_Num_Rows and Rows_Num_Columns, the data should be identical, but there should be no entries after 5 days.

The last part of the test verifies that the ‘create new spreadsheet’, ‘select spreadsheet’, ‘open spreadsheet’ and ‘update spreadsheet’ options work correctly.

Enter the Creating_Selecting_Updating container, and change the data source for the Time Series elements to None, then back to MS-Excel. Open the property dialog for the Select_Existing element, and go to the Excel tab. Choose Select existing MS-Excel file and choose 10Row10Column.xls. Click the Excel button in the data section and specify cell A1 on the sheet "Data in Columns" as the starting cell. Choose Import data now from MS-Excel, and verify using the View Data button on the Definition tab the following result:

Time (d)	Value
1	10
2	20
3	30
4	40
5	50
6	60
7	70
8	80
9	90
10	100

Now open the Create_New time series element - create a new spreadsheet called TSTest.xls. Open it using the Open command accessed through the options button. Enter 1,2,3,4,5 in column A and 10,20,30,40, 50 in column B. Save and close the Excel file. Click the Excel button in the data section and specify cell A1 on Sheet1 as the starting cell. Choose Import data now from MS-Excel, and verify using the View Data button on the Definition tab that the data you input into the new spreadsheet has been properly imported.

GS60c_Recording_Time_Series_Cond

OBSOLETE AS OF GOLDSIM 10.10

GS61_SubSystem_Stock

This test ensures that stocks within SubSystems (excluding Internal Clock SubSystems) participate in the update to time process.

Run the model - it should run to completion. Compare the plots in the SubSystem, Conditional, Looping and Resources containers to Figures GS61_1 through GS61_4 below. Enter the Internal_Clock container and check the Internal Clock option on the SubSystem container - an error should be generated and the model should not run.

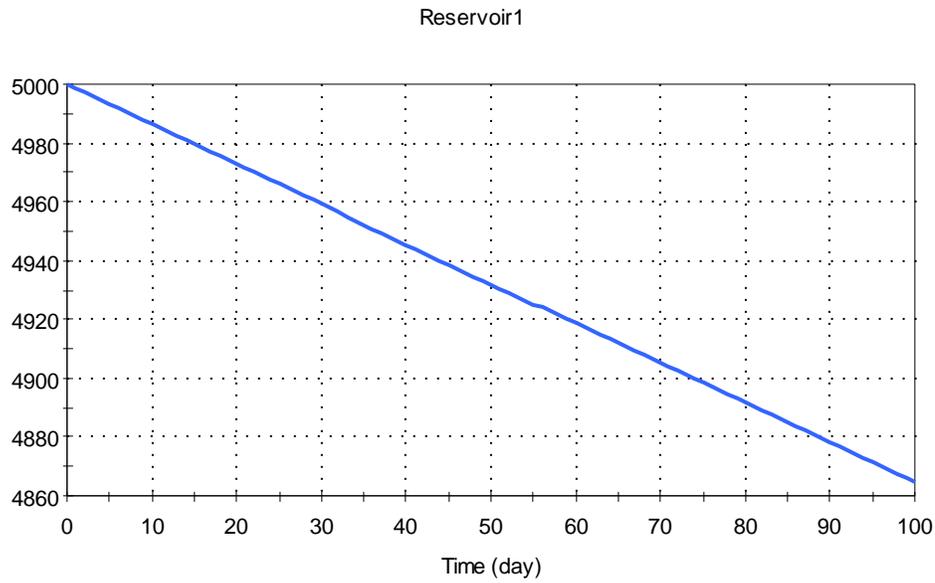


Fig. GS61_1 – SubSystem

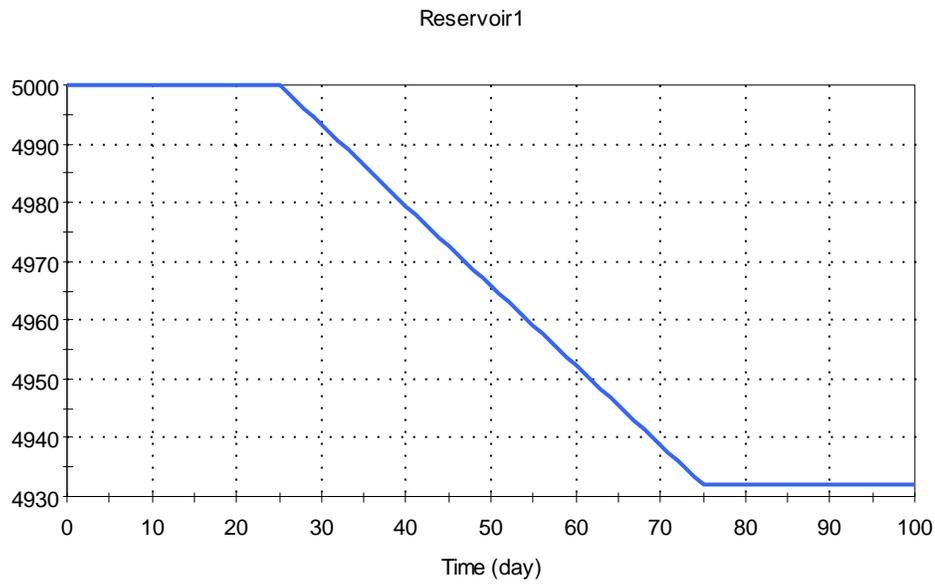


Fig. GS61_2 – Conditional Container

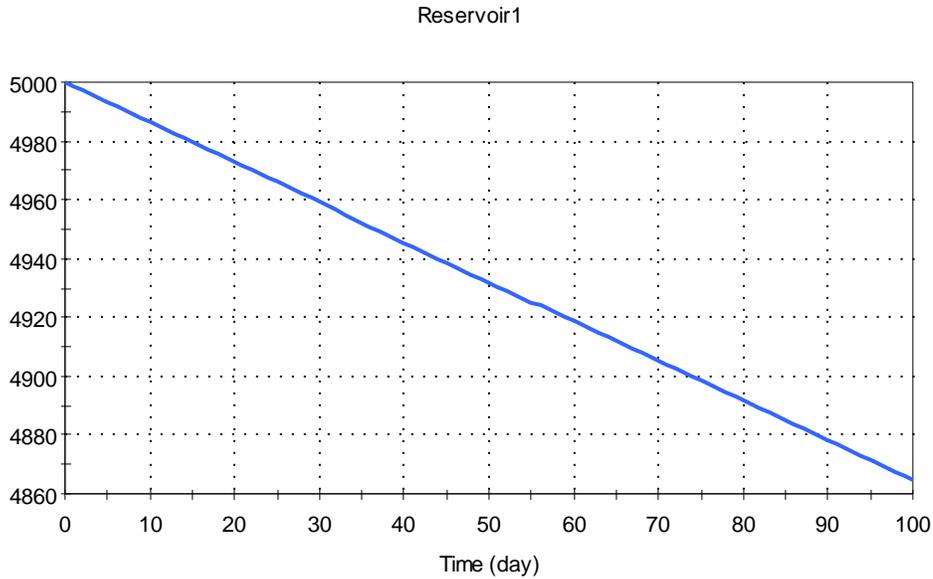


Fig. GS61_3 – Looping Container

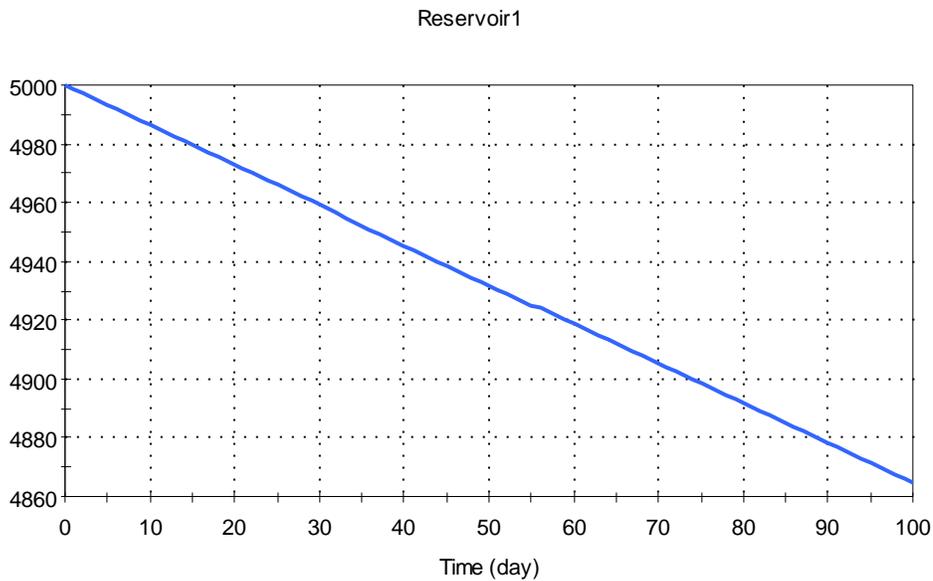


Fig. GS61_4 – Local Resources Store

GS62_Resources

This test verifies general Resource functionality as well as resource functionality specific to conditional containers by requiring resources from continuous scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62_1 through GS62_8 below.

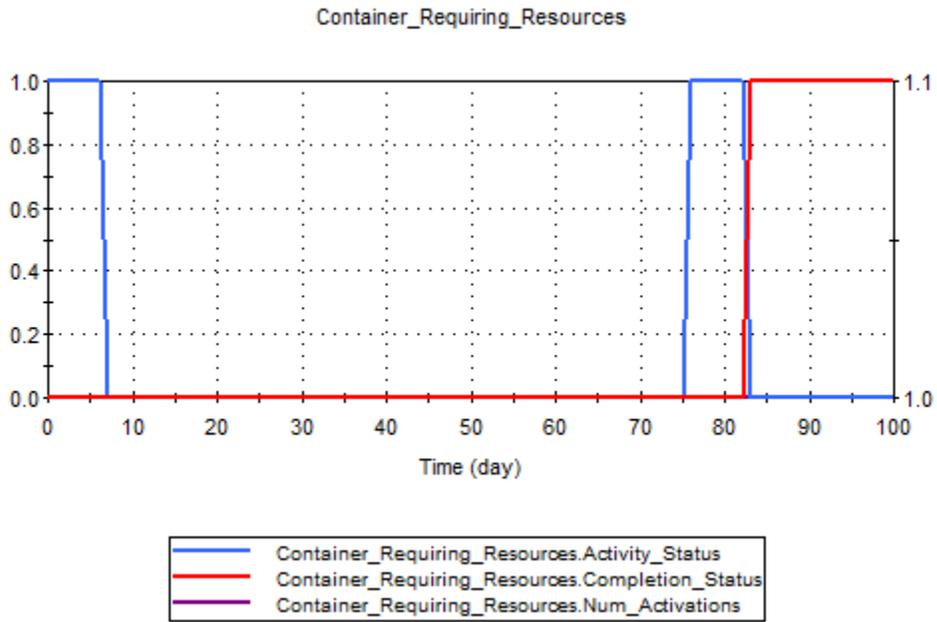


Fig. GS62_1 – Status Activations

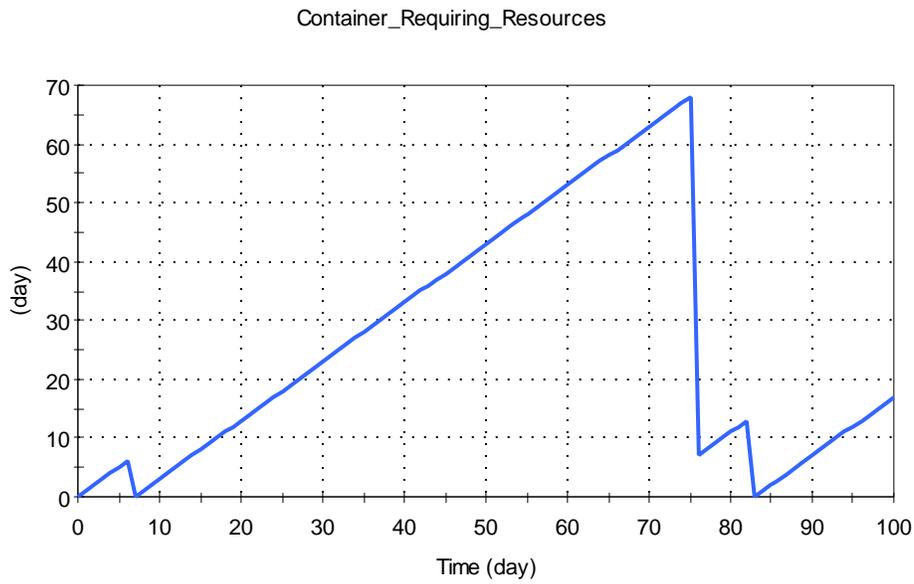


Fig. GS62_2 – Duration

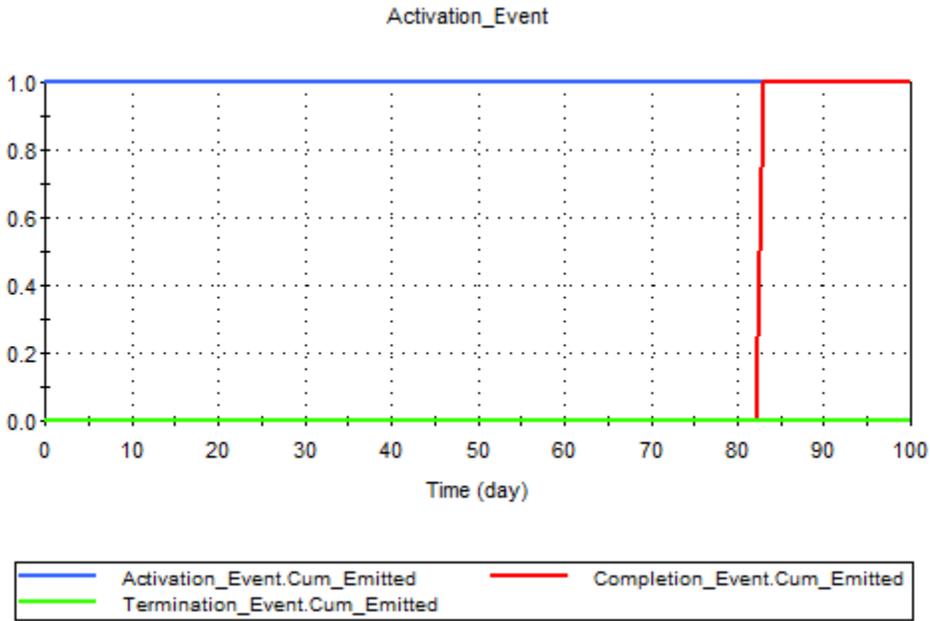


Fig. GS62_3 – Event_Plots

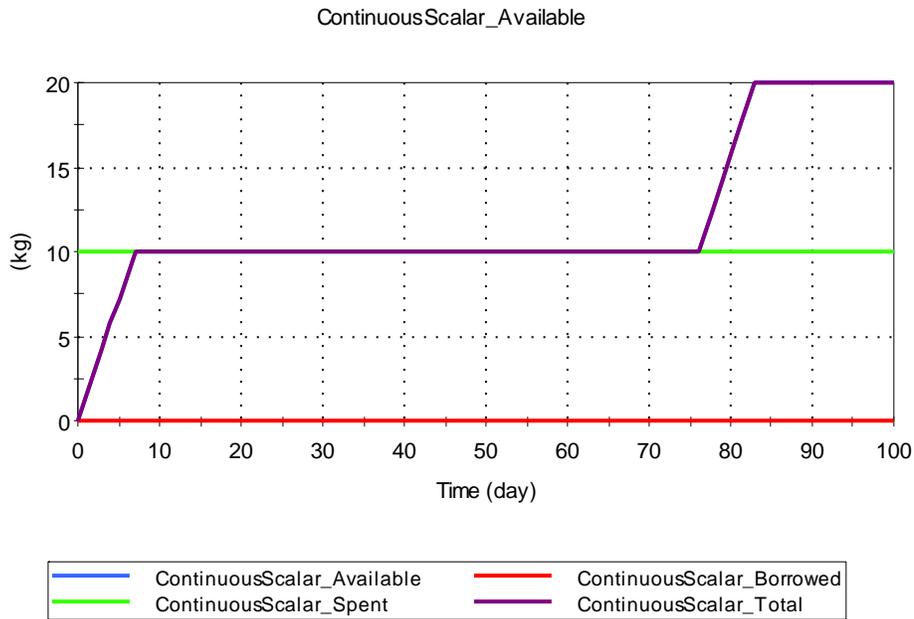


Fig. GS62_4 – ContinuousScalar

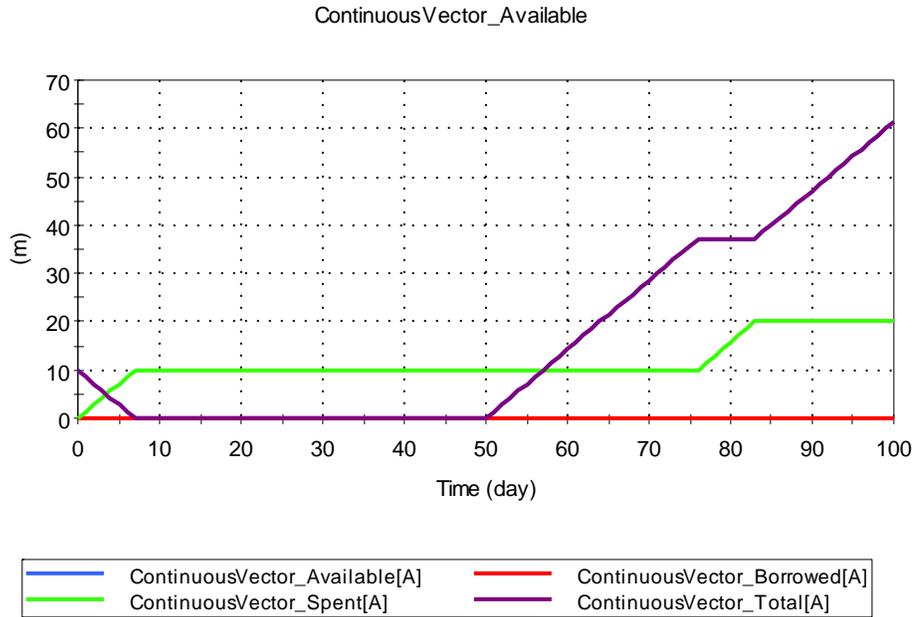


Fig. GS62_5 – VectorA

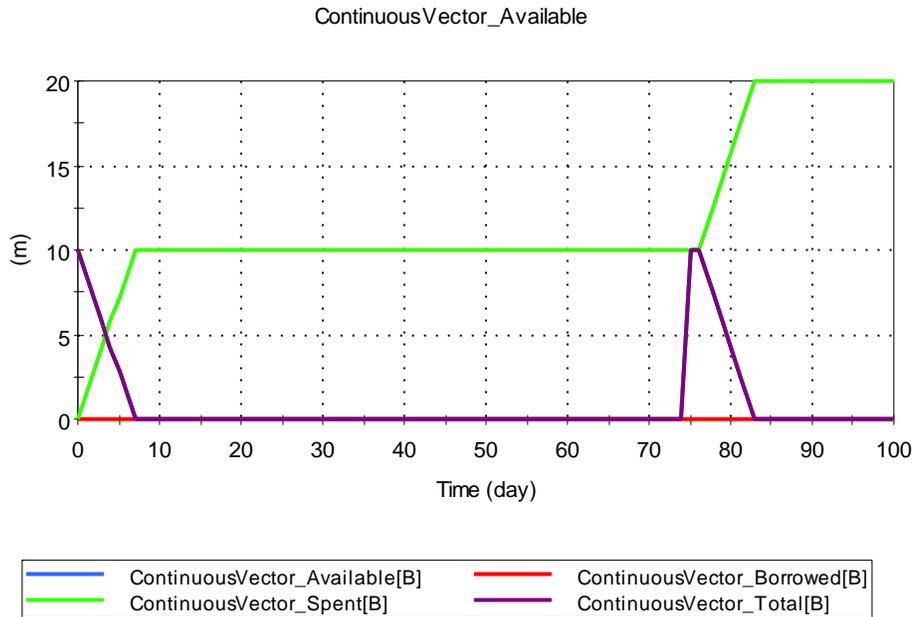


Fig. GS62_6 – VectorB

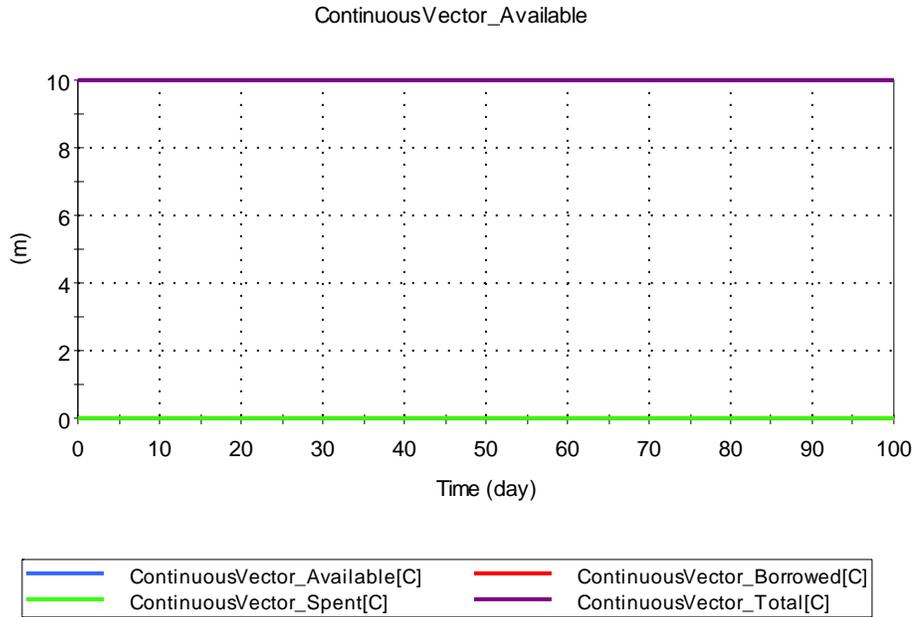


Fig. GS62_7 – VectorC

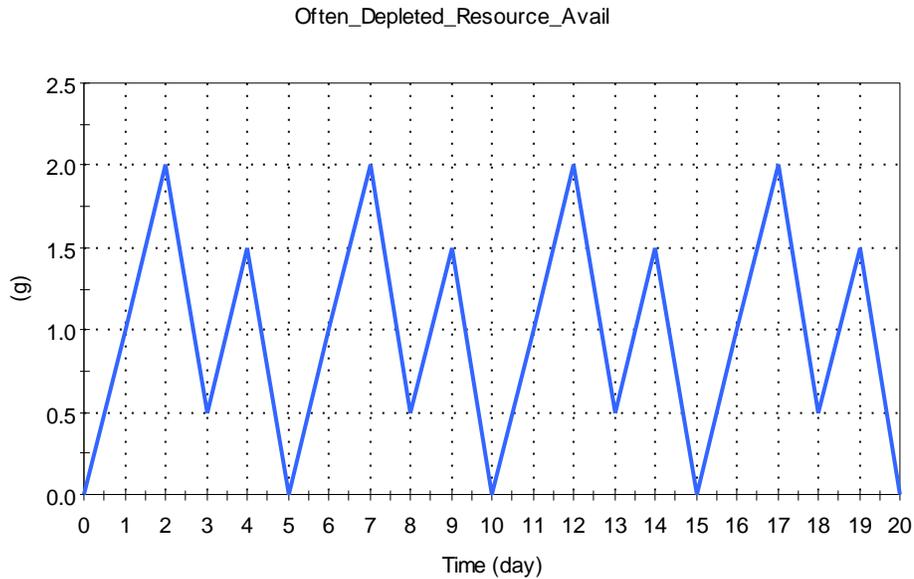


Fig. GS62_8 – Often_Depleted

GS62b_Resources

This test verifies general Resource functionality as well as resource functionality specific to Triggered Events by requiring resources from discrete scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62b_1 through GS62b_5 below.

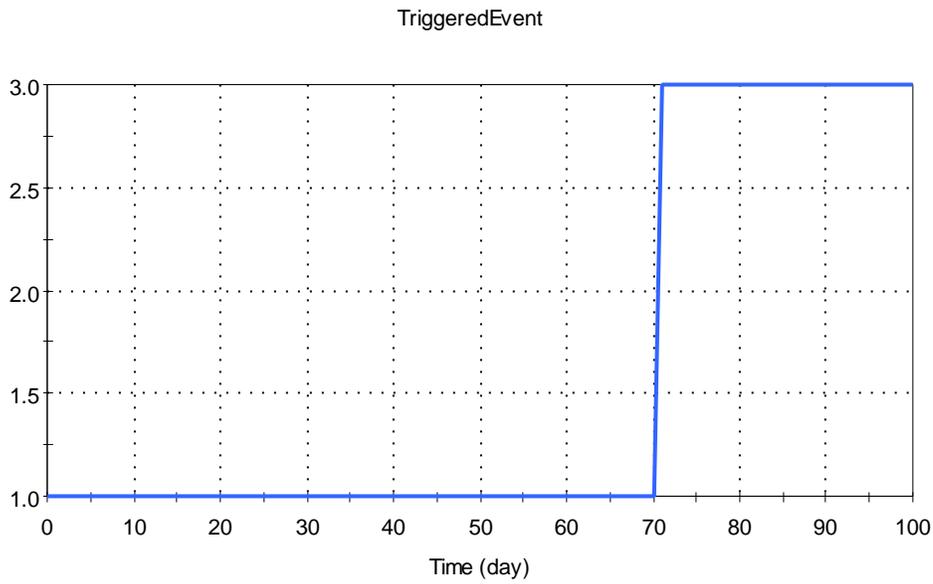


Fig. GS62b_1 – Cum_Emitted

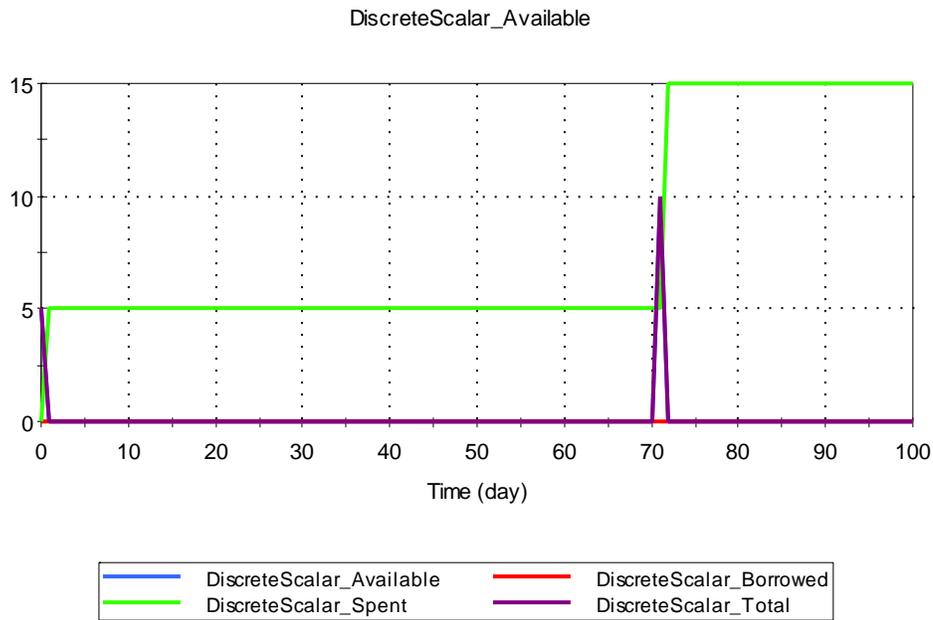


Fig. GS62b_2 –DiscreteScalar

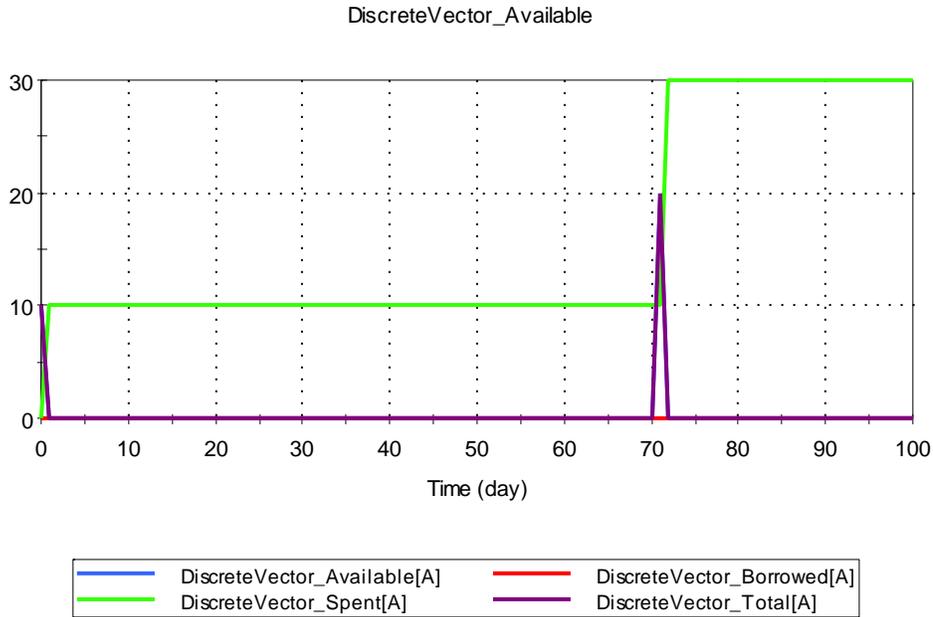


Fig. GS62b_3 – VectorA

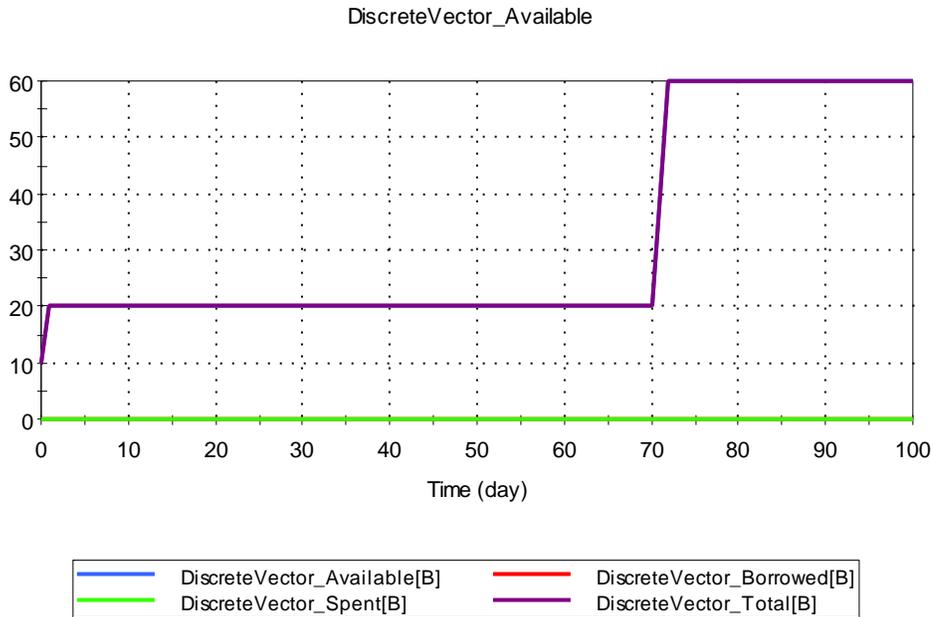


Fig. GS62b_4 – VectorB

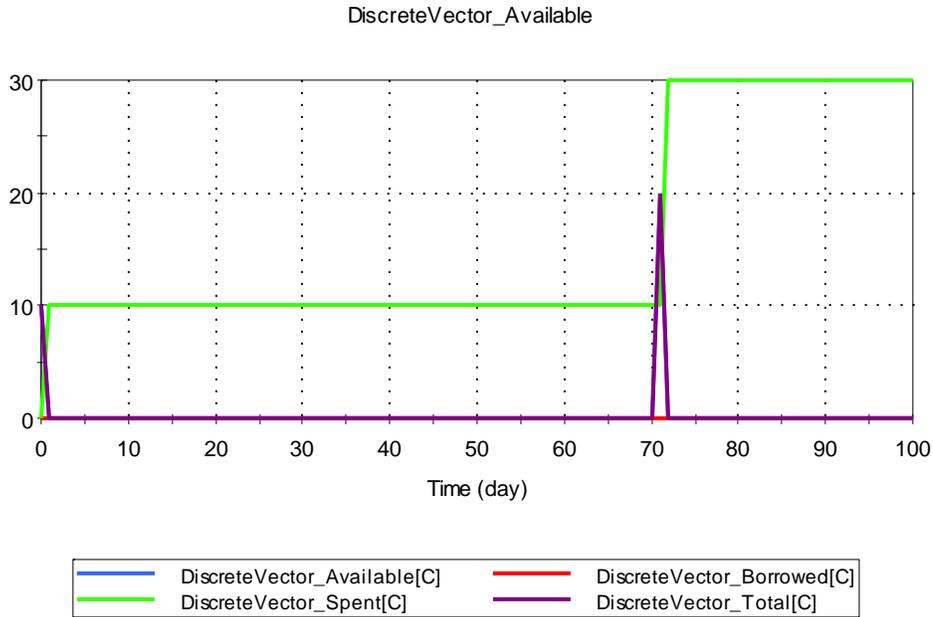


Fig. GS62b_5 – VectorC

GS62c_Resources

This test verifies general Resource functionality as well as resource functionality specific to Event Delays by requiring resources from discrete scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62c_1 through GS62c_6 below.

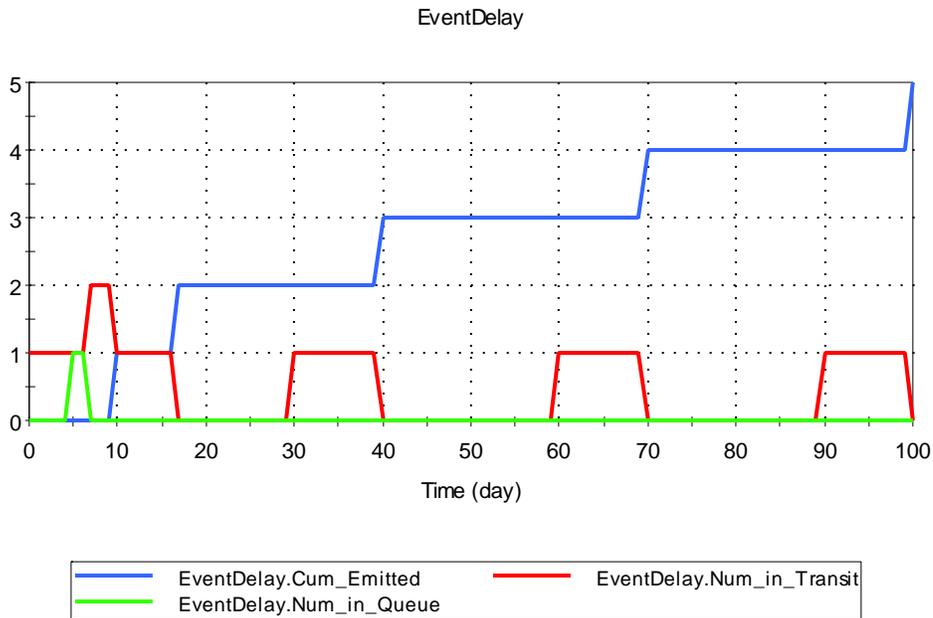


Fig. GS62c_1 – EventDelayOutputs

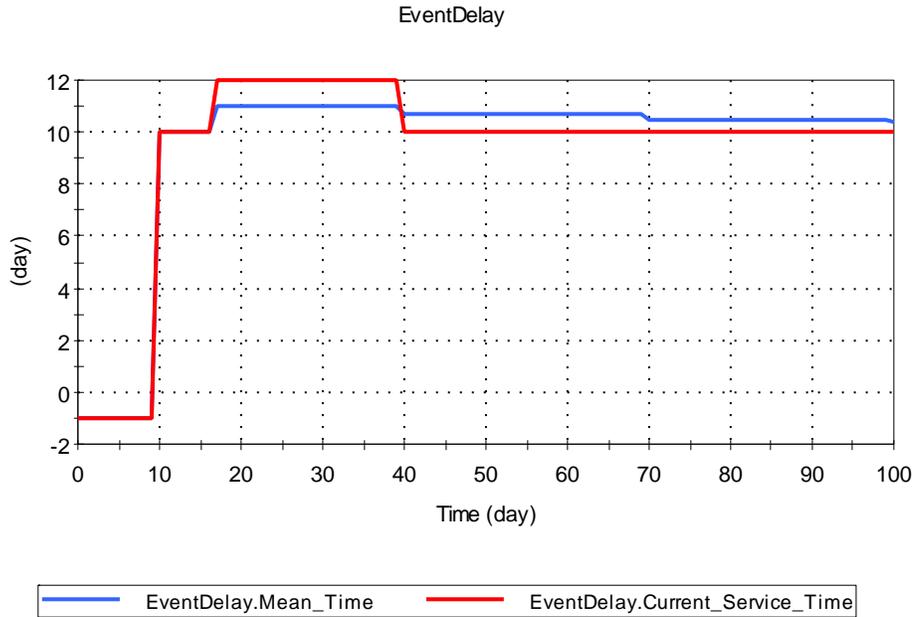


Fig. GS62c_2 – ServiceTimes

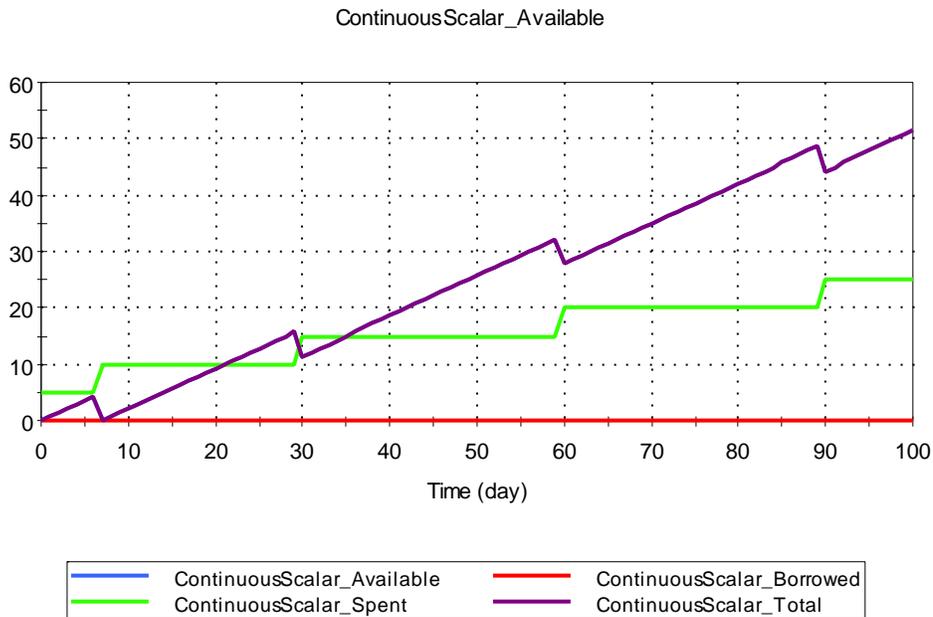


Fig. GS62c_3 – ContinuousScalar

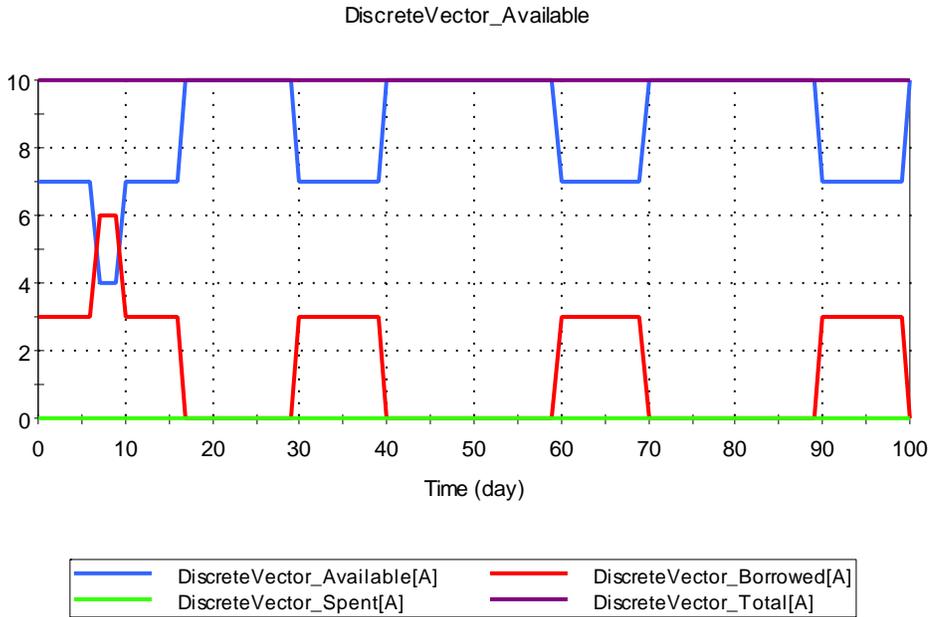


Fig. GS62c_4 – VectorA

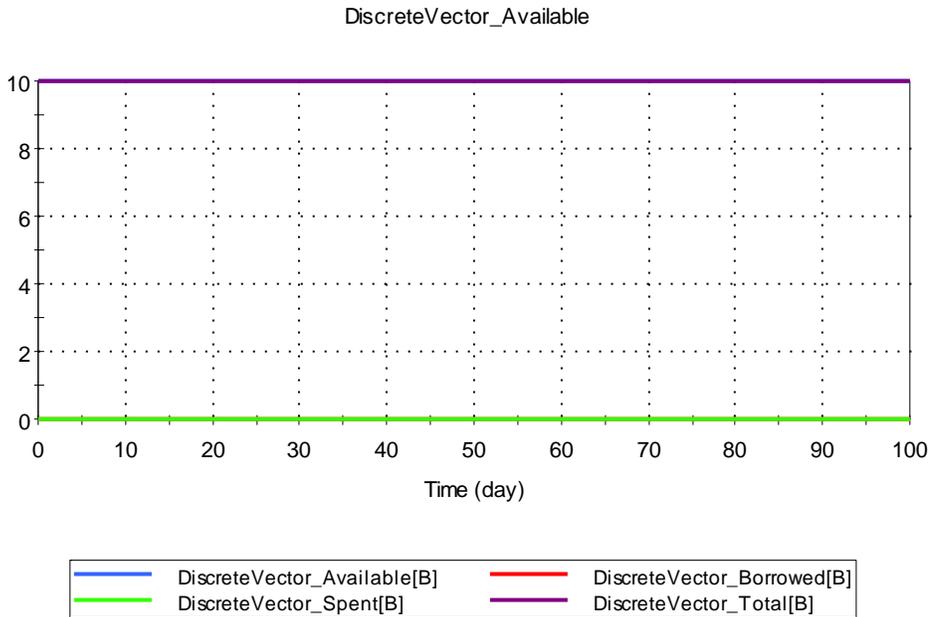


Fig. GS62c_5 – VectorB

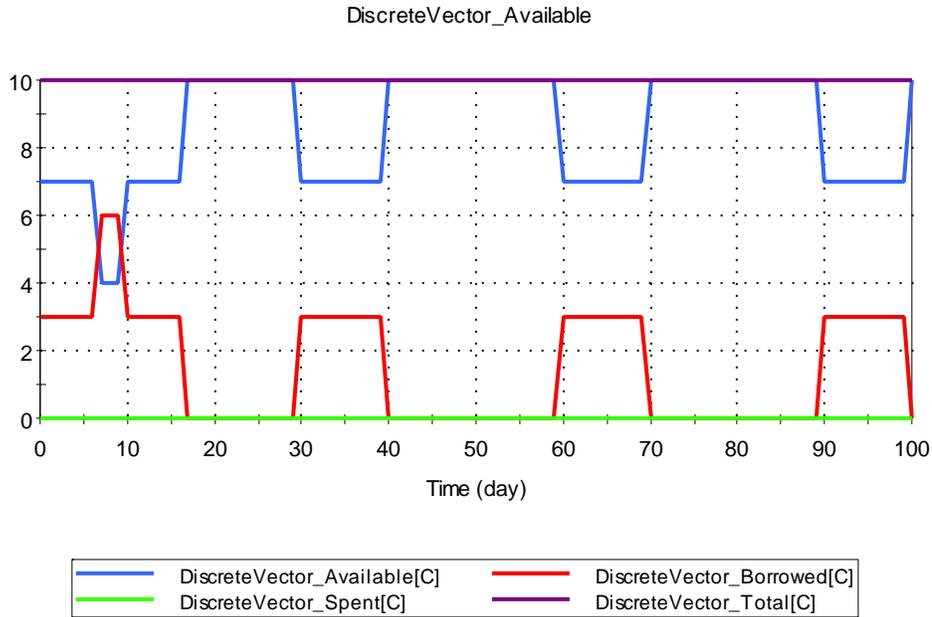


Fig. GS62c_6 – VectorC

GS62d_Resources

This test verifies general Resource functionality as well as resource functionality specific to Discrete Change Delays by requiring resources from discrete scalar and vector resources for activation and operation.

The verifier should run the model and ensure the plots correspond with the expected results in Fig. GS62d_1 through GS62d_5 below.

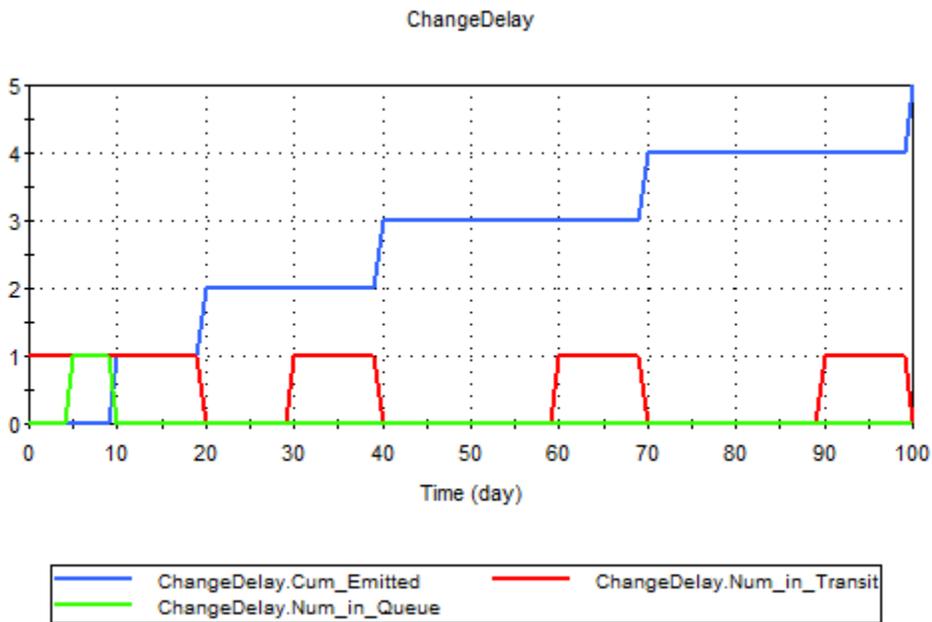


Fig. GS62d_1 – ChangeDelayOutputs

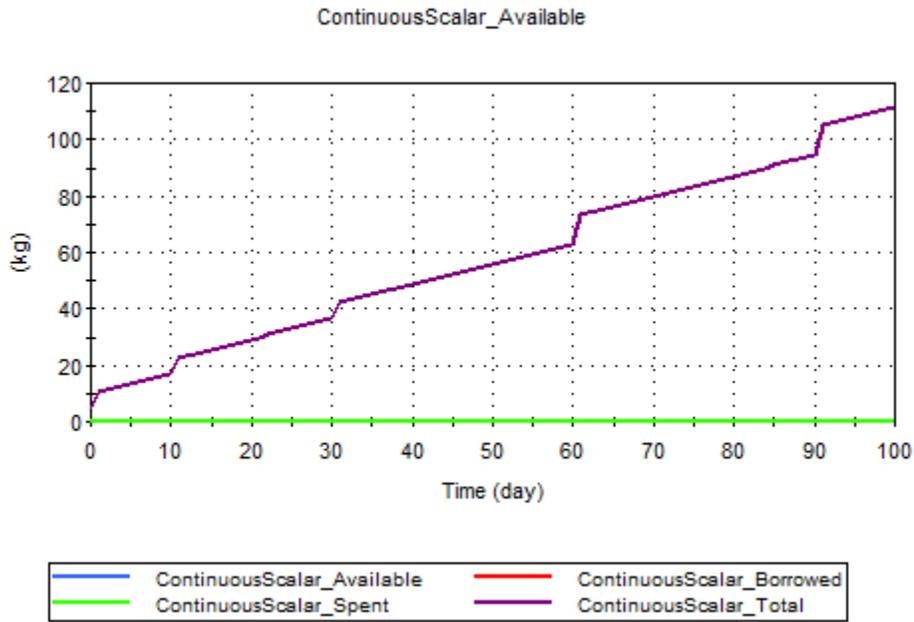


Fig. GS62d_2 –ContinuousScalar

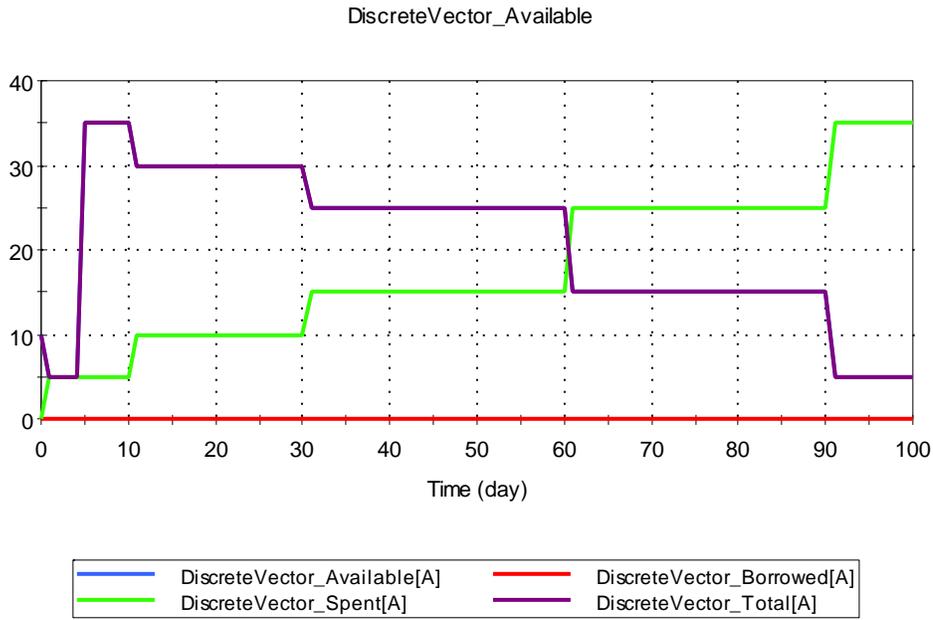


Fig. GS62d_3 – VectorA

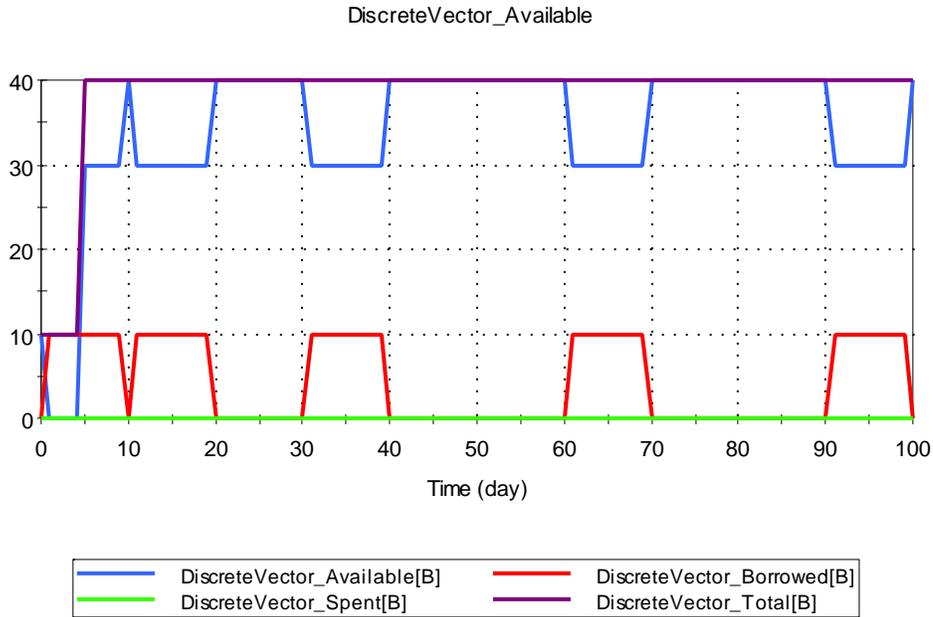


Fig. GS62d_4 – VectorB

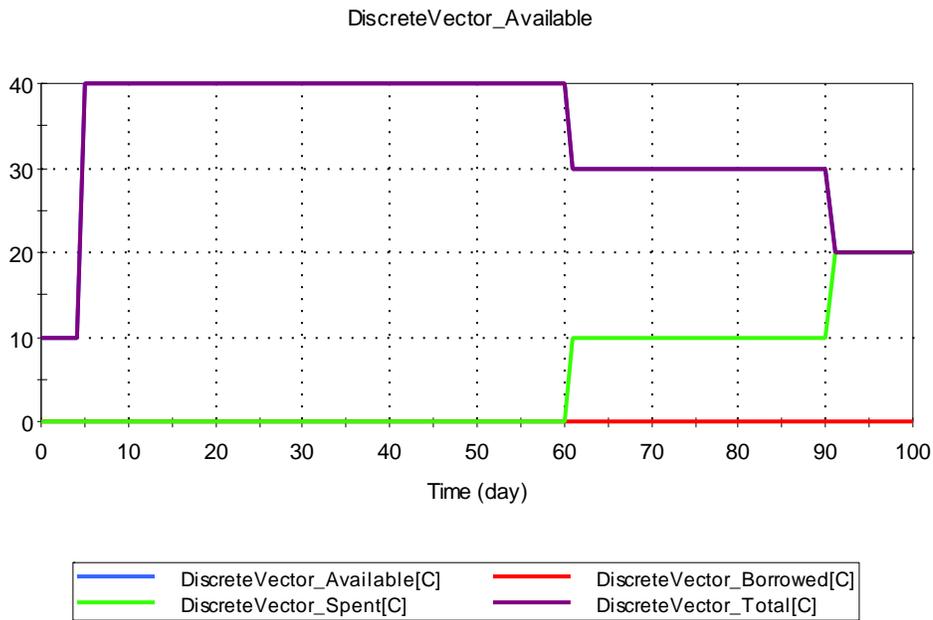


Fig. GS62d_5 – VectorC

GS62e_Resource_Results

This test verifies that Resource results function correctly. The verifier should run the test and open the Resources dialog using F8. Confirm that the Locations dialog shows the result below in Figure GS62e_1. Then open the ContainerWithStore container and verify that the Locations dialog shows the result pasted to the left of the container.

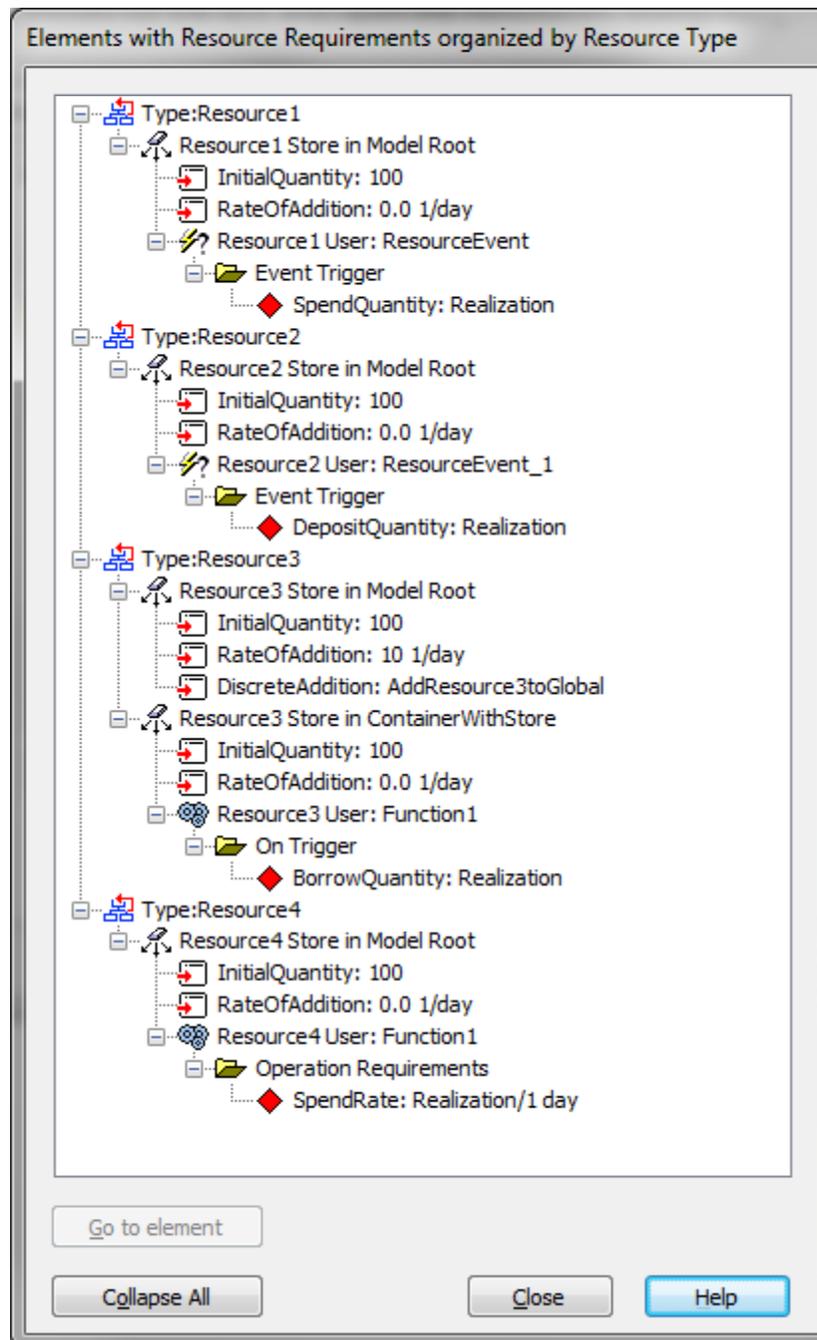


Figure GS62e_1 (Global Locations Dialog)

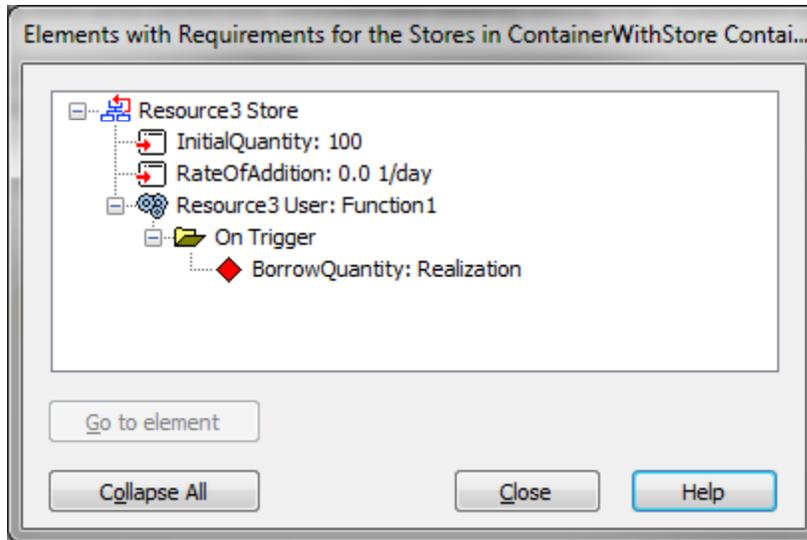


Figure GS62e_2 (Container With Store Locations Dialog)

View the Histories dialog for the model. Each realization elements which spend or deposit resources at the current Realization number. Resources will be borrowed at the current realization number for the duration of the simulation. Confirm this using the example results in Figure GS62e_3 (for Realization 1) and GS62e_4 (for Realization 10).

View History for all Resource Types, Stores, Requirements

Type	Store Location	Item	0	1	2	3	4	5	6	7
-Resource1 (-)	-Model	Store- total amount in system:	100	99	98	97	96	95	94	93
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- ResourceEvent : Event Trigger (Spent)	0	1	2	3	4	5	6	7
-Resource2 (-)	-Model	Store- total amount in system:	100	101	102	103	104	105	106	107
		User- ResourceEvent_1 : Event Trigger (Deposit)	0	-1	-2	-3	-4	-5	-6	-7
-Resource3 (-)	Model	Store- total amount in system:	200	210	220	230	240	250	260	270
	-ContainerWithStore	Store- total amount in system:	100	100	100	100	100	100	100	100
		Store- Amount unused:	99	99	99	99	99	99	99	99
		Store- Amount borrowed:	1	1	1	1	1	1	1	1
		User- Function1 : On Trigger (Borrowed)	1	1	1	1	1	1	1	1
-Resource4 (-)	-Model	Store- total amount in system:	100	99	98	97	96	95	94	93
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- Function1 : Operation Requirements (Spent)	0	1	2	3	4	5	6	7

Note: deposits of resources are displayed as negative numbers. View: Realization 1

Figure GS62e_3 (Realization 1 Results)

View History for all Resource Types, Stores, Requirements

Type	Store Location	Item	0	1	2	3	4	5	6	7
-Resource1 (-)	-Model	Store: total amount in system:	100	90	80	70	60	50	40	30
		Store- Cumulative amount spent:	0	10	20	30	40	50	60	70
		User- ResourceEvent : Event Trigger (Spent)	0	10	20	30	40	50	60	70
-Resource2 (-)	-Model	Store: total amount in system:	100	110	120	130	140	150	160	170
		User- ResourceEvent_1 : Event Trigger (Deposit)	0	-10	-20	-30	-40	-50	-60	-70
-Resource3 (-)	Model	Store: total amount in system:	200	210	220	230	240	250	260	270
	-ContainerWithStore	Store: total amount in system:	100	100	100	100	100	100	100	100
		Store- Amount unused:	90	90	90	90	90	90	90	90
		Store- Amount borrowed:	10	10	10	10	10	10	10	10
		User- Function1 : On Trigger (Borrowed)	10	10	10	10	10	10	10	10
-Resource4 (-)	-Model	Store: total amount in system:	100	90	80	70	60	50	40	30
		Store- Cumulative amount spent:	0	10	20	30	40	50	60	70
		User- Function1 : Operation Requirements (Spent)	0	10	20	30	40	50	60	70

Note: deposits of resources are displayed as negative numbers. View: Realization | 10 | Collapse All | Close | Help

Figure GS62e_4 (Realization 10 Results)

Minimum, Maximum and Mean results can be confirmed by comparing the results from the first few steps to the screenshots in Figure GS62e_5 through Figure GS62e_7 below.

View History for all Resource Types, Stores, Requirements

Type	Store Location	Item	0	1	2	3	4	5	6	7
-Resource1 (-)	-Model	Store: total amount in system:	100	0	0	0	0	0	0	0
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- ResourceEvent : Event Trigger (Spent)	0	1	2	3	4	5	6	7
-Resource2 (-)	-Model	Store: total amount in system:	100	101	102	103	104	105	106	107
		User- ResourceEvent_1 : Event Trigger (Deposit)	0	-100	-200	-300	-400	-500	-600	-700
-Resource3 (-)	Model	Store: total amount in system:	200	210	220	230	240	250	260	270
	-ContainerWithStore	Store: total amount in system:	100	100	100	100	100	100	100	100
		Store- Amount unused:	99	99	99	99	99	99	99	99
		Store- Amount borrowed:	1	1	1	1	1	1	1	1
		User- Function1 : On Trigger (Borrowed)	1	1	1	1	1	1	1	1
-Resource4 (-)	-Model	Store: total amount in system:	100	0	0	0	0	0	0	0
		Store- Cumulative amount spent:	0	1	2	3	4	5	6	7
		User- Function1 : Operation Requirements (Spent)	0	1	2	3	4	5	6	7

Note: deposits of resources are displayed as negative numbers. View: Minimum | | Collapse All | Close | Help

Figure GS62e_5 (Minimum)

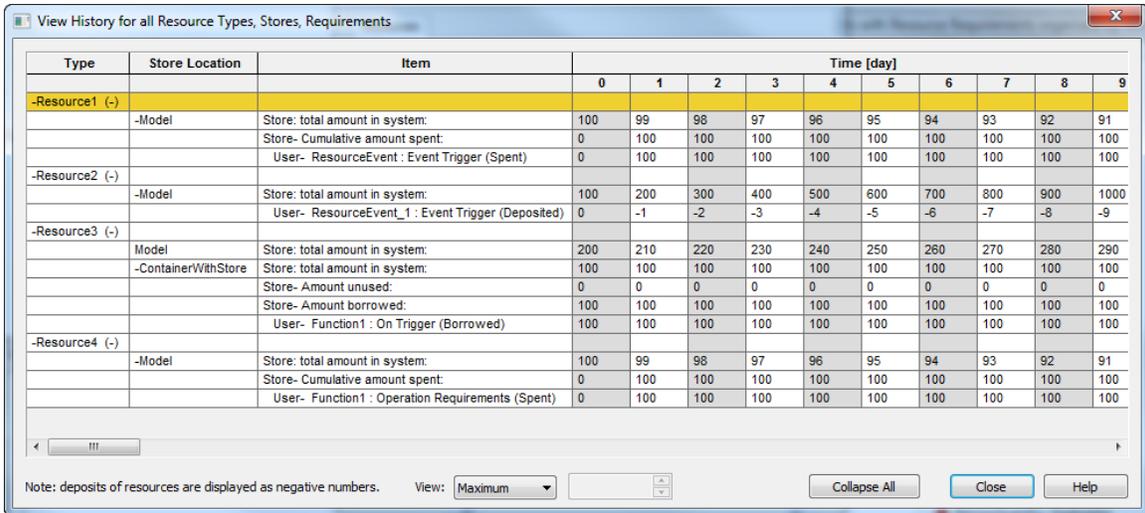


Figure GS62e_6 (Maximum)

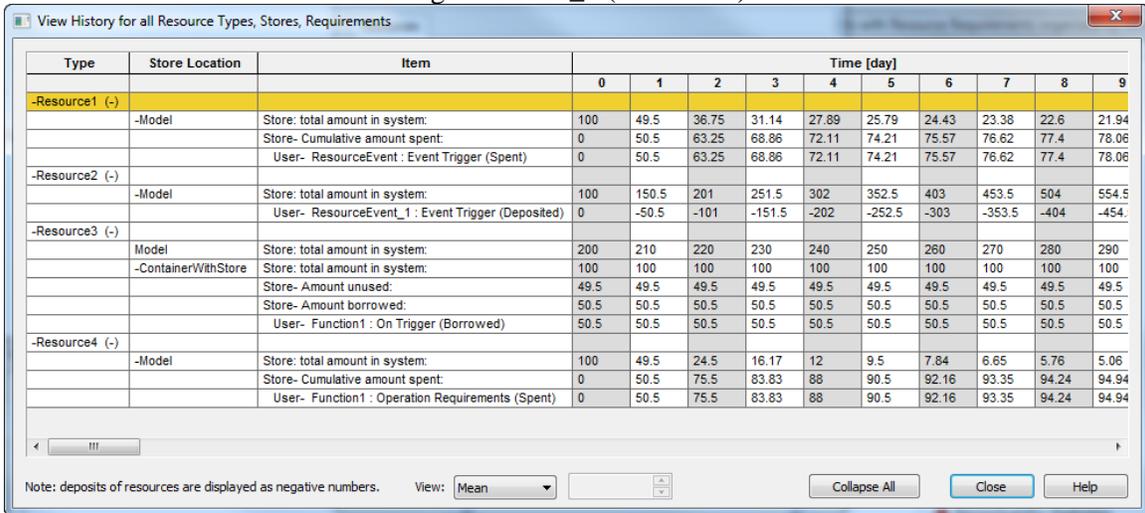


Figure GS62e_7 (Mean)

GS62f_Resources

This test verifies Resource functionality in SubModels. It is a copy of the GS62_Resources test with a second copy of the GS62_Resources test imported as a SubModel.

The verifier should run the model and ensure the plots in the main model and SubModle correspond with the expected results in Fig. GS62_1 through GS62_7 below.

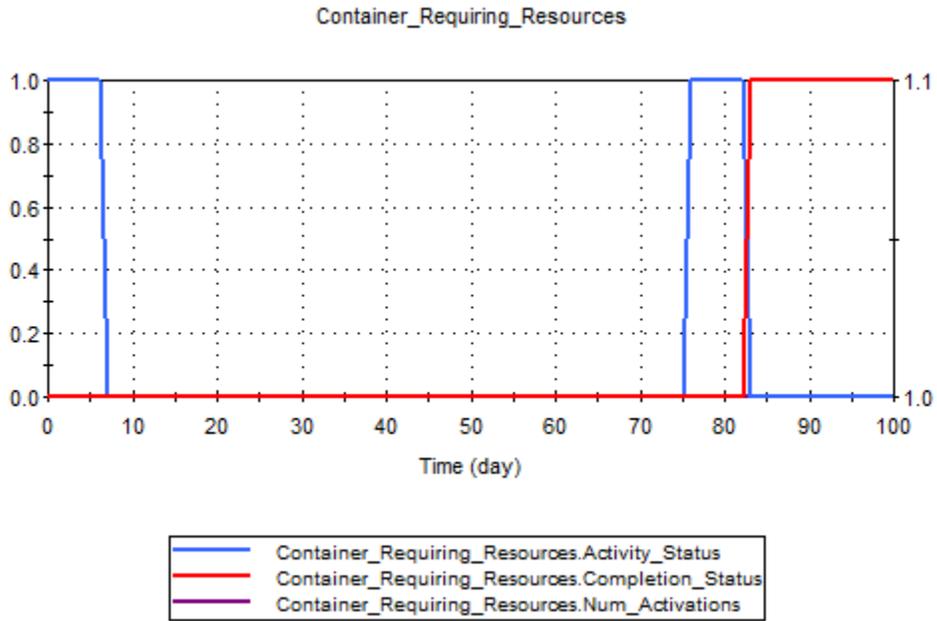


Fig. GS62f_1 – Status_Activations

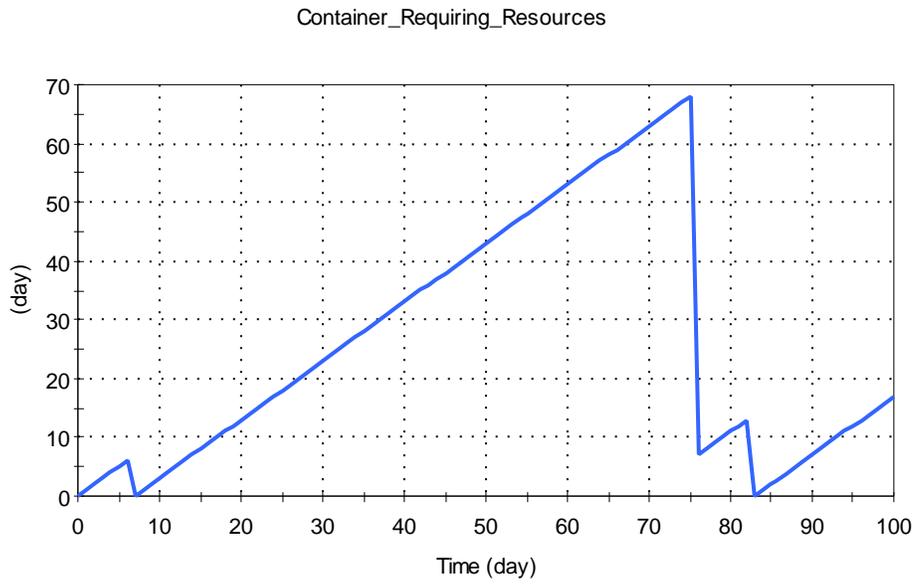


Fig. GS62f_2 – Duration

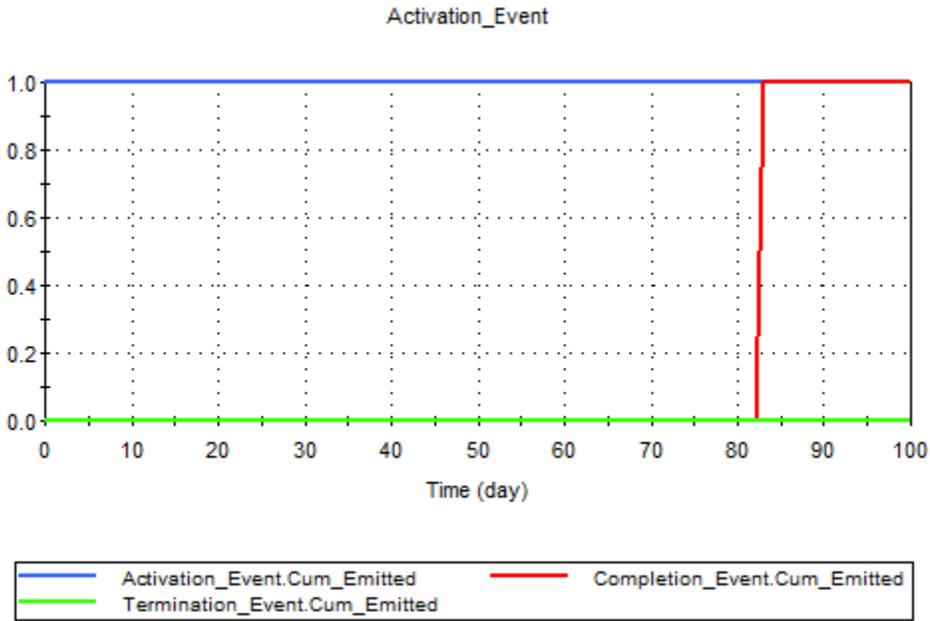


Fig. GS62f_3 – Event_Plots

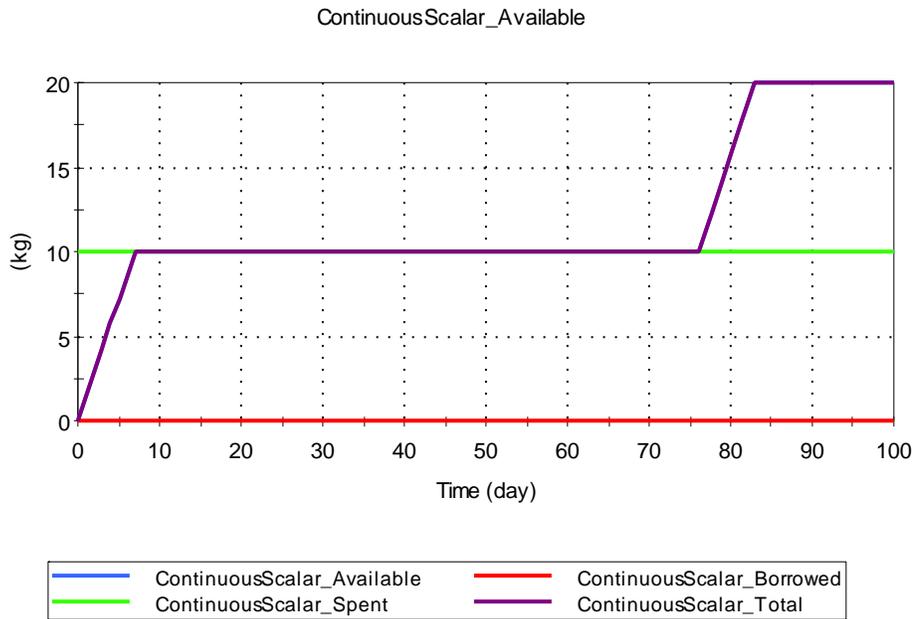


Fig. GS62f_4 – ContinuousScalar

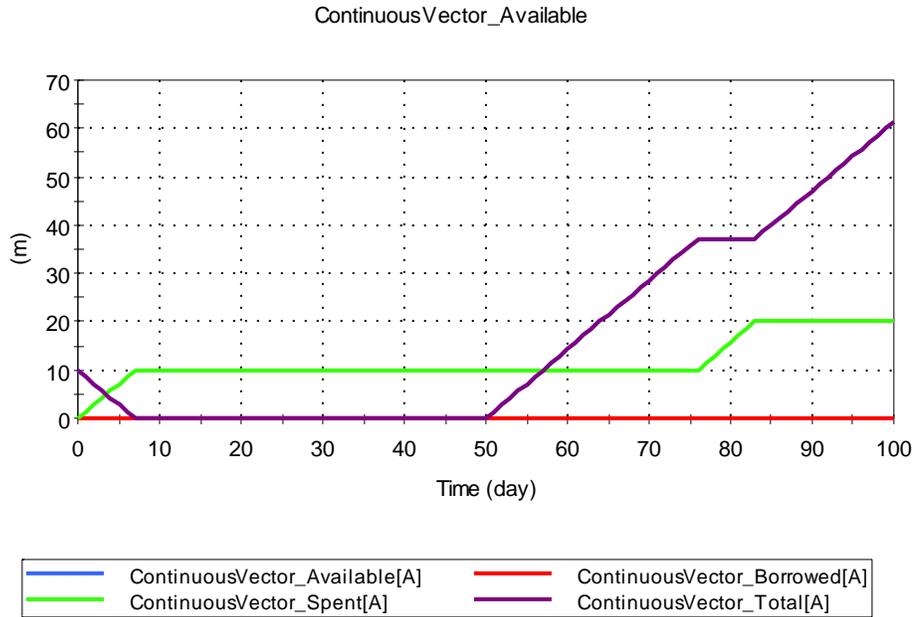


Fig. GS62f_5 – VectorA

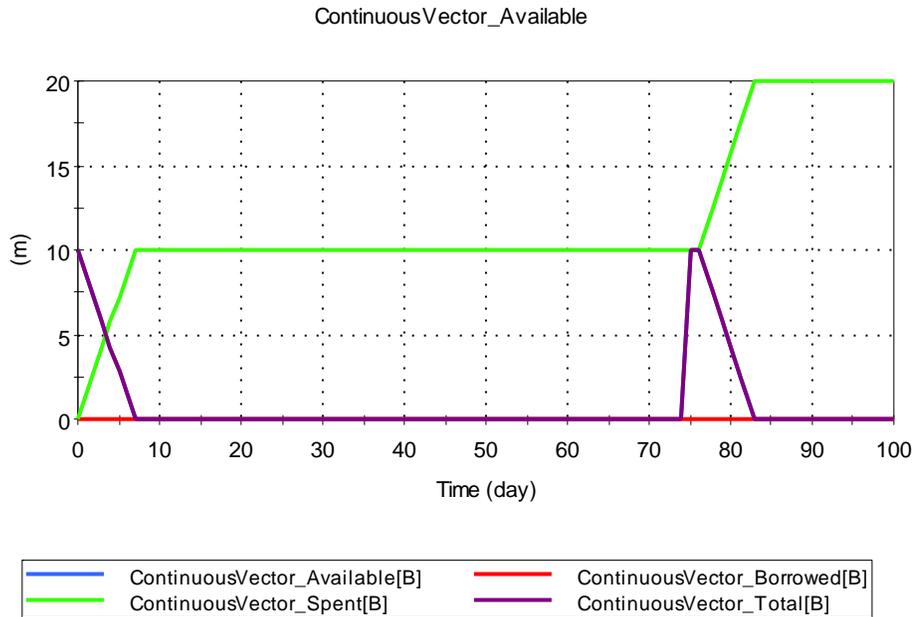


Fig. GS62f_6 – VectorB

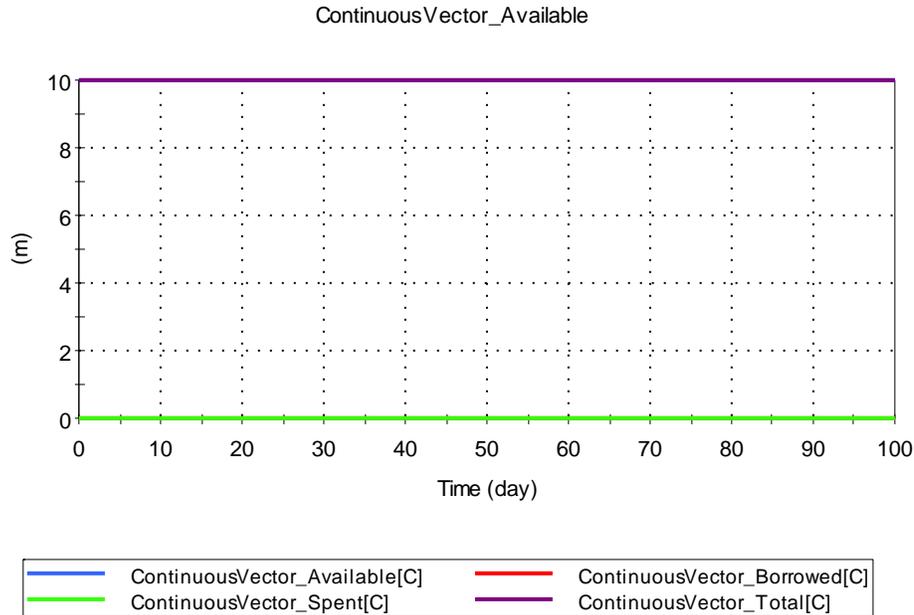


Fig. GS62f_7 - VectorC

GS63_Script_General

There are 6 files testing the script element's calculations. One is a file of general tests that examine all statement types to varying degrees (GS63_Script_General). These tests are similar to real world applications, with several scripts sorting vectors, one calculating a correlation matrix, and one calculating a square root by Newton's method. The other five files (GS63b to GS63f) are aimed at testing specific loop statements and logging of messages, errors, and warnings from the script element. Throughout all tests, variable definition and assignment statements, if statements, and break and continue statements are also tested.

GS63_Script_General consists of 6 script elements. The tester should run the model and confirm that the element True_if_all_Scripts_worked is true. If that element is not true, it is necessary to look more closely at each script element's verification, as described below.

The first script in this file is called Index_and_Sort. This element does a bubble sorting algorithm that should give the same results as the vector function sort123. It tests nested for loops and if statements and assignment to arrays. If this script is working, the element True_if_Sort_Worked will be true.

The next two script elements, Correlation_Matrix_For_Loop and Correlation_Matrix_While_Loop, calculate by different techniques the correlation matrix for a uniform random matrix of numbers. As the names indicate, one script element uses nested for loops and one element uses nested while loops; both test assignment of a matrix item by item. They should give the same result as the element Correlation_Matrix_From_Excel. If these scripts are functioning normally, the elements True_if_Correlation_works1 and True_if_Correlation_works2 will both be true.

The next two script elements in the file, `Tied_Rank_by_Do_Loop` and `Tied_Rank_by_For_Loop`, calculate the tied ranks for a vector of random integers with several ties. These elements test nested while loops, do loops, for loops, and assignment to vectors. If these script elements are working, the element `True_if_Tied_Rank_Worked` should be true.

The final test in this file calculates the square root of a number through Newton's method. It tests for loops, if statements, and break statements. If this script is functioning properly, the element `True_if_Square_Root_Works` should be true.

GS63b_Script_If_and_Log

This file tests if statements, log statements, and showing messages. The tester should set the element `Turn_on_Container1` to false and then run the model. The following three messages should be produced:

Var1 is equal to 9

Check that Input1 is equal to 5. If so, this test works, but check also that this message is added as a message to the run log.

If input1 does not have a value of 6, then you should be seeing this message. This will be added to the run log as a warning, so check there.

Then the tester should change the element `Turn_on_Container1` to true and run the model. When `Etime` is equal to 50 days, this should generate a correctly parsed error message like this:

You should see this message as a fatal error at Etime of 50 days if Turn_on_Container1 is true. Check that this appears in the run log at 50 days. This message occurred at Etime=50 days

GS63c_Script_For

This file tests for loops, including nested for loops, for loops with break and continue statements, for loops with non-constant increments, and for loops with reassignment of the loop variable. The tester should run the model and confirm the element `True_if_all_work` is true. If this element is not true, at least one of the script elements is not working. To find out which, if any, of the script elements is not working, the tester should look at the elements with names beginning with "True" to see which one is false.

GS63d_Script_Do

This file tests do loops, including nested do loops, repeat loops within do loops, reassignment of the do loop variable, and do loops that count down without the loop variable exactly matching the stopping value. The tester should run the model and confirm the element `True_if_all_work` is true. If this element is not true, the tester should examine the conditional expression elements with names beginning with "True" to see which script element is not functioning properly.

GS63e_Script_Repeat

This file tests repeat loops, including nested repeat loops, repeat loops with break and continue statements and assignments to matrices. The tester should run the model and confirm the element

True_if_everything_works is true. If this element is not true, at least one of the three script elements is not functioning properly and it is necessary to look at the conditional expression elements with names beginning with “True” to see which script element is not working.

GS63f_Script_While

This file tests while loops, including a simple while loop and a nested while loop. The tester should run the model and confirm the element True_if_everything_works is true. If this element is false, one of the two script elements is not working properly. In this case, the tester should examine the other two elements with names beginning with “True” to see which of the two script elements with while loops is not functioning properly.

GS64_CausalitySequence_View

This test verifies the UI and proper viewing of Causality Sequence in the Causality Sequence dialog.

1. Open GS64a_CausalitySequence_View.gsm. Click F9 in order to update the sequences. Click F10 to open the Causality Sequence dialog. Make sure that Container1, three discrete changes (DC1, DC2 and DC3), and three reservoir elements (Pond1, Pond2 and Pond3) are displayed in the Function sequence view. Change to the Static sequence view and make sure that three inflows are displayed. Close the dialog.
2. Go into Container2. Open the Causality Sequence dialog and check that both the Function and Static sequence views display identically to the ones in the main model container. Change the selection to “Elements in current container/child containers. Two discrete changes (DC2 and DC3) and two pond elements (Pond2 and Pond3) should be displayed. Change the Selection to Elements in the current container only. You should see only DC2 and Pond2.
3. Go back to the main model container. Now enter Container1. Open the Causality Sequence dialog. Six elements should appear in the function sequence and none in the static sequence. Close the dialog, select a few elements and re-open the causality sequence dialog. Selected elements names should be shown bold.

GS64_CausalitySequence_AddPrecedent

This test verifies the proper functioning of Causality Sequence through defining precedents for elements.

1. Open GS64b_CausalitySequence_AddPrecedents.gsm. Go into the Container Add_Precident. Run the model, open the result plot and make sure that all three discrete change signals are emitted on the 11th second. Go back the edit mode.
2. Add DC2 as a precedent of DC1, DC3 as a precedent of DC2. Make sure that input ports of DC1 and DC2 have changed their colors to blue. Open the Causality Sequence dialog

and make sure that the order is DC3, DC2 and DC1. DC2 and DC1 should be highlighted with blue. Make sure that the precedent condition is stated in element tool tips in the dialog.

3. Tick the check box for showing causality sequence position in element tooltips. Close the dialog and check that precedent conditions are stated in tooltips.
4. Try adding DC1 as a precedent of DC3. It should fail because it causes a loop in the logic.
5. Run the model and check that DC3 is emitted on the 12th second.
6. Go into Add-Precedent_Fail. Try adding DC5 as a precedent for DC4. This should fail because it causes a loop in the logic.

TIME AND MONTE-CARLO TESTS

3.2 BASIC TIME AND MONTE CARLO TESTS

TMC-01 Time-Control Tests

Test TMC_01 confirms that the desired run-duration, time-step length and plot-steps are functioning correctly. It uses a simple Integrator element to generate a time-history indicating the time-points used. The test uses 100 time steps of 1 second each, for a total duration of 100 sec. It plots every second time step for the first 10 seconds, then every tenth time step for the balance of the simulation. The rate of change is 1/sec until time 50, then 2/sec thereafter.

Confirm that time-history results are generated at 0, 2, 4, ..., 10, 20, ... 100 seconds, that the time-history plot has two straight-line sections with a slope-change at 50 seconds, and that the final result is 149.

TMC-02 Monte Carlo Tests

Test TMC_02 tests the random-number generation process. It uses a stochastic distribution (Uniform 0-1), and carries out three tests:

1. With Latin hypercube sampling (LHS) enabled, do 100 realizations of the system. Review the 'results array' table to confirm that there is exactly one result between 0.00 - 0.01, one between 0.01 - 0.02, and so on up to 0.99 - 1.00.
2. Then, disable LHS and run the model for 1,000 realizations. Open in turn elements Result1 through Result1_9 and display the results array table. Copy the contents of the last two columns (the confidence bounds) to the clipboard, and paste them in turn into each of the ten highlighted sections of the associated spreadsheet file (TMC02.xls), in the first sheet.

After the tenth paste the CheckRatio term at the top of the spreadsheet should show up green, indicating that it lies between 0.5 and 2.0. This is the fraction of results that are outside of the confidence bounds, divided by the expected number outside (1000). (Expected mean is 1.0).

3. Similarly, open the R2 through R2_9 elements and display their results array tables. For the second entry (0.5), copy the contents of the last two columns (the confidence bounds) to the clipboard, and paste them into one of the ten highlighted sections of the associated spreadsheet file's second sheet.

After the tenth paste the CheckRatio term at the top of the spreadsheet should show up green, indicating that it lies between 0 and 0.3 (the mean fraction outside the confidence limits). Expected mean is 0.1.

TMC-03 Correlation Tests

Test TMC_03 generates a set of **rank**-correlated stochastic element values for four correlated elements. The desired **rank**-correlation matrix for these is:

	A	B	C	D
A	1.00	0.50	0.00	-0.50
B	0.50	1.00	N/A	N/A
C	0.00	N/A	1.00	N/A
D	-0.50	N/A	N/A	1.00

The Verifier should confirm that the calculated results for 1,000 realizations are close to the above table (the “N/A” values need not be checked). Because GoldSim uses an approximate algorithm to generate correlated variables, the results for the +/- 0.5 correlations are only expected to be accurate to within one significant figure.

TMC-04 Confidence Bounds on Mean Values

t-Distribution Approach

GoldSim version 7.21.100 added a capability to estimate confidence bounds on the mean value for a Result Distribution element. This approach uses the t distribution, which is strictly valid only if the underlying distribution is normal. The 5% and 95% confidence bounds are calculated as defined below:

$$P\{\bar{X} + t_{0.05} \frac{S_x}{\sqrt{n}}\} < \mu = 0.05 \text{ (i.e., 5\% bound = } \bar{X} - t_{0.05} \frac{S_x}{\sqrt{n}} \text{)}$$

$$\text{and } P\{\bar{X} + t_{0.95} \frac{S_x}{\sqrt{n}}\} \geq \mu = 0.05 \text{ (i.e., 95\% bound = } \bar{X} + t_{0.05} \frac{S_x}{\sqrt{n}} \text{)}$$

Where:

\bar{X} is the sample mean
 $t_{0.05}$ is the 5% value of the t distribution for n-1 degrees of freedom

$t_{0.95}$	is the 95% value, = $-t_{0.05}$.
s_x	is the sample mean
μ	is the true mean of the population, and
n	is the number of samples (realizations).

As the number of realizations, n , becomes large the Central Limit theorem becomes effective, the t distribution approaches the normal distribution, and the assumption of normality is no longer required. Normality may generally be assumed for n in the order of 30 to 100 or greater.

Verification Test

Test problem TimeMonteCarlo-04.gsm contains a single Stochastic element. Run the sample for the numbers of realizations in the following table, and confirm manually that the confidence bounds on the mean correspond to the correct t -distribution values using the above formulae. The fourth column in the table, $N_{0.05}$, shows the corresponding deviation of the normal distribution.

# Realizations	Deg. Of freedom	$T_{0.05}$	$N_{0.05}$
10	9	1.833	1.645
100	99	1.666	1.645
1000	999	1.645	1.645

For example, for a random sampling seed of 1 (repeated sampling sequence) and with no Latin Hypercube Sampling, the following are the 5% and 95% confidence bounds calculated from the simulated sample mean and standard deviation for S:

# Realizations	Simulated Sample Mean	Simulated Sample Std Dev	5% Confidence Bound	95% Confidence Bound
10	0.2834	0.6830	-0.1125	0.6793
100	0.1098	0.8817	-0.0371	0.2566
1000	-0.0131	0.9923	-0.0648	0.0384

TMC-04b CorrelationValueCheck

This test verifies that GoldSim correctly calculates correlation coefficients and sensitivity analysis results based on rank and based on value. It uses three uniform distributions, with distributions B and C correlated to A.

The verifier should run the model and verify that the results from both calculation methods for the Sensitivity Analysis and Variable Correlation results agree to two significant figures. (Because uniform distributions are used, there will be little difference in terms of the two calculation methodologies as it is unlikely that there will be two identical sampled values).

The values for the calculated correlation coefficients should also be compared with the actual values:

B is correlated to A with a 0.6 correlation coefficient
 C is correlated to A with a 0.3 correlation coefficient

TMC-05 Autocorrelation

This test verifies that autocorrelation of stochastics works properly. The Autocorrelation stochastic is correlated to itself with a coefficient of 0.5. The Stochastic2 element in the \Correlation_to_Element container should be correlated to Stochastic1 with a coefficient of 0.75.

The verifier should run the model and view the correlation coefficients. As no confidence bounds are provided, the model should be run a number of times to ensure that the coefficient values are centered around the expected value.

TMC-06 Sensitivity Analysis

This test verifies the proper functioning of the sensitivity analysis features and correlation coefficient calculation in the Multivariate result element.

This model should reproduce the results of Mishra (2004).

The verifier should run the model for 1,000 realizations, and then display the sensitivity analysis window. It should be confirmed that the partial rank correlation coefficients should approximately match those from Mishra:

v ~-0.93
k ~-0.71
B ~-0.89

In addition, the verifier should display the correlation matrix, and confirm that the rank correlations are similar to the Mishra results (the small results in the table should be zero, and are non-zero due to randomness):

	Result	V	k	B
Result	1	0.83	0.61	0.46
X2	0.83	1	0.49	0.02
X3	0.61	0.49	1	-0.01
X1	0.46	0.02	-0.01	1

Note that a variance of up to 10% in the values calculated by GoldSim is acceptable.

TMC-07_Sensitivity Analysis

This test confirms the correct calculation of the different statistics provided in the sensitivity analysis, with the exception of the importance measure.

This test is run on the function $Y = X1 + X2^2 + 10X3^3$.

Where:

X1 is a random variable with a uniform distribution between 1 and 2.

X2 is a random variable with a uniform distribution between -10 and 10.

X3 is a random variable with a uniform distribution between -2 and 2.

The verifier should run the model with and without low-end importance sampling enabled for X3. They should then confirm the results in the Sensitivity Analysis display of the Analysis element by comparing them to those in the Verification Plan. The verifier should note that exact results are expected only for cases where importance sampling is disabled. If importance sampling is enabled small variations (less than 0.05) from the results in the plan are acceptable.

Analysis based on values:

Variable Correlations:

	Y	X2	X3	X1
Y	1	0.006	0.618	-0.002
X2	0.006	1	0.008	0.000
X3	0.618	0.008	1	-0.003
X1	-0.002	0.000	-0.003	1

*Sensitivity Analysis:*R² value: 0.381366

Variable	Corr. Coeff.	SRC	Partial Coeff.
X2	-0.006	0.002	0.002
X3	0.618	0.618	0.618
X1	-0.002	0.000	0.001

*Analysis based on rank:**Value Correlations:*

	Y	X2	X3	X1
Y	1	-0.008	0.618	0.013
X2	-0.008	1	0.008	0.000
X3	0.618	0.008	1	-0.003
X1	-0.013	0.000	-0.003	1

*Sensitivity Analysis:*R² value: 0.35194

Variable	Corr. Coeff.	SRC	Partial Coeff.
X2	-0.008	-0.012	-0.015
X3	0.593	0.593	0.593
X1	-0.013	-0.011	-0.013

Note: If necessary to confirm or modify these results, a spreadsheet which implements the same methodology as GoldSim is available in SourceSafe with the Time and Monte Carlo Tests. It is called SensitivityAnalysisCorrelationCheckTMC-07.xls.

TMC-08_Importance

This test verifies the calculation of the importance statistic in the Sensitivity Analysis option in the Multivariate result element.

The verifier should run the model for 1000 realizations and open the Sensitivity Analysis dialog in Result1.

Stochastic1 is a uniform distribution between 0 and 1, with variance equal to 0.083336.

Stochastic2 is a uniform distribution between 0 and 0.1, with variance equal to 8.3336 E-4.

This means that the importance of Stochastic1 has a theoretical value of 0.99, while the theoretical value for Stochastic2's importance is 0.01.

In this case, the actual values (even though we are running 1000 realizations) will be slightly different (as GoldSim is partitioning the range of final values in the multivariate element to determine the local variance for the importance calculation).

Importance values for Stochastic1 between 0.975 and 0.995, and for Stochastic2 between 0.000 and 0.03 are acceptable.

TMC-09_Strata_Sampling

This test verifies the correct function of the mid-point/random point LHS strata sampling option. The test contains a uniform stochastic (0, 10000), and the model is run for 11,000 realizations.

The verifier should run the model with the mid-point option selected. The values from the result array should be copied to the TMC-09_Strata_Sampling.xls worksheet under "Mid-point" results. Note that the tester should display 8 significant figures in the Result Array table (the number of significant figures can be checked and adjusted by hitting CTRL+SHIFT+S in the table). The process should then be repeated with the random point option selected and copied to the Random section of the TMC-09_Strata_Sampling.xls worksheet. The verifier should check that the results generated by GoldSim are acceptable in the Results section of the worksheet.

3.3 RESULT PRESENTATION TESTS

Result-01 Time-History Results Presentation

Test Result-01_TimeHistoryResult.gsm produces 10 realizations of a 20-step time history for a matrix expression. Each realization consists of a random number (0-1) multiplied by $\sin(\text{time})$ multiplied by the constant matrix:

Row\Col	11	12	13
Sunday	1	11	1*time sec
Monday	2	12	2*time sec
Tuesday	3	13	3*time sec
Wednesday	4	14	4*time sec
Thursday	5	15	5*time sec
Friday	6	16	6*time sec
Saturday	7	17	7*time sec

The Verifier should use the time-history display functions to display raw and graphical histories for the results, testing the ability to plot single and multiple components of the data, and single and multiple realizations.

Next, return to Edit mode and open the properties dialog for the element Result1. Delete all of the inputs (if any are present). Next, click the "Add input" button, then double-click on the element "Result". All of the outputs from "Result" should be automatically added as outputs to Result1 (7 x 3 = 21 matrix elements). Run the model again to produce results for Result1. Next,

select the different outputs using the Select Array Items dialog and ensure that the proper results are displayed.

Result-02 Array-Result and Distribution Result Presentation

Part 1. Array Results. The Expression Element 'Result' produces 10 realizations of a matrix expression, evaluated at time=5{sec}. The expression is the same as for test Result-01.

First, the user should use the array-result display (for element Result1) to confirm:

Correct table-view display for each realization

Correct chart-view display for each realization

Correct calculation of total row/columns (using Ctrl-T).

Second, the user should open the Array of Final Values for the element Result (i.e., the table of output values). The user should then test sorting the table of values by column. Click on the column header "11". The header should change to red and the table should sort by increasing value in that column (if it is not already sorted that way). Click again to sort the table by decreasing order in that column. Ensure that the entire table sorts (i.e., the row headers and the remaining columns' values should remain "tied to" the corresponding value in the sorted column. Sort the table by the other columns and ensure sorting works correctly. Finally, right-click the mouse in the table and select "reset sorting" to return the table to its original form. Ensure that this feature works correctly.

Third, the user should switch to edit mode and change the name of the expression element "Result" and ensure that the edited name is automatically updated in outputs section of the result element "Result1" (Result1 is linked to Result). To check this, right-click on Result1, select Properties, and then view the name in the "link" input field to ensure that it matches the edited name for Result. Rename the expression element to 'Result' and re-run the model.

Part 2. Preview Chart for Distribution Results. Element 'Random' produces results for 10 realizations. Open the Distribution Result Result2. Exercise all of the options for the preview chart (e.g., confidence bounds on/off, switching from PDF to CDF to CCDF and back, probability calculator, etc.) to ensure that they work. Ensure that changes made to Result2 (e.g., changing the scale of the X axis in the chart view) do not affect Result3, which also displays the results from Random.

Result-03 Probability Results Presentation

Test Result-03_ProbabilityResult.gsm file contains several stochastic elements and functions. After running 10,000 realizations, the Verifier should confirm the following items:

Confirm that the mean, standard deviation, skewness and kurtosis for the results of the two normal distributions match their input definitions (10, 5, 0, 0) and (20, 10, 0, 0) respectively.

Confirm that the mean and standard deviation for the sum of the two normal distributions are 30 and 11.2.

Confirm that the statistics summary table for the sum of the normals approximately matches the results below. Results may only be correct to 1 significant figure near the tails of the distribution:

Probability	Value
0.001	-3.60
0.010	3.96
0.050	11.58
0.100	15.66
0.250	22.44
0.500	30.00
0.750	37.56
0.900	44.34
0.950	48.42
0.990	56.10
0.999	63.6

Result-04 Screening of Results

This file tests the entire screening process for stochastic results. Test Result-04_ResultScreening.gsm contains two stochastic elements. One is a normal distribution with mean=10 and standard deviation=5. The other is an identical distribution truncated at 5 and 20. This test runs 10,000 realizations, and then screens the results based on the output from the first element, screening for results between 5 and 20.

To screen the results for the element “Normal”, go to Run|Screen Realizations. The screening dialog should show up with the appropriate settings in place. Click “Update List” and then “OK” to complete screening. “Normal” is now truncated.

The Verifier should confirm that the result-statistics for the screened element are essentially the same as those for the truncated-distribution element (i.e., mean of 11.2 and standard deviation of 3.6). To view the result statistics, click on the output port for the element “Normal”, then right click on the output named “Normal”, then select “Final Value” and “Result Distribution”.

Result-05 Controlling and Tracking Saved Results

This test (Result-05_ControllingTrackingResults.gsm) evaluates the various options for saving time histories and arrays of final values. The tests are as follows:

1. Put the model in Edit Mode, then go to the View Menu and select “Highlight Saved Results”. Check the options for “Time Histories” and “Final Values”. Then look at the main browser window. The elements Data1, Stochastic1, Expression1, and Container1 should be shown in bold font in the model browser to indicate that time histories and final values will be saved for these elements (the default settings for the file upon opening the file is to save results for these elements).
2. Run the model. Enter Container1 and view the time history for Expression1 (or Result1). The chart should show three time histories (one for each species that make up the vector called Expression1) for each realization. Similar results for a total of 10 realizations should be available. (If the Probability History button is selected, de-select it to view the results for each realization.)

3. Exit Container1, enter Edit Mode, then open Container1's dialog box. Clear the Final Values and Time Histories checkboxes and then go to the information tab. Run the model. The number of saved time histories should be 1, while the number of saved final values should be 0. Enter Container1 and open the element dialog boxes one by one. The “Final Value” checkboxes for all elements should be turned off (i.e., not checked). The “Time Histories” boxes should be turned off for the Data and Stochastic elements, but should be on for the Expression element. Verify that the time history for the expression element was saved by viewing the time history from the Expression element and the Result element.
4. Look at the main browser window. Data1 and Stochastic1 should be shown in normal text (indicating no results were saved), while Expression1 and Container1 should be shown in bold text (indicating results were saved).
5. Exit Container1. Enter Edit Mode, open Container1's dialog box and check the boxes next to Time Histories and Final Values for the subelements and close the dialog. Run the model. Go to the information page – the number of saved time histories and final values should now be 5. Enter Container1 and open the element dialog boxes one by one. The “Final Value” and “Time History” checkboxes for all elements should be turned on (i.e., checked). Verify that the final values and time histories were saved by viewing them for each element. The results should be the same as for the initial model run in step 1 above.

Result-06 Probability Histories

This test (Result-06_ProbHistories.gsm) runs 1000 realizations of the model but saves only ten (10) of the realizations, as defined in the Model Simulation Settings dialog box. This test verifies that the information essential for computing the probability histories is saved (e.g., the mean and sum of the squares of the simulated values at a given time) even though the full time histories are not saved.

Note: when you open each result element, first ensure that the element displays the *chart form* of the *probability histories*. Make any adjustments necessary to the display to get in this form before carrying out the corresponding tests, because the instructions are based on this format.

To perform the test, first run the model. Then perform the following tasks:

1. Inside the Container “Scalar_Tests”, Open the Time-History Result element called “Time Histories”. Ensure that the Chart View median time history values match those shown in Figure Result-06.1 below (this figure was generated in Excel using median values obtained from the Table View for the same GoldSim element. Next, Click on the probability-history button at the top of the chart to switch to time-history mode. Time histories should be available for only ten (10) realizations (provided that only ten are saved in the Model Simulation Settings dialog box). Switch back to probability-history mode. Click on the Chart Style button. Edit the chart style to ensure that the probability history chart can be edited and that changes “stick”. Click on the table-view button. The table should show the mean value, standard deviation, median, lower and upper bounds, and the selected confidence bounds (5th and 95th percentiles, in this case) as a function of time for the duration of the simulation.

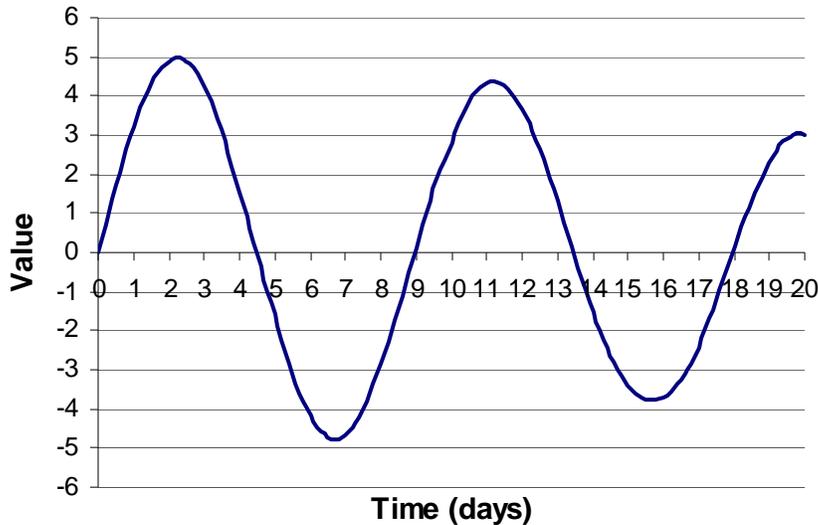


Figure Result-06.1. Median-value probability history

2. Inside the Container “Vector_Tests”:

Part 1. Open the Time-History Result element called "Time Histories_Vector". By default, the MEAN time history for all four matrix elements will be shown (see Figure Result-06.2). Ensure that the simulated results match Figure Result-06.2. Click on the Mean Time History button to switch to the View Realizations mode. Ensure that the ten (10) individual saved realizations are available for all four vector elements. Next, click on the table-view button. The MEAN time history (i.e., the mean value for 1,000 realizations at each point in time) for each of the four vector elements should appear side-by-side in table form. Click on the Probability History button to switch to viewing a single realization. Ensure that the simulated values for all four vector elements can be viewed side-by-side (one realization at a time) for the ten saved realizations.

Part 2. Next, click on the properties dialog button, then Select Array Items, and de-select all but one of the items (i.e., vector elements). Click OK and then "Display Table". When the Mean Time History button is selected, the table should show the mean value, standard deviation, median, lower and upper bounds, and the selected confidence bounds (5th and 95th percentiles in this case) as a function of time for the simulation. When the Mean Time History button is de-selected, the time histories for all of the saved realizations should be shown side-by-side for the selected vector element. Repeat for the Chart View. In the Chart View, each realization is plotted separately, and the mean time history will also show the median, the bounds, and the selected percentiles. Finally, re-select all four Array Items and then save the model.

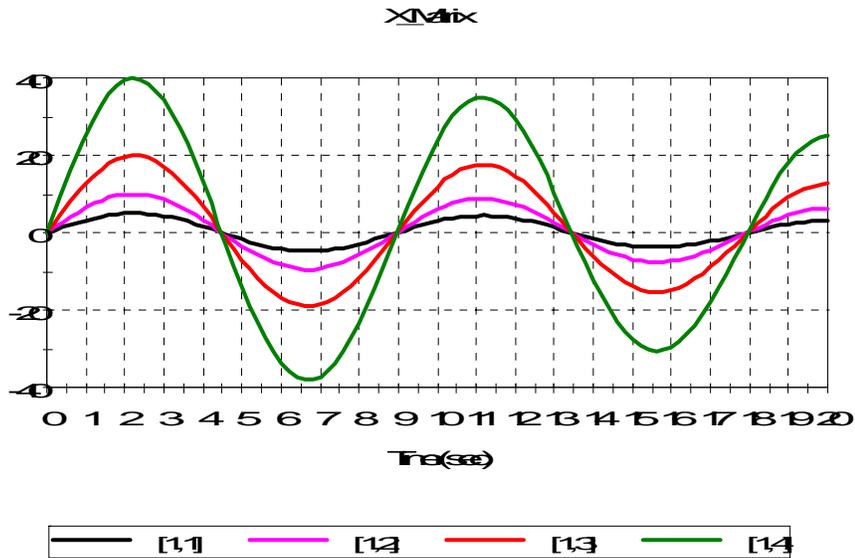


Figure Result-06.2. Mean-value probability history for four array elements.

3. Enter the container called "Matrix_Tests".

Open the Time-History Result element called "Time Histories_Matrix". This element can simultaneously display either 1) the time histories for each realization OR 2) the mean time histories for every matrix element in a single row or column of the matrix (i.e., the results for all four elements in a single row or single column in the same chart or table). Follow the instructions outlined above for Parts 1 and 2 for "Time_Histories_Matrix". The steps and results are similar, except that now four matrix outputs are plotted instead of four vector outputs.

4. Enter the container called "Condition_Tests".

Open the Time-History Result element called "Cond_Time_Histories". This element should display the mean fraction true history chart. Click on the table-view icon and confirm that the table values are equivalent to the chart. Then click to turn off probability-view, and confirm that the first ten histories can be displayed as true/false or 1/0 values.

Then open the Result Distribution element "Cond_PDF". Confirm that the display indicated two possible values, False or True, and that each has a 50% probability.

5. Enter the container called "Saving_Time_Histories." To confirm that statistical results reflect the full set of 1000 realizations, copy the table results from the Time_Histories graph into the Result-06.xls spreadsheet. Rerun the model, saving all time histories, and copy the table from the Time_Histories element to the Results-06_ProbHistories.xls spreadsheet. Ensure that the difference between the two sets of results is within the acceptable range (<0.05 deviation on average over all timesteps).

Result-06a Probability Histories from Distributed Processing

This test is the same test as Result-06, but Result-06a verifies the probability-history calculations using the distributed processing (i.e., networked) feature of GoldSim. To complete this test, run the test file using two local slaves, and then verify results as in Result-06.

Open the file Result-06_ProbHistories.gsm.

To start the local slaves and run the test file, do the following: *Launch a GoldSim slave on the local machine by typing the following in the Windows Run dialog (accessed from the Start button):*

“path to GoldSim.exe” –s

Include the quotes and leave a space between the last quotation mark and the hyphen. Upon entering this command, the GoldSim Network Client dialog will appear on the slave machine (which is also the local machine), with a Client Status of “Client is Ready to Connect to Master”.

Repeat Step 2 to open a second slave on the local machine.

Next, specify the slaves’ network addresses in the Network Settings dialog on the master machine. This can be done by selecting “Run on Network...” from the Model menu and then entering the local machine’s network name for both of the slaves.

Press the “Update Slave Status” button to make connections between the master and slave machines. Ensure that the master recognizes both slaves as active.

Run the networked simulation by pressing the “Run Simulation” button.

When the simulation is complete, check results as described for Result-06.gsm.

Result-07 Dynamic Result Viewing

This file (Result-07_DynamicViewing.gsm) verifies that results can be viewed during model simulations, and that they updated dynamically. The test proceeds as follows:

Part 1. Dynamic Time Histories. Enter the container named Time_Histories. Repeat the following steps for each element Scalar, Vector, and Matrix in succession:

Activate the Run Controller. Slide the speed-control slider to the left.

Open the appropriate result element (i.e., Scalar_TH, Vector_TH, or Matrix_TH).

Run the model. Ensure that the time histories are updated with time and that they match the expected result shown in the corresponding figure in the test file.

Part 2. Dynamic Array Chart. Open Array1, select 2D plot and run the model. The plot should update dynamically as the model is run. You should see the final value at the end of each realization reported on the chart.

Part 3. Dynamic Multi-Variate Chart. Open Multi_Variate1, run the model, and ensure that it updates dynamically as the model is run. You should see a linear 1:1 plot (perfectly-correlated variates) building with time (see the chart in the test file).

Part 4. Dynamic PDF Chart. Open PDF1, run the model, and ensure that it updates dynamically as the model is run. You should see the PDF plot building with time.

Result-08 Time History Export

This test (Result-08_TimeHistoryExport) verifies the proper functioning of the time history export to text and spreadsheet files.

The verifier should delete all Result8_*.xls and Result8_*.txt files from the test directory. Run the model. New files for each of the result elements should be created. Enter each file and verify that the data has been correctly exported (the data exported is ETime*Realization Number in days). Expected final values for statistics (exported only from even numbered result elements, i.e., Result8_2.xls and Result8_14.txt would have statistics) are:

Mean/Median = 55
Lower bound = 10
Upper bound = 100

Also, the verifier should check that data in each of the text files has the correct number of significant digits (4 for Result8_13.txt, and 6 for Result8_14.txt), and that time values are exported with Result8_13.txt and not with Result8_14.txt.

Result8_15.xls should contain data and statistical information from Expression1 (ETime * Realization) and Expression2 (Realization).

Deactivate automatic export for Result1 and Result13. Change the simulation to a calendar time simulation with duration 10 days. Run the model and ensure that Result8_1.xls and Result8_13.txt are unchanged. Verify that the other exported files now display the simulation time in calendar time.

Now change the save location and filename of the excel file in Result2. Change the location so it is saved outside the local directory, by specifying an absolute path. Make the filename be %rundate%_%runtime%.xls. Run the model again and confirm Results8_2.xls in the local directory is the same as the newly created file with the current rundate and runtime in the filename.

Result-09 Time History Export Overflow Check

This test (Result-09_ExportOverflow.gsm) verifies that Excel correctly generates an error when the amount of data exported exceeds the number of available cells on the worksheet.

To run the test, the verifier should first run the model if it's not already in Result mode. This generates one realization of data with 100000 data points (too much data to be accommodated in the number of rows and columns in an Excel worksheet).

Go to the Excel tab in the result element and select the Save in rows option. Click the **Export Now** button. You should receive an error stating that the column number for cell FF1 is too large.

Repeat the same process but instead select the Save in columns option. Click the **Export Now** button. You should receive an error stating that the row number for cell A100002 is too large.

Result-10 Global Export Setting

This test (Result-10_GlobalExport.gsm) verifies the proper functioning global results export settings on the Results tab of the Model|Options dialog.

To run the test, ensure the simulation is in elapsed time mode and set for a duration of 10 days. In the Results tab of the Model|Options dialog, set the Automatic Export for Result Elements to "Do not export results." Delete Result10.xls if it exists in the test directory and run the model. Result10.xls should not be created. Re-enter the Results tab of the Model|Options dialog and change the Automatic Export for Result Elements drop down to "Prompt before exporting results". Re-run the model and click No when prompted to export results. Again Result10.xls should not be created. Re-run the model again, and this time, export results.

View Result10.xls and verify that the data have been correctly exported (the data exported is ETime*Realization Number in days). Expected final values for statistics are:

Mean/Median = 55
Lower bound = 10
Upper bound = 100

Change the simulation to a calendar time simulation with duration 10 days. Go back to the Results tab of the Model|Options dialog and change the Automatic Export for Result Elements drop down to "Export results after simulation." Run the model - you will be asked if you wish to overwrite the data in Result10.xls. Click Yes and verify that Result10.xls now displays the simulation time in calendar time.

Result-11 Quantile for Multiple Histories

This test verifies the correct functioning of the "Display this result if multiple histories are selected" option in the Probability Histories dialog. This setting allows users to define the quantile that should be displayed when viewing time history data.

To test this feature, the verifier should open the test file, Result-11_Time_History_Quantile.gsm. This file contains two time history elements – one that is linked to two scalar expressions, and the other linked to two elements of a vector expression. Both time histories should always produce values that start at zero, and move linearly towards the value that corresponds with the specified quantile.

The verifier should note that time histories where not all realizations are saved will differ slightly from the results calculated by the Result Distribution element (which uses the exact final values

from all realizations). The verifier should note that discrepancies for predicted and plotted values are expected to be larger for quantiles more distant from the median.

The test should first be run with the Quantile set to Mean. The verifier should run the model with 1001 realizations, saving all time histories. The verifier should ensure that the mean values predicted by the Result Distribution elements correspond with the final values plotted in the corresponding Time History element. This process should be repeated with 1001 realizations saving 10 time histories, and a finally with one saved time history. The verifier should note that mean plots centered around zero with not all time histories saved may be erratic, but are acceptable as long as the largest absolute values are less than 1E-4.

The quantile should then be set to one of the pre-defined values (e.g. 50%). The model should be run with 1001 realizations, saving all time histories. The final value plotted for the time history should correspond with the value predicted for the specified quantile by the calculator in the Result Distribution element. The test should be repeated, but only 10 of the 1001 time histories should be saved. Again the predicted and plotted values should be compared. The test should then be run with a single realization, and the verifier should ensure that the graph title shows "Time History" instead of the specified quantile.

Finally the quantile should then be set to a user-defined value (e.g. 42.5%). The model should be run with 1001 realizations, saving all time histories. The final value plotted for the time history should correspond with the value predicted for the specified quantile by the calculator in the Result Distribution element. The test should be repeated, but only 10 of the 1001 time histories should be saved. Again the predicted and plotted values should be compared. The test should then be run with a single realization, and the verifier should ensure that the graph title shows "Time History" instead of the specified quantile.

Result-12 Table Format Text File Export

This test verifies the proper functioning of table format text file export in the Time History element. It consists of two test files, Result-12a_Single_Rel_Table_Export.gsm and Result-12b_Multi_Rel_Table_Export.gsm, which test table export functionality in single and multiple realization simulations. The verifier should note that the text file output is in tab-delimited format as opposed to a grid format, so column headers may not line up exactly with the corresponding data.

Single Realization Case: Result-12a_Single_Rel_Table_Export.gsm

The verifier should load the test file and ensure that Result-12_Single_Rel_Scalar.txt and Result-12_Single_Rel_Vector.txt have been deleted prior to running the test. After running the model, Result-12_Single_Rel_Scalar.txt and Result-12_Single_Rel_Vector.txt should be created, and should contain a header block (marked by exclamation points stating the source model and element information) along with the same information as the corresponding Time History elements in table view.

Multiple Realization Case: Result-12b_Multi_Rel_Table_Export.gsm

The verifier should ensure that Result-12_Multi_Scalar.txt and Result-12_Multi_Vector.txt have been deleted prior to running the test. The "Display this result if multiple histories are selected" option in the Probability Histories dialog should be set to "Mean."

The verifier should then run the model with 100 realizations, saving all time histories. The two text files should be created with the appropriate header information and the data inside should correspond directly with the data displayed in Table view in the corresponding Result element.

The model should then be rerun with only 10 of the 100 time histories saved. Again the verifier should ensure that the data in the two text files is identical to the data shown in Table view in the two Time History elements.

These tests should be repeated should then be run with the "Display this result if multiple histories are selected" option in the Probability Histories dialog set to a user-selected value other than Mean.

Result-13 Enabling/Disabling Time History Results

This test is designed to test the functioning of the Disable Time History result feature.

To perform the test, the verifier should open the Result-13_TH_Disable.gsm test file and follow these steps:

1. Open the Property dialog for Expression1. Ensure the Time History result flag is checked. Open Result1 and disable it. Return to Expression1's property dialog and ensure that the Time History result flag is unchecked.
2. Add a new Expression element. Ensure that the Time History result flag is checked. Add it as an input to Result1. Return to the new Expression's property dialog and ensure that the Time History result flag has been cleared.
3. Open the property dialog for Container1 and clear the "Enable Time Histories" checkbox. Run the model - ensure that none of the result files (Result-13_Excel.xls, Result-13_Table.txt and Result-13_Text.txt) are created in the test directory. Also ensure that none of the three Time History elements in Container1 can be opened.
4. Return to Edit mode and enter \Container1\Container2. Enable the Result4 Time History element. Go back to Container1's property dialog. The "Enable Time Histories" checkbox should now have a square inside it. Check the Enable Time Histories checkbox and run the model. The three export files should be created, and Result2, Result3 and Result4 should be accessible in Result Mode.

Result-14 Results Inside SubModels

This test is designed to ensure that Result elements inside a SubModel record the appropriate values when the "Save Results from most recent Simulation" option is selected.

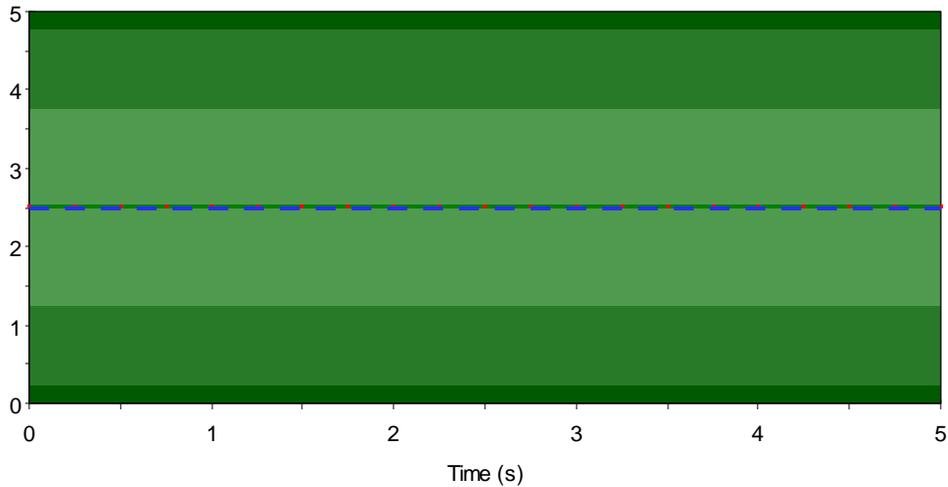
The test contains two SubModels – Static and Dynamic. The model should first be run with the Save Results option turned off in both SubModels. The model should run to completion without errors. Confirm that no results are saved inside the Submodels, and that result elements there behave appropriately when double-clicked.

The verifier should then run the model with the Save Results option turned on. The model should run to completion and the verifier should then check the following:

Dynamic SubModel:

Time_History: The graph of the Time History element should be as follows:

Time_History



Result Distribution: Results should be uniformly distributed over the range from 0 to 5. The Result_Distribution element should also report the following statistics:

Mean: 2.5

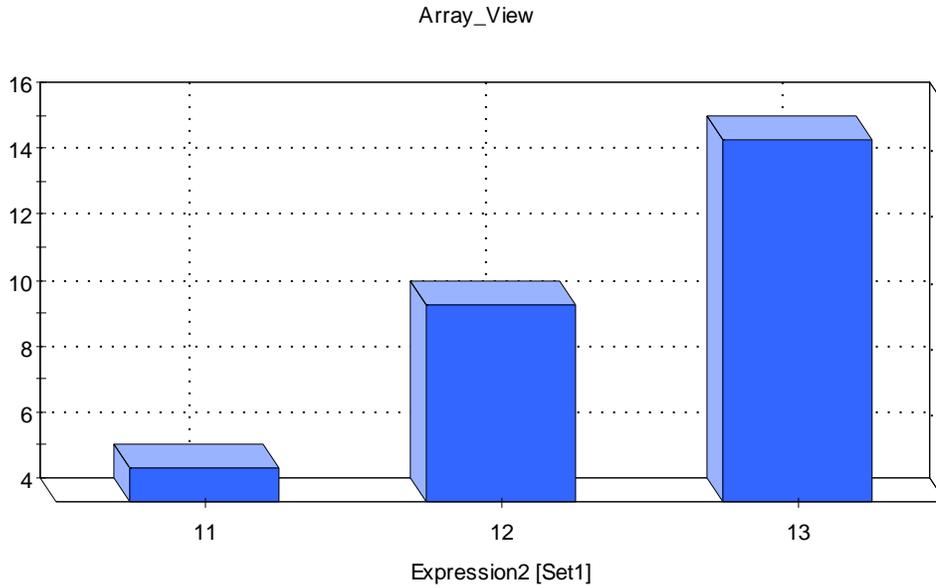
S.D.: 1.4577

5%/95%: 2.2592/2.7408

Multivariate Element: The multivariate element should report the following values for correlations:

	Stochastic1	Stochastic2	Stochastic3
Stochastic1	1	0.5	0.8
Stochastic2	0.5	1	N/A
Stochastic3	0.8	N/A	1

Array Chart: The element should provide the following graph for Realization 101:



Static SubModel:

Result Distribution: Results should be uniformly distributed over the range from 0 to 5. The Result_Distribution element should also report the following statistics:

Mean: 2.5

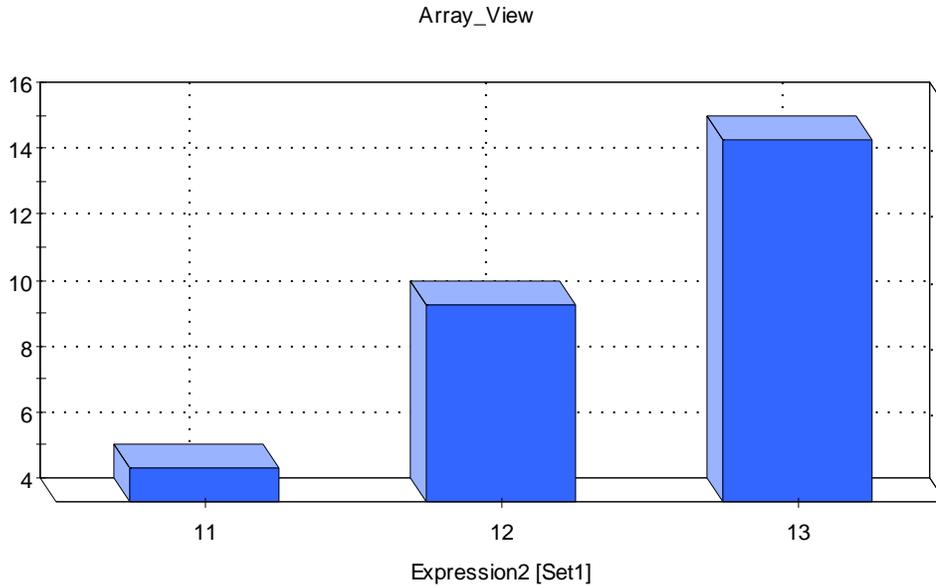
S.D.: 1.4577

5%/95%: 2.2592/2.7408

Multivariate Element: The multivariate element should report the following values for correlations:

	Stochastic1	Stochastic2	Stochastic3
Stochastic1	1	0.5	0.8
Stochastic2	0.5	1	N/A
Stochastic3	0.8	N/A	1

Array Chart: The element should provide the following graph for Realization 101:



Result-15 Mixed Discrete and Continuous Results

This test verifies that GoldSim correctly plots mixed discrete and continuous data. The test consists of two stochastics - one is a Boolean with an equal chance of being true or false. If the Boolean stochastic is true, the result is sampled from a uniform distribution on (0,10). Otherwise the result is 5.

The verifier should run the model and ensure that GoldSim plots a spike in the data in the histogram bin that includes 5. The mean probability density elsewhere should be 0.05. CDF and CCDF plots should also be checked to ensure that the discrete behavior at 5 is captured.

Result-16 Scattered Plot Result Classification

This verification is designed to test the result classification for multi-variate scatter plots. The test contains three elements including stochastic elements that are connected to a multi-variate plot. The model runs for 100 realizations and the results are classified into 3 different classes.

The first class, Reali_LT20, contains results from the first 19 realizations (Realization_Number <20). The next class, F_LT_0, contains points from realizations where the value F is less than zero, and all the rest is labeled Other. Because F is defined $S2 * \sin(\text{Realization})$, where S2 is randomly sampled from an interval between 0 and 1, F should be scattered randomly between -1 and 1. Therefore those 81 points which didn't pass the condition for Reali_LT20 should be approximately equally divided into F_LT_0 and Other.

To perform this test, the verifier should open the Result-16_ScatteredPlot_Result_Classification.gsm test file and follow these steps:

1. Open the Classification tab of the Multi-Variate Properties dialog and confirm the following classification categories are defined:

Legend Label	Classification Condition	Count
Real_LT20	Realization_Number < 20	n/a
F_LT_0	F < 0	n/a
Other	<i>all others</i>	n/a

2. Close the properties dialog and run the model. Open the 3D plot, and confirm the following remarks on the plot:
 - a. Real_LT20 (blue) points are scattered all over the plot seen from any direction, consisting of 20 percent of all points. (Figure Result 16-1)
 - b. Rotate the plot so that the label F is shown horizontally in front. Confirm that all F_LT_0 (red) points are on the left side and all Other (pink) points are on the right side of the plane F = 0. (Figure Result 16-2)
3. Right click on the plot and from the context menu choose to "Switch to 2D view." Confirm that all F_LT_0 (red) points are on the left and Other (pink) points are on the right side of the line F = 0. (Figure Result 16-3)
4. Open the result property dialog and go to the Classification tab. Make sure that there are 19 points in the first label Class1 and that the rest of 81 points are approximately equally divided into two other labels.

Now we are going to test adding a new label to the classification. The new label is going to be called S1_LT_05 and has a condition of "S1 < 0.5." Because S1 randomly samples values between 0 and 1, approximately half of examined points fall into this category.

5. Add a new label. Name the label S1_LT_05, and define the condition "S1 < 0.5" and hit enter. Make sure that the counts are automatically updated. It should show something close to 50.
6. Move the label S1_LT_05 down using the "Move Down" button until it is underneath F_LT_0. Confirm that the counts are updated. Values should be approximately as follows:

Real_LT20	Realization_Number < 20	19
F_LT_0	F < 0	41
S1_LT_05	S1 < 0.5	21
Other	<i>all others</i>	19

7. Go back to the 3D plot and confirm that points with a new color (S1_LT_05) are added.

4. CONTAMINANT TRANSPORT TESTS

Note that because the CT/RT component of GoldSim is a separate module, the user may have to use the File/Extension Modules... menu to enable it. The contaminant transport/radionuclide transport module also has its own options dialog, which is accessed through the Model/Options menu.

The verifier should note that the degree of precision to be expected when comparing the contaminant transport tests to the reference values is variable. In some cases, the reference results do not represent exact analytical values, but are the results of independent software programs that have some degree of numerical approximation.

For test cases involving Cell elements, GoldSim's algorithm should in general provide results accurate to at least 2 or 3 significant figures, depending on the timestep length and the precision setting for the model. This degree of precision should be expected of the calculated changes in values from the initial to the final states, but this precision will not necessarily occur when calculating near-zero final values. For example, if the initial condition for a problem had a concentration of 10.0, and the final value was expected to be 5.0, the result should be within three significant figures of 5.0. However, if the initial concentration was 10.0 and the final concentration was $1.0e-10$, the result should only be expected to be less than 0.001.

4.1 PIPE TESTS

The GoldSim pipe element provides a powerful ability to calculate mass transport in porous/fractured media, including advection, dispersion, radionuclide chain decay, and matrix diffusion.

The test problems described in the following section fall into two distinct categories: comparison with analytical solutions, and cross-verification with published results from an independent solute transport code (PICNIC) (Barten, 1996). The cross-verification allows a greater range of features to be tested, as analytical solutions to problems incorporating diffusion and retardation in both the flowing fracture and immobile zones are rare.

The test problems were designed to test a hierarchy of transport processes represented in the Pipe element, and range in complexity from strictly one-dimensional advective-dispersive transport of a single, non-reactive solute, to cross verification of the migration of a three-member decay chain with the PICNIC code. The PICNIC tests were performed by Dr. Werner Barten of Paul Scherrer Institute (PSI).

CT_Pipes-01 : Single-porosity Test Problem

In this test the following components of the Pipe element are tested:

- basic advective dispersion algorithm
- effect of infill porosity
- effect of infill retardation
- effect of coating retardation

- effect of pipe fluid saturation
- effect of suspended particulates

This problem consists of the transport of a single stable solute (decay constant $\lambda = 0.0$) by advection and dispersion in a single-porosity domain. The pipe is 100m long, with a flow rate of 1.0 m³/day, the pipe's flowing area, A , equals 1.0 m² and the longitudinal dispersivity, α , is 1.0 m. Diffusion along the flow direction is neglected. The Ogata and Banks (Ogata and Banks, 1961) analytic solution is for a Dirichlet boundary condition setting the inlet concentration to 1.0 Ci/m³. This is a close approximation to GoldSim's constant-flux boundary condition of 1g/day, and the difference is minor and is only apparent at very early times.

A subset of the Ogata and Banks analytic results is presented in the following table:

Distance along Fracture (m)	Time 25 days	Time 50 days	Time 75 days
40	0.0215	0.8679	0.9986

Test problem CT_Pipes-01 contains five pipes which should each match the above table:

1. An unretarded pipe with no infill.
2. A pipe with an infill with porosity = 0.2, density = 2600kg/m³, and partition coefficient = 0.0003076923{m³/kg}. The partition coefficient produces a retardation factor of 5, which exactly cancels the effect of the porosity.
3. A pipe one tenth as long (4m), with a coating having an effective retardation of 10 (1mm of material with density = 2500kg/m³ and partition coefficient = 1.8{m³/kg}). This also produces a retardation factor of 5, which exactly cancels the effect of the porosity.
4. A pipe with a saturation of 0.1, and a coating thickness of 0.0001. This gives an effective retardation factor of R=10, which counteracts the effect of the saturation.
5. A pipe one half as long (20m), with a coating and suspended solids having a combined retardation factor of R=2. (Make the amount of solute dissolved/suspended equal to the amount sorbed on the coating:

$$A(1m)(1 + C_p K_d) = P(1m)t_c \rho K_d$$

where:

A	=	Flowing area, L ²
C _p	=	Concentration of suspended particulates, ML ⁻³
ρ	=	Density of the solid, ML ⁻³
K _d	=	Partition actor, L ³ M ⁻¹
P	=	Perimeter, L
t _c	=	Coating thickness, L

Have GoldSim solve this problem three times, using the three different precision options (low, medium and high) from the model option menu. Confirm that all solutions are within acceptable accuracy (at least two significant figures correct, with the exception of results at 100 days at low precision, which are expected to be slightly higher than analytical values at 1.008).

CT_Pipes-02: Transport of Tritium in a System of Parallel Fractures

This problem models the transport of a decaying, non-sorbing (i.e., $R = 1.0$) solute in a double-porosity system comprised of parallel fractures embedded in a low-permeability, low-porosity rock matrix. The solute is tritium which has a half-life of 12.35 years ($\lambda = 1.54 \times 10^{-4} \text{ day}^{-1}$). The flow system is 50 m in length and the aperture of the parallel fractures, spaced at 0.1 m, is 100 μm . With this setting, for a gross area of 1m^2 the pipe flowing area, A , is equal to 10^{-3} m^2 . The flow rate is $10^{-4} \text{ m}^3/\text{day}$, giving a velocity of 0.1 m/day in the fractures. The longitudinal dispersivity of the fractures, α_L , is 0.1 m. The free-solution diffusion coefficient for tritium, D^o , equals $1.38 \times 10^{-4} \text{ m}^2/\text{day}$. The matrix porosity, θ_{im} , and tortuosity, τ , are 0.01 and 0.1, respectively. A maximum diffusion distance, d , equal to the half-spacing of the fractures (0.05m) was used.

The analytical solution (Sudicky and Frind, 1982) has a concentration fixed at $1.0\text{g}/\text{m}^3$ at the inlet boundary. Again, after the early-time period this is a close approximation to GoldSim's constant mass flux of $10^{-4} \text{ g}/\text{day}$. Note that the extremely low dispersivity for this case results in a high Peclet number, and as a result it is necessary to increase the number of de Hoog terms to 25 (Model/Option/Mass Transport).

The following table presents the analytical solution at times of 1,000, 10,000 and 100,000 days (equal to steady state).

Distance along Fracture (m)	Time 1,000 days	Time 10,000 days	Time 100,000 days
50	0.0000	0.4332	0.4305 ¹

CT_Pipes-03: Single Fracture with Two Diffusive Zones in Parallel

This case tests the transport of a non-decaying solute in a single 5m long fracture with two matrix immobile zones attached in parallel. The results are compared against those obtained independently by PSI using PICNIC.

The mobile fracture has a flow area of $9.3006 \times 10^{-5} \text{ m}^2$, a velocity of 16830.7 m/yr, and a dispersion length of 0.25m. The free-water diffusivity of the solute is $2.5 \times 10^{-11} \text{ m}^2/\text{sec}$. The first associated slab immobile zone (MB_1) has a thickness of 6.2mm, porosity of 0.062, density of $2500\text{kg}/\text{m}^3$, perimeter of 2.0m, and tortuosity of 1.0. The solute is non-sorbing in MB_1, and therefore has a partition coefficient of $0.0 \text{ m}^3/\text{kg}$.

The second slab immobile zone (MB_2) has a thickness of 0.5mm, a porosity of 0.062 and a tortuosity of 1.0. The partition coefficient for MB_2 is $2.232 \times 10^{-4} \text{ m}^3/\text{kg}$. Immobile zone 1 (MB_1)

¹ This value is approximate, due to the solution technique used in the reference. Two significant figures of accuracy is acceptable.

covers 40% of the fracture surface area, with MB_2 covering the remainder. A mass of 1g is released into the pathway as a delta function at the start of the simulation.

Time, yrs	Mass flux, g/yr
0.001	~310
0.002	~140
0.004	~51
0.01	~3.5

Note: PICNIC results may be somewhat higher than GoldSim at early times, due to their different boundary conditions. GoldSim results should match the PICNIC results to 1 – 2 significant figures.

CT_Pipes-04: Single Fracture with Two Diffusive Zones in Series

This case tests the ability of GoldSim to model two immobile zones in series. The results are again compared against those obtained independently by PSI using PICNIC.

The properties of the flowing fracture are identical to test case CT_Pipes-03. The first “skin” immobile zone adjacent to the fracture is 1mm in thickness and has the properties of MB_1. The second immobile zone is 0.5mm in thickness and has the properties of MB_2. The input to the pathway is a mass of 1g, released as a delta function at the start of the simulation.

Time, yrs	Mass flux, g/yr
0.0004	~1600
0.001	~120
0.004	~18
0.01	~9.5

Note: PICNIC results may be somewhat higher than GoldSim at early times, due to their different boundary conditions.

CT_Pipes-05: Single Fracture with Skin and Two Diffusive Zones in Parallel

This test case combines a skin diffusive zone in series with two immobile zones in parallel. The results are again compared against those obtained independently by PSI using PICNIC.

The source definition, and the parameters for the flowing fracture and the two immobile zones in parallel are identical to those in CT_Pipes-03. The skin immobile zone immediately adjacent to the fracture (MB_3) has a thickness of 1.0mm, a porosity of 0.1 and a tortuosity of 1.0. The partition coefficient for the skin is $2 \times 10^{-4} \text{ m}^3/\text{kg}$.

Time, yrs	Mass flux, g/yr
0.001	~290
0.002	~130
0.004	~54

0.01	~19
------	-----

Note: PICNIC results may be somewhat higher than GoldSim at early times, due to their different boundary conditions.

CT_Pipes-06: Single Fracture with Stagnant Zone

As there are no published solutions for pathways with stagnant zones, this example compares the GoldSim stagnant zone model to an approximate solution using a series of Cells that represent the stagnant zone explicitly.

The single pathway is 10m in length, with a total fracture area of 0.1m^2 , and a flow rate (Q) of $0.1\text{m}^3/\text{yr}$. The fraction of the area in the stagnant zone (F) is 0.6, and the transfer rate into the stagnant zone (β) is 0.5m^{-1} . A mass of 1g is released into the pathway as a delta function at the start of the simulation. The dispersivity is 0.102m, equal to half the cell-length.

The replicate cell model comprises 49 cells in series to represent the flowing portion of the fracture, and a parallel row of 49 cells representing the stagnant portion of the fracture. Each “flowing” cell is attached to a stagnant zone cell via two advective connections flowing $\beta \times Q \times$ cell length between the cells.

Expected results are shown in the table below. GoldSim results should match these to 1 – 2 significant figures.:

Approximate Solution	
Time, yrs	Mass Flux, g/yr
5	0.064
10	0.096
15	0.037
20	0.0081

CT_Pipes-07: Fracture with Changing Properties

This test is based on CT_Pipes-02, and tests the pipe’s response to changing material properties. At a time of 10,000 days the rock matrix porosity is tripled, from 0.01 to 0.03. As a result, all mass entering the pathway after 10,000 days will have a breakthrough curve that is approximately three times more delayed, and will emerge at a significantly lower concentration due to the increased radioactive decay.

The results should show a ‘mirror image’ of the initial breakthrough curve starting at 10,000 days, as the original batch of input flushes out. The second batch should start to breakthrough subsequently, with a breakthrough-time approximately three times greater than the original curve, and at a reduced level due to decay.

CT_Pipes-08: Decay-chain Transport with Matrix Diffusion

This problem models the transport of a radioactive species and its daughters in a double-porosity system comprised of parallel fractures embedded in a low-permeability, low-porosity rock matrix. The aperture of the parallel fractures, spaced at 0.1 m, is 100 μm . With this setting, the pipe area for a single 1m wide fracture, A , is 10^{-4} m^2 . The pore velocity is 100 m/yr in the fractures and the longitudinal dispersivity of the fractures, α_L , is 10 m. The matrix porosity and tortuosity are 0.01 and 0.1, respectively. A maximum diffusion distance, d , equal to the half-spacing of the fractures (0.05 m) was used.

This analytic comparison involves the transport of the decay chain Uranium 234 \rightarrow Thorium 230 \rightarrow Radium 226 in a system of parallel fractures. The matrix (i.e., immobile zone) retardation factors for U^{234} , Th^{230} and Ra^{226} were assigned values equal to 1.43×10^4 , 5.00×10^4 and 5.00×10^2 , respectively, and the decay constants equal 2.83×10^{-6} , 9.00×10^{-6} and $4.33 \times 10^{-6} \text{ year}^{-1}$, respectively. For simplicity, retardation on the surfaces of the fractures (i.e., pipes) was neglected. The diffusion coefficients for each of the species, D^o , were assigned identical values equal to $3.154 \times 10^{-2} \text{ m}^2/\text{year}$. A prescribed concentration of 1.0 mol/m^3 was assigned for U^{234} at the fracture inlet, and 0.0 mol/m^3 was used as the inlet concentration for Th^{230} and Ra^{226} .

The tabulated analytical results from Hodgkinson and Maul (1985) at 100,000 years, at selected distances along the pipe are shown below:

Analytical Solution for Verification Test CT_Pipes-08

Distance	Concentration (mol/m3)		
	U-234	Th-230	Ra-226
10	9.54E-01	1.84E-02	1.12E-02
50	6.80E-01	2.51E-02	5.79E-02
100	2.50E-01	6.39E-03	7.80E-02
200	4.27E-03	5.66E-05	7.37E-02
400	4.80E-09	0.00E+00	5.80E-02

Note: To obtain the final values for the different distances, change the value of the Length data element to each of the distances shown in the table.

CT_Pipes-09: Source Length

This files tests the “Source Length” feature of the Pipe Pathway Element. The file consists of two Pipe Pathways. Run the model to see results. The first pipe has an advective transit time of 3 seconds, and a source-zone over the first 2/3 of its length.

The breakthrough curve (accessed by clicking on the result element) should start at time 1.0, and increase linearly to a peak of 1.0 after 3.0 seconds. The concentration should drop linearly to 0 over the time range from 7 to 9 seconds. The second pipe has a source-zone twice as long as the pipe itself. Its breakthrough curve should start at time 0, increase to 0.5 after 3 seconds, and drop back to 0 starting at 6 and ending at 9 seconds.

CT_Pipes-10: Suspended Solids in Pipes

This test compares the calculated breakthrough times for three species to the expected retarded times. The model contains suspended solids and a skin, which compete for sorption of the suspended solids. The more suspended solids, the less the retardation due to the skin.

Run the model, and display the breakthrough curves in the time-history element. Compare the times when the concentration equals 0.5 to the retarded times calculated by element RetTimes, and confirm that they are within a few percent.

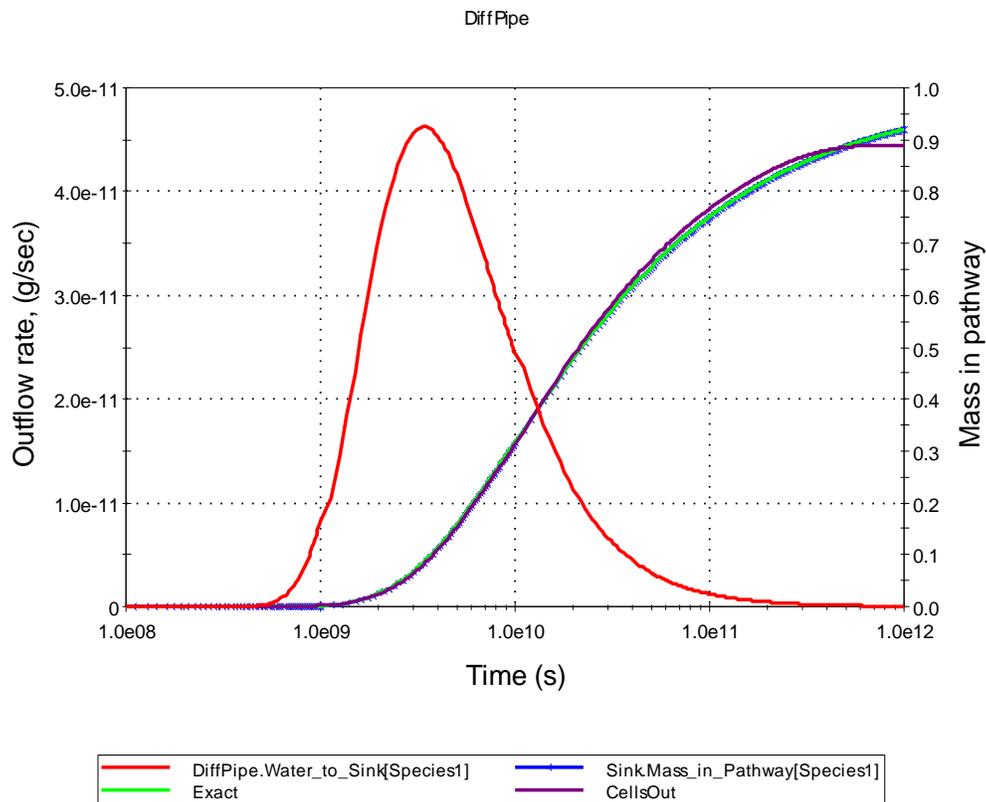
Analytical Solution for Verification Test CT_Pipes-10

Species	Median Breakthrough Time, sec
Species1	10.00
Species2	14.55
Species3	35.00

CT_Pipes-11 Longitudinal Diffusion in Pipes

This test has a negligible advective flow rate through a Pipe element. The user should confirm that the cumulative discharge to the Sink Cell matches the analytical solution. Note that the system of Cells is only present for comparison purposes, and is not expected to match the exact result closely. Also note that the calculated concentration leaving the Pipe element is not expected to be realistic, as it is simply set equal to the mass outflux rate divided by the water flow rate.

The plot element should show results similar to the following figure:



4.2 CELL TESTS

These test problems are specifically targeted at verifying the mixing cell algorithm. With one exception, rather than using Source Terms, mass is entered into the system by specifying an initial condition in one or more cells. All problems in this group are run without radioactive decay. With one exception, a 100 year timestep is used for these problems.

Solutions which cannot be readily computed analytically (e.g., coupled sets of differential equations) were solved using the commercially available program MATLAB® (Math Works Inc.). MATLAB® is a mathematical analysis program that can be used to solve complex matrix equations.

The default for all of the Cell tests is to run with high accuracy and the family-by-family solution option. Test CT_Cells5-03 specifically tests the medium and low accuracy options.

CT_Cells1 - Partitioning and Media Concentrations

These problems verify the correct partitioning of mass within a cell and the calculation of concentrations. One cell is defined, with no connections, and an initial mass inventory with 100 Ci each of Am-241, Am-242, and Am-243.

Expected concentrations for these tests (and other tests in this section) are computed as follows:

$$c_{ims} = P_{ime} M_{is} W_s$$

where:

$$P_{ime} = \frac{K_{mre}}{\sum_{g=1}^{NM_i} K_{gre} \cdot AM_{ig}}$$

and:

M_{is}	=	moles of species s in cell i;
W_s	=	atomic weight of species s;
K_{mre}	=	partition coefficient between medium m and reference fluid r for element e (where species s is an isotope of element e) [(L3 reference fluid r)/(L3 fluid m)] or [(L3 reference fluid r/M solid m)];
K_{gre}	=	partition coefficient between medium g and reference fluid r for element e (where species s is an isotope of element e) [(L3 medium r)/(L3 fluid g)] or [(L3 medium 1/M solid g);
AM_{ig}	=	amount of medium m in cell i [L3 fluid m] or [M solid g]; and
NM_i	=	the number of media in cell i.

The total amount of moles of an element that cell i can hold when the reference fluid is saturated can be computed as follows:

$$Msat_{ie} = cmax_{re} \sum_{m=1}^{NM_i} K_{mre} \cdot AM_{im} = \frac{cmax_{re}}{P_{ire}}$$

where $cmax_{re}$ is the molar solubility of element e in reference fluid r .

If the sum of the moles of all of the isotopes of element e (Mt_{ie}) does not exceed $Msat_{ie}$, the equation shown above can be used to compute concentrations.

If, however, Mt_{ie} exceeds $Msat_{ie}$, it implies that mass has precipitated out of the system, and the concentrations must be computed as follows:

$$C_{ims} = C_{ims, ds} + C_{ims, p}$$

where

$$C_{ims, ds} = \left(\frac{M_{is}}{Mt_{ie}} \right) [P_{ime} \cdot Msat_{ie}]$$

$$C_{ims, p} = \left(\frac{M_{is}}{Mt_{ie}} \right) [P'_{ime} \cdot (Mt_{ie} - Msat_{ie})]$$

and

$C_{ims, ds}$ = the dissolved (for fluids) or sorbed (for solids) concentration of species s in medium m within cell i [M/L³ or M/M];

$C_{ims, p}$ = the precipitated concentration of species s in medium m within cell i [M/L³];

W_S = atomic weight of species s ;

$$P'_{ime} = \frac{1}{\sum_{g=1; g \neq \text{fluid}}^{NM_i} AM_{ig}} \quad (\text{if } m \text{ is a non-suspended solid});$$

$$P'_{ime} = 0 \quad (\text{if } m \text{ is a fluid})$$

Hence, $C_{ims, p}$ is zero if m is a fluid.

The P'_{ime} operator partitions precipitated mass among the solids present in the cell based on their masses (i.e., the concentration of precipitated mass in each solid is the same).

Note that when suspended particulates are present, the *effective* concentration in a fluid is computed as follows:

$$C_{eims} = C_{ims} + \sum_{t=1}^{NPT_{im}} C_{it, ds} \cdot cp_{imt}$$

where:

- c_{ims} = the dissolved concentration of species s in fluid m within cell i [M/L³];
 NPT_{im} = the number of solid media suspended in fluid m within cell i ;
 $c_{it,ds}$ = the sorbed concentration of species s in solid medium t within cell i [M/M];
 and
 cp_{imt} = the concentration of solid particulate t within fluid m in cell i [M/L³].

Hence, particulates are only assumed to carry sorbed contaminant. Precipitated contaminant does not move with particulates.

CT_Cells1-01 - Partitioning Between Two Fluids and Two Solids in a Cell

A single cell is assigned two fluid media (WATER, the reference, and OIL) and two solid media (SAND and CLAY). The initial inventory of the cell contains 100 Ci each of Am-241, Am-242 and Am-243, input as 29.09g, 10.27g, and 500.8g respectively. The solubility of Am in WATER is unlimited.

The volume, masses and partition coefficients for the media are listed below:

Medium	Volume (m ³) or Mass (kg)	Partition Coefficient relative to WATER (m ³ /m ³) for fluids; (m ³ /kg) for solids
WATER	10	1
OIL	5	0.1
SAND	10	0.2
CLAY	20	5

Using the equations presented above, the constant concentrations in each of the media are as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER	2.586E-1	9.131E-2	4.451E+0
OIL	2.586E-2	9.131E-3	4.451E-1
SAND	5.172E-2	1.826E-2	8.902E-1
CLAY	1.293E+0	4.565E-1	2.226E+1

CT_Cells1-02 - Partitioning Between Fluids and Solids in a Cell, 0 Partition Coefficient for One Solid

This problem is identical to CT_Cells1-01, except the partition coefficient for CLAY is specified as zero. The volume, masses and partition coefficients for the media are listed below:

Medium	Volume (m ³) or Mass (kg)	Partition Coefficient relative to WATER (m ³ /m ³) for fluids; (m ³ /kg) for solids
WATER	10	1
OIL	5	0.1
SAND	10	0.2
CLAY	20	0

Using the equations presented above, the constant concentrations in each of the media are as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER	2.327E+0	8.217E-1	4.006E+1
OIL	2.327E-1	8.217E-2	4.006E+0
SAND	4.655E-1	1.643E-1	8.022E+0
CLAY	0	0	0

CT_Cells1-03 - Partitioning Between Fluids and Solids in a Cell, Solubility Limit Exceeded

This problem is identical to CT_Cells1-01, except the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m³).

Using the equations presented above, the constant concentrations in each of the media are as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER	1.357E-2	4.791E-3	2.336E-1
OIL	1.357E-3	4.791E-4	2.336E-2
SAND	9.216E-1	3.254E-1	1.586E+1
CLAY	9.867E-1	3.484E-1	1.698E+1

CT_Cells1-04 - Partitioning Between Fluids and Solids in a Cell with Suspended Particulates

This problem is identical to CT_Cells1-01, except that a portion of each of the two solids is suspended in each of the two fluids. The suspended solid concentrations are listed below:

Solid	Concentration in WATER (kg/m ³)
SAND	0.2
CLAY	0.02

Using the equations presented above, the constant *effective* concentrations in each of the media are as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER	2.948E-1	1.041E-1	5.074E+0
OIL	2.586E-2	9.131E-3	4.451E-1
SAND	5.172E-2	1.826E-2	8.902E-1
CLAY	1.293E+0	4.565E-1	2.226E+1

CT_Cells1-05 - Partitioning between Fluids and Solids in a Cell with Solubility Limit and Suspended Particulates

This problem is identical to CT_Cells1-04, except that the solubility limit defined in CT_Cells1-03 is imposed. Note that when a solubility limit is exceeded, precipitated species are assumed to 'plate out' only onto solids, and not onto suspended (particulate) solids.

Using the equations presented above, the constant effective concentrations in each of the media are as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER	1.547E-2	5.462E-3	2.663E-1
OIL	1.357E-3	4.791E-4	2.336E-2
SAND	9.943E-1	3.511E-1	1.711E+1
CLAY	1.059E+0	3.741E-1	1.824E+1

CT_Cells1-06 - Concentration in a Cell, Solubility Limit Exceeded, One Medium

This problem is identical to CT_Cells1-03 except the only medium present in the cell is WATER.

Using the equations presented above, the constant concentrations in WATER are as follows:

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER	1.357E-2	4.791E-3	2.336E-1

CT_Cells1-07 - Partitioning Between Fluids and Solids in a Cell with Solubility Limits, Suspended Particulates, and Inaccessible Porosity

This problem is similar to CT_Cells-05, except that part of the porosity in both of the solids is inaccessible, and a number of the input values have been modified. Since the dissolved species cannot access the inaccessible pore spaces, this effectively reduces the amount of fluids in the cell.

If the user specifies an available porosity for an element in a solid to be less than 1, the effective volume of fluid for that element in a cell containing that solid is reduced (and AM becomes element specific). In particular, for fluids, AM_{ige}^* is computed as follows:

$$AM_{ige}^* = VR_{ie} \cdot AM_{ig} = \left\{ \frac{\sum_{h=1; h=fluid}^{NM_i} AM_{ih} - \left[\sum_{h=1; h=solid}^{NM_i} AM_{ih} \frac{n_h}{DD_h} (1 - f_{he}) \right]}{\sum_{h=1; h=fluid}^{NM_i} AM_{ih}} \right\} AM_{ig}$$

where:

- VR_{ie} = the volume reduction factor for element e for fluids in cell i;
- AM_{ig} = the actual amount of medium g in cell i [m^3 fluid] or [kg solid];
- n_h = the porosity of solid h;
- DD_h = the dry density of solid h [kg/m^3]; and
- f_{he} = is the fraction of accessible porosity for element e in solid h.

In this problem, the actual media quantities are $10 m^3$ WATER, $5 m^3$ OIL, 50,000 kg SAND, and 20,000 kg CLAY. The K_d for sand is $2E-5 m^3/kg$, and the K_d for CLAY is $5E-5 m^3/kg$. The solubility of Am has been reduced to $2.5E-4$. The concentration of suspended SAND is $2000 kg/m^3$ in WATER. The concentration of suspended CLAY is $200 kg/m^3$ in WATER. SAND is assigned a porosity of .25, and a dry density of $2000 kg/m^3$. CLAY is assigned a porosity of .4, and a dry density of $2500 kg/m^3$. The element of interest in this problem (Am) has an accessible porosity of 90% in SAND and 50% in CLAY. Using the equation presented above, this results in a effective volume factor for Am for the fluids in the cell of 0.85167.

Using the equations presented previously, the constant effective concentrations in each of the media are as follows:

Medium	Am-241 (g/m^3) or (g/kg)	Am-242 (g/m^3) or (g/kg)	Am-243 (g/m^3) or (g/kg)
WATER	1.425E-5	5.031E-6	2.453E-4
OIL	1.357E-6	4.791E-7	2.336E-5
SAND	6.061E-4	2.140E-4	1.043E-2
CLAY	6.061E-4	2.140E-4	1.043E-2

CT_Cells1-08 – Fixed Concentration Boundary Conditions

This tests cells that have fixed concentration boundary conditions. The test has two parts. The first tests advective connections from a cell with a fixed concentration, and the second tests diffusive connections from a cell with a fixed concentration boundary condition.

The advective test compares the results of two cells in series to a reservoir element that integrates an advective flux. The diffusive flux test has two cells with a diffusive connection and, to simulate a fixed concentration in one cell, a discrete change element is used to replace any mass that leaves the cell on each time step. As the time step approaches zero the difference between the two sets of diffusive cells should approach zero.

The tester should run the model. Then the tester should enter the Fixed_Concentration_Diffusive container and confirm the result graph looks like the image pasted beside it. The tester should also enter the fixed_Concentration_Advective container and confirm the Max_difference element is near zero ($< 1e-6$ g).

CT_Cells2 - Advective Connections from Cells

These problems test simple advective connections from cells. For these problems, one or more advective connections *from* the cell to a sink are defined with non-zero flows. For problems in which decay is turned off, the total mass in the cell is governed by the following equation:

$$M_{is} = \sum_{c=1}^{NC_i} f_{cs}$$

where:

- M_{is} = rate of increase of species s in cell i [M/t];
- NC_i = number of mass transfer connections for cell i ; and
- f_{cs} = influx rate of species s (into cell i) through connection c [M/t].

Note that for an advective connection from cell i , f_{cs} is defined as follows:

$$f_{cs} = -(C_{ims} + \sum_{t=1}^{NPT_{im}} C_{its, ds} \cdot cp_{imt})q_c$$

where:

- q_c = the rate of advection for connection c [L³/t for fluid connections and M/t for solid connections];
- C_{ims} = the concentration of species s in medium m within cell i [M/L³ if m is a fluid; M/M if m is a solid];
- NPT_{im} = the number of solid media suspended in medium m within cell i ;
- $C_{its, ds}$ = the sorbed concentration of species s in solid medium t within cell i [M/M];
- cp_{imt} = the concentration of solid particulate t within fluid m in cell i [M/L³];

Note that by definition, q_c cannot be a negative number.

The second term accounts for the advection of suspended solids in a fluid. Note that for solid advective connections, the second term is not applicable (i.e., $NPT_{im} = 0$).

The manner in which the concentrations (e.g., C_{ims} , C_{its}) are computed for each species in every medium in a cell was discussed above in Section 5.7.1.

CT_Cells1 -08 – Cells with Fixed Concentrations

This model tests cells with fixed concentration boundary conditions. There are two tests in this model. The tester should run the model and confirm the Max_Difference element in the Fixed_Concentration_Advective container is near zero ($< 1e-6$ g) and that the plot in the Fixed_Concentration_Diffusive container matches the image pasted beside it.

In the Fixed_Concentration_Advective test, water advects from a cell with a fixed concentration to a sink. A reservoir is used to integrate the mass loading rate over time as verification. The two methods should be identical (Max_Difference < 1e-6 g)..

In the Fixed_Concentration_Diffusive test, a cell with a fixed concentration has a diffusive connection to a sink cell (Sink2). A second pair of cells is set up to emulate these calculations. In the second set, there is a diffusive connection, but a fixed concentration boundary condition is emulated by simply replacing the amount of mass that diffused to the sink cell (Sink3) on the previous time step. The differences between Sink2 and Sink3 should approach zero as the timestep length approaches zero.

CT_Cells2 -01 - Simple Fluid Advection

This problem is identical to CT_Cells1-01, except a second cell is added, with an advective connection between the two cells. The second cell contains only WATER, and the flow rate (QW) from the first cell to the second cell is 0.1 m³/yr.

For a cell with only one advective connection and no decay, the governing equation is:

$$M_{is} = -c_{ims} * QW$$

Substituting for c_{ims} , and recalling that in this case m is WATER, the above equation becomes:

$$M_{is} = -(QW * P_{i,WATER,e}) m_{is}$$

The solution to this equation is

$$m_{is} = m_{is}^0 \exp\{- (QW * P_{i,WATER,e}) t\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each medium can be readily computed as discussed in the previous section. The analytical solution is presented in the following table. Note that Results are not expected to match the very small exact results at time 10,000 with high precision.

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	2.37E-1	8.37E-2	4.07
time = 1000	1.06E-1	3.75E-2	1.83
time = 10,000	3.57E-5	1.26E-5	6.14E-4
OIL			
time = 100	2.37E-2	8.37E-3	4.07E-1
time = 1000	1.06E-2	3.75E-3	1.83E-1
time = 10,000	3.57E-6	1.26E-6	6.14E-5
SAND			
time = 100	4.73E-2	1.67E-2	8.15E-1
time = 1000	2.13E-2	7.51E-3	3.66E-1
time = 10,000	7.13E-6	2.52E-6	1.23E-4
CLAY			
time = 100	1.18	4.18E-1	2.04E+1

time = 1000	5.32E-1	1.88E-1	9.15
time = 10,000	1.78E-4	6.30E-5	3.07E-3

CT_Cells2 -02 - Fluid Advection with Multiple Connections

This problem is identical to CT_Cells2-01, except that three connections involving WATER, OIL and SAND are defined for the cell, with flow rates of QW (0.02 m³/yr), QO (0.3 m³/yr), and QS (0.25 kg/yr), respectively. Allowing for the partition factors, these media carry the same amount of Am as the water in CT_Cells2-01.

The governing equation becomes:

$$M_{is} = - \sum C_{ims} * Q_m$$

Since $\sum C_{ims} * Q_m = QW$ (as defined in the previous problem), the results should be identical to CT_Cells2-01. Note that Results are not expected to match the very small exact results at time 10,000 with high precision

CT_Cells2 -03 - Fluid Advection with Solubility Constraint

This problem is identical to CT_Cells2-01, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m³). The solubility and flow rates are low enough such that the cell is always saturated. The rate of advection for water is reduced to 0.02 m³/yr.

The governing equation is:

$$M_{is} = -c_{i,WATER,s} QW$$

Substituting for the concentration terms, and recalling that solubility limit is exceeded, the above equation becomes:

$$M_{is} = -(QW * P_{i,WATER,e} * msat_{ie}) m_{is} / mt_{ie}$$

Writing this in terms of the three species, the system of equations is:

$$M_{i1} = -QW [P_{i,WATER,e} * msat_{ie}] (m_{i1} / mt_{ie})$$

$$M_{i2} = -QW [P_{i,WATER,e} * msat_{ie}] (m_{i2} / mt_{ie})$$

$$M_{i3} = -QW [P_{i,WATER,e} * msat_{ie}] (m_{i3} / mt_{ie})$$

$$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$$

The solution (using MATLAB) is as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1
time = 10,000	1.35E-2	4.75E-3	2.32E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	9.21E-1	3.25E-1	1.59E+1
time = 1000	9.13E-1	3.22E-1	1.57E+1
time = 10,000	8.32E-1	2.94E-1	1.43E+1
CLAY			
time = 100	9.86E-1	3.48E-1	1.70E+1
time = 1000	9.78E-1	3.45E-1	1.68E+1
time = 10,000	8.97E-1	3.17E-1	1.54E+1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2 -04 - Fluid Advection with Particulates

This problem is identical to CT_Cells2-01, except a portion of each of the two solids is suspended in WATER.

Solid	Concentration in WATER (kg/m ³)
SAND	0.1
CLAY	0.01

The governing equation is:

$$M_{is} = -[C_{i,WATER,s} + (C_{i,SAND,s} * cp_{i,WATER,SAND}) + (C_{i,CLAY,s} * cp_{i,WATER,CLAY})] QW$$

Substituting for the concentration terms, the above equation becomes:

$$M_{is} = -QW [P_{i,WATER,e} + (P_{i,SAND,e} * cp_{i,WATER,SAND}) + (P_{i,CLAY,e} * cp_{i,WATER,CLAY})] m_{is}$$

The solution to this equation is:

$$m_{is} = m_{is}^0 \exp\{-[QW [P_{i,WATER,e} + (P_{i,SAND,e} * cp_{i,WATER,SAND}) + (P_{i,CLAY,e} * cp_{i,WATER,CLAY})] t\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each media can be readily computed as discussed in the previous section. The analytical solution is as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	2.52E-1	8.88E-2	4.33
time = 1000	1.07E-1	3.77E-2	1.84
time = 10,000	2.05E-5	7.23E-6	3.53E-4
OIL			
time = 100	2.35e-2	8.30E-3	4.05E-1
time = 1000	9.99E-3	3.53E-3	1.72E-1
time = 10,000	1.91E-6	6.76E-7	3.30E-5
SAND			
time = 100	4.70E-2	1.66E-2	8.10E-1
time = 1000	2.00E-2	7.05E-3	3.44E-1
time = 10,000	3.83E-6	1.35E-6	6.59E-5
CLAY			
time = 100	1.18	4.51e-1	2.02E+1
time = 1000	5.00E-1	1.76E-1	8.60
time = 10,000	9.57E-5	3.38E-5	1.65E-3

CT_Cells2 -05 - Fluid Advection with Particulates and Solubility Constraint

This problem is identical to CT_Cells2-01, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m³) and a portion of the SAND and CLAY is suspended in WATER (0.1 kg/m³ SAND and 0.01 kg/m³ CLAY). The advective flow rate for water is reduced to 0.05 m³/yr.

The governing equation is:

$$M_{is} = -[C_{i,WATER,s} + (C_{i,SAND,s} * cp_{i,WATER,SAND}) + (C_{i,CLAY,s} * cp_{i,WATER,CLAY})] QW$$

Substituting for the concentration terms, and recalling that solubility limit is exceeded, the above equation becomes:

$$M_{is} = - QW \{ [P_{i,WATER,e} * msat_{ie}] + cp_{i,WATER,SAND} * [P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY} * [P_{i,CLAY,e} * msat_{ie}] \} (m_{is} / mt_{ie})$$

Writing this in terms of the three species, the system of equations is:

$$M_{i1} = - QW \{ [P_{i,WATER,e} * msat_{ie}] + cp_{i,WATER,SAND} * [P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY} * [P_{i,CLAY,e} * msat_{ie}] \} (m_{i1} / mt_{ie})$$

$$M_{i2} = - QW \{ [P_{i,WATER,e} * msat_{ie}] + cp_{i,WATER,SAND} * [P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY} * [P_{i,CLAY,e} * msat_{ie}] \} (m_{i2} / mt_{ie})$$

$$M_{i3} = -QW\{[P_{i,WATER,e} * msat_{ie}] + cp_{i,WATER,SAND}[P_{i,SAND,e} * msat_{ie}] + cp_{i,WATER,CLAY}[P_{i,CLAY,e} * msat_{ie}]\}(m_{i3} / mt_{ie})$$

$$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$$

The solution (solved using MATLAB) is as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	1.44E-2	5.09E-3	2.48E-1
time = 1000	1.44E-2	5.09E-3	2.48E-1
time = 10,000	1.44E-2	5.09E-3	2.48E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	9.54E-1	3.37E-1	1.64E+1
time = 1000	9.32E-1	3.29E-1	1.60E+1
time = 10,000	7.08E-1	2.50E-1	1.22E+1
CLAY			
time = 100	1.019	3.60E-1	1.75E+1
time = 1000	9.97E-1	3.52E-1	1.72E+1
time = 10,000	7.72E-1	2.73E-1	1.33E+1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2 -06 - Simple Solid Advection

This problem is identical to CT_Cells2-01, except the solid SAND is being advected, rather than WATER.

The flow rate of sand (QS) from the first cell to the second cell is 0.05 kg/yr.

For a cell with only one advective connection and no decay, the governing equation is:

$$M_{is} = -c_{ims} * QS$$

Substituting for c_{ims} , and recalling that in this case m is SAND, the above equation becomes:

$$M_{is} = -(QS * P_{i,SAND,e}) m_{is}$$

The solution to this equation is

$$m_{is} = m_{is}^0 \exp\{-(QS * P_{i,SAND,e}) t\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each media can be readily computed as discussed in the previous section. The analytical solution is as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	2.56E-1	9.05E-2	4.41
time = 1000	2.37E-1	8.35E-2	4.07
time = 10,000	1.06E-1	3.75E-2	1.83
OIL			
time = 100	2.56E-2	9.05E-3	4.41E-1
time = 1000	2.37E-2	8.35E-3	4.07E-1
time = 10,000	1.06E-2	3.75E-3	1.83E-1
SAND			
time = 100	5.13E-2	1.81E-2	8.82E-1
time = 1000	4.73E-2	1.67E-2	8.15E-1
time = 10,000	2.13E-2	7.51E-3	3.66E-1
CLAY			
time = 100	1.28	4.25E-1	2.21E+1
time = 1000	1.18	4.18E-1	2.04E+1
time = 10,000	5.32E-1	1.88E-1	9.15

CT_Cells2 -07 - Advection with Multiple Connections from Different Media

This problem is identical to CT_Cells1-01, except an advective connection from the cell exists for all four media (WATER, OIL, SAND, and CLAY). The WATER flow rate is QW (0.1 m³/yr), OIL flow rate is QO (0.05 m³/yr), the SAND flow rate is QS (0.05 kg/yr) and the CLAY flow rate is QC (0.20 kg/yr).

The governing equation is:

$$M_{is} = -c_{i,WATER,s} * QW - c_{i,OIL,s} * QO - c_{i,SAND,s} * QS - c_{i,CLAY,s} * QC$$

Substituting for the concentrations, the above equation becomes:

$$M_{is} = -(QW * P_{i,WATER,e} + QO * P_{i,OIL,e} + QS * P_{i,SAND,e} + QC * P_{i,CLAY,e}) m_{is}$$

The solution to this equation is:

$$m_{is} = m_{is}^0 \exp\{-((QW * P_{i,WATER,e} + QO * P_{i,OIL,e} + QS * P_{i,SAND,e} + QC * P_{i,CLAY,e}) t)\}$$

Given the total mass in the cell as a function of time, the mass flux from the cell and the concentration in each media can be readily computed as discussed in the previous section. The analytical solution is shown in the following table. Note that Results are not expected to match the very small exact results at time 10,000 with high precision.

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	9.60E-2	3.39E-2	1.65
time = 1000	1.28E-5	4.53E-6	2.21E-4
time = 10,000	<1E-40	<1E-40	<1E-40
OIL			
time = 100	9.60E-3	3.39E-3	1.65E-1
time = 1000	1.28E-6	4.53E-7	2.21E-5
time = 10,000	<1E-40	<1E-40	<1E-40
SAND			
time = 100	1.92E-2	6.78E-3	3.30E-1
time = 1000	2.57E-6	9.06E-7	4.42E-5
time = 10,000	<1E-40	<1E-40	<1E-40
CLAY			
time = 100	4.80E-1	1.69E-1	8.26
time = 1000	6.42E-5	2.27E-5	1.10E-3
time = 10,000	<1E-40	<1E-40	<1E-40

CT_Cells2 -08 - Fluid Advection with Particulates into a Pipe Pathway

This problem is identical to CT_Cells2-04, except that the cell is connected to a pathway.

The governing equation is:

$$M_{is} = -[C_{i,WATER,s} + (C_{i,SAND,s} * c_{p_i,WATER,SAND}) + (C_{i,CLAY,s} * c_{p_i,WATER,CLAY})] QW$$

The solution for the cell concentrations and fluxes is identical to CT_Cells2-04.

Additional test: The test problem has an expression called TotalMass that computes the sum of the mass in the original cell plus the mass in the Sink downstream of the pipe pathway. Confirm that all of the mass that originates in the original cell ends up in the sink, by checking that the mass in TotalMass at the end of the simulation equals the amount at the beginning of the simulation.

CT_Cells2 -09 - Fluid Advection with Solubility Constraint; Concentration Drops Below Solubility

This problem is similar to CT_Cells2-04, except that the solubility and flow rate are specified such that after a certain time period, the solubility constraint is no longer exceeded in the cell. The second cell is dimensioned such that the solubility limit is exceeded in the receiving cell at some time after the first cell has dropped below the limit.

The initial mass of each species in the first cell is 10 Ci and the advective flow rate of WATER is 0.2 m³/year. The quantities of media in the second cell are 1.2 times larger than in the first cell.

For cell 1, the governing equation is:

$$M_{1s} = -c_{1,WATER,s} QW1$$

For cell 2, the governing equation is:

$$M_{2s} = c_{1,WATER,s} QW1$$

This results in a non-linear set of equations (solved by MATLAB). The solution is as follows:

Cell 1

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 10	1.35E-2	4.75E-3	2.32E-1
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 500	1.35E-2	4.75E-3	2.32E-1
time = 1000	5.71E-3	2.02E-3	9.83E-2

Sink

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 10	1.99E-4	7.04E-5	3.43E-3
time = 100	2.00E-3	7.04E-4	3.43E-2
time = 500	9.98E-3	3.52E-3	1.72E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2-10 - Solid Advection with Solubility Constraint

This problem is identical to CT_Cells2-07, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m³). The solubility and flow rates are low enough such that the cell is always saturated. The rate of advection for SAND is reduced to 0.01 kg/yr.

The governing equation is:

$$M_{is} = -c_{i,SAND,s} QS$$

Substituting for the concentration terms, and recalling that solubility limit is exceeded, the above equation becomes:

$$M_{is} = -QS [P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e} (mt_{ie} - msat_{ie})] m_{is} / mt_{ie}$$

Writing this in terms of the three species, the system of equations is:

$$M_{i1} = -QS [P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e} (mt_{ie} - msat_{ie})] m_{i1} / mt_{ie}$$

$$M_{i2} = -QS [P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e} (mt_{ie} - msat_{ie})] m_{i2} / mt_{ie}$$

$$M_{i3} = -QS [P_{i,SAND,e} * msat_{ie} + P'_{i,SAND,e} (mt_{ie} - msat_{ie})] m_{i3} / mt_{ie}$$

$$mt_{ie} = m_{i1} + m_{i2} + m_{i3}$$

The solution (using MATLAB) is as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1
time = 10,000	1.35E-2	4.75E-3	2.32E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	8.92E-1	3.15E-1	1.54E+1
time = 1000	6.61E-1	2.33E-1	1.14E+1
time = 10,000	3.29E-2	1.16E-2	5.66E-1
CLAY			
time = 100	9.56E-1	3.38E-1	1.65E+1
time = 1000	7.25E-1	2.56E-1	1.25E+1
time = 10,000	9.75E-2	3.44E-2	1.68

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells2-11 – Advective Links with Negative Flow Rates

This test verifies that cell elements support negative advective flow rates.

In this test Cell A has an initial inventory consisting of Species A, while Cell B has an inventory consisting of species B. The initial flow rate is from B to A, and the half-life for the amount of mass in each cell is 14 days (note that half-life does not refer to decay in this case, but rather to the amount of material in each cell).

Later, the flow switches to be from A to B, and the half-life changes as well (to 3.46 days).

The verifier should run the model and confirm that the masses in each Cell diminish appropriately, with the approximate half life specified by the HalfLife element (this can be confirmed graphically by comparing the MassesChart Time History plot in the model to Figure CT_Cells2-11a below).

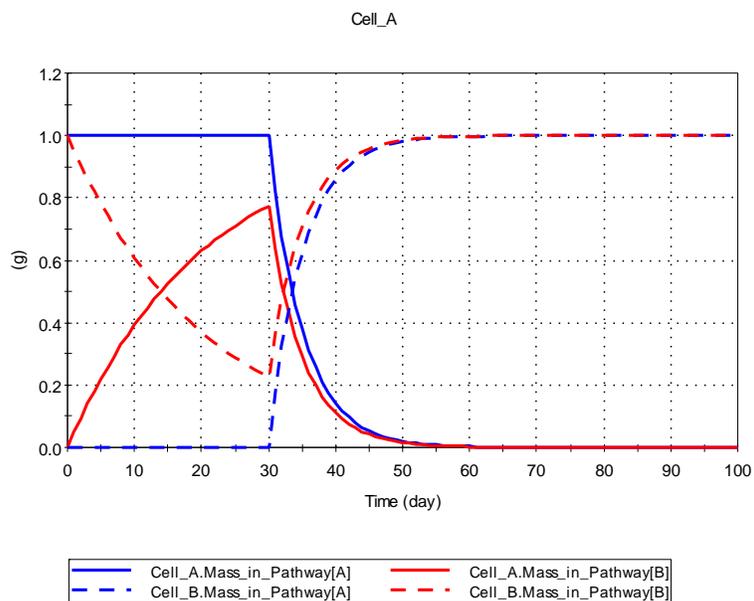


Figure CT_Cells2-11a

The verifier should then enter the Pipe_Test container and create an advective link between CellA and the Pipe. The verifier should specify a negative flow rate for the link, and then run the model. A fatal error should be generated.

CT_Cells2-12 – Colloid Velocity Multiplier

This test verifies that the Colloid Velocity Multiplier functions properly. The test verifies the effect of the Velocity Factor on the speed of species flow from the Cell and Pipe elements when a high Kd is specified, then checks to ensure the flux is not affected by the Velocity Factor for low Kd values.

The verifier should start by setting the Kd value to 1m³/g and the VelFactor element to 5 (representing a five-fold increase in velocity). The verifier should run the model, then open the Fluxes plot and confirm that the flux is 0.005 g/s. Next the verifier should open the Breakthrough plot and verify that the peak of the breakthrough curve occurs at 11s.

The test should then be repeated with a Kd of 1ml/g. In this scenario, the small Kd dominates. The Fluxes plot should show a flux of 1E-6 g/s. The verifier should then open the Breakthrough plot and verify that the peak of the breakthrough curve occurs at 50s.

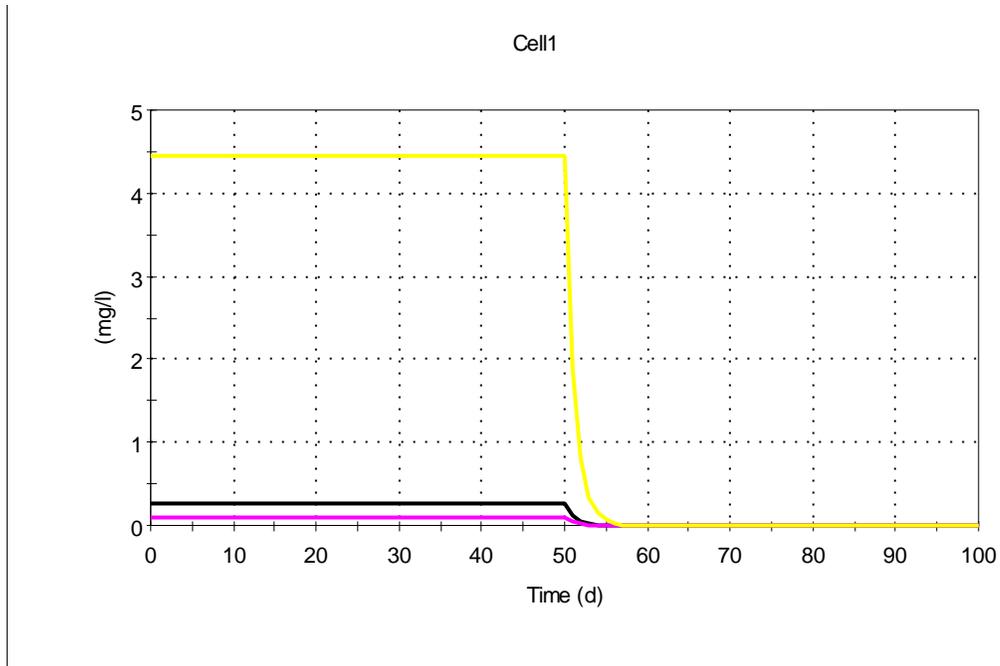


Figure CT_Cells2-12

CT_Cells3 - Diffusive Connections from Cells

These problems test simple diffusive connections from cells. For these problems, one or more diffusive connections *from* the cell to a sink are defined. For problems in which decay is turned off, the total mass in the cell is governed by the following equation:

$$M_{is} = \sum_{c=1}^{NC_i} f_{cs}$$

where:

- M_{is} = rate of increase of species s in cell i [M/t];
- NC_i = number of mass transfer connections for cell i ; and
- f_{cs} = influx rate of species s (into cell i) through connection c [M/t].

Note that for an advective connection from cell i , f_{cs} is defined as follows:

Diffusive mass transfer connections can only be specified to occur through fluids. The flux f_{cs} to path i is computed as follows for diffusive mass transfer connections:

$$f_{cs} = D_{cs} \left(-C_{ims} + \frac{C_{jns}}{K_{nms}} \right) + \sum_{t=1}^{NPT_{im}} PFD_{ct} \cdot D_{ct} \left(-C_{its, ds} \cdot CP_{imt} + C_{jts, ds} \cdot CP_{jnt} \right)$$

where:

- D_{cs} = diffusive conductance for species s in connection c [L³/t];
- C_{ims} = the dissolved concentration of species s in medium m within cell i [M/L³];
- C_{jns} = the dissolved concentration of species s in medium n within cell j [M/L³];

K_{nms}	=	partition coefficient between fluid medium n (in cell j) and fluid medium m (in cell i) for species s [L ³ medium m / L ³ medium n];
NPT_{im}	=	the number of particulate solid media in fluid m within cell i;
PFD_{ct}	=	Boolean flag (0 or 1) which indicates whether diffusion of solid t suspended in the fluid for connection c is allowed;
D_{ct}	=	diffusive conductance for particulate t in connection c [L ³ /t];
$c_{its,ds}$	=	the sorbed concentration of species s associated with solid t within cell i [M/M];
cp_{imt}	=	the concentration of solid particulate t within fluid m in cell i [M/L ³];
$c_{jts,ds}$	=	the sorbed concentration of species s associated with solid t within cell [M/M]; and
cp_{jnt}	=	the concentration of solid particulate t within fluid n in cell j [M/L ³].

The first term in Equation (1-4) accounts for diffusion of dissolved species, while the second term accounts for diffusion of particulates suspended in the fluid. Note that unlike advective connections, the fluid media involved in cells i (medium m) and j (medium n) need not be identical. Note also that if j is a pathway, c_{jns} and cp_{jnt} are assumed to be zero. (Hence, mass can diffuse from a cell to a pathway, but cannot diffuse from a pathway to a cell).

The diffusive conductance terms are computed as follows:

$$D_{cs} = \frac{A_c}{\frac{L_{ci}}{d_{ms} \cdot t_{Pci} \cdot n_{Pci}} + \frac{L_{cj}}{d_{ns} \cdot t_{Pcj} \cdot n_{Pcj} \cdot K_{nms}}}$$

where:

A_c	=	the area of diffusive connection c [L ²];
L_{ci}	=	diffusive length for connection c in cell i [L];
L_{cj}	=	diffusive length for connection c in cell j [L];
d_{ms}	=	diffusivity for species s for fluid m (in cell i) [L ² /t];
d_{ns}	=	diffusivity for species s for the fluid n (in cell j) [L ² /t];
tp_{ci}	=	tortuosity for the porous medium P_{ci} defined for connection c in cell i (≤ 1);
tp_{cj}	=	tortuosity for the porous medium P_{cj} defined for connection c in cell j (≤ 1);
np_{ci}	=	porosity for the porous medium P_{ci} defined for connection c in cell i;
np_{cj}	=	porosity for the porous medium P_{cj} defined for connection c in cell j; and
K_{nms}	=	partition coefficient between fluid media n (in cell j) and fluid media m (in cell i) for species s [L ³ medium m / L ³ medium n].

and

$$D_{ct} = \frac{A_c}{\frac{L_{ci}}{d_{mt} \cdot t_{Pci} \cdot n_{Pci}} + \frac{L_{cj}}{d_{nt} \cdot t_{Pcj} \cdot n_{Pcj}}}$$

where A_c , L_{ci} , L_{cj} , t_{Pci} , t_{Pcj} , n_{Pci} , and n_{Pcj} are as defined previously, and

d_{mt}	=	diffusivity for particulate t within the fluid m (in cell i) [L ² /t]; and
----------	---	---------------------------------------------------------------------------------------

d_{nt} = diffusivity for particulate t within the fluid n (in cell j) [L^2/t].

If j is a pipe, L_{cj} is automatically assumed to be 0 (no diffusive resistance is present on the pipe side of the connection). The equation above does not contain a partitioning term because, as will be shown below, intermedia diffusive transport is not allowed for suspended particulates.

The partition coefficient (K_{mns}) present in the above equations is defined as follows:

$$K_{mns} = \frac{K_{nre}}{K_{mre}}$$

where:

K_{mre} = partition coefficient between fluid medium m and reference fluid r for element e (where species s is an isotope of element e) [L^3 fluid r/L^3 fluid m]; and

K_{nre} = partition coefficient between fluid medium n and reference fluid r for element e (where species s is an isotope of element e) [L^3 fluid r/L^3 fluid n].

Note that K_{mre} and K_{nre} are direct user inputs.

PFD_{ct} is defined as follows:

IF [fluid m = fluid n]

THEN ($PFD_{ct} = 1$),

ELSE ($PFD_{ct} = 0$)

That is, diffusive transport of particulates through a fluid from cell i to receiving cell (or pipe) j is only allowed if fluid m (in cell i) is the same as fluid n (in cell or pipe j).

Particulate solid concentrations in fluids (cp_{imt} , cp_{jnt}) are specified directly by the user.

Contaminant concentrations in various media (c_{ims} , c_{jns} , c_{its} , c_{jts}) are computed as described in Section 5.7.1.

CT_Cells3 -01 - Simple Diffusion

This problem is identical to CT_Cells1-01, except a second cell is added, with a diffusive connection between the two cells (WATER to WATER). Both cells contain all four media, and the diffusive connection properties are as listed below:

	diffusive length (m)	tortuosity	porosity
Cell 1	0.02	0.1 (SAND)	0.3 (SAND)
Cell 2	0.02	0.15 (CLAY)	0.4 (CLAY)

The diffusive area is 20 m^2 and the diffusivity for all species in water is $1e-3 \text{ m}^2/\text{yr}$.

For a cell with only one diffusive connection to another cell through the same fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{cs} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s})$$

$$M_{2s} = D_{cs} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3 -02 - Simple Intermedia Diffusion

This problem is identical to CT_Cells3-01, except that the diffusive connection is from WATER to OIL. The diffusivity for all 3 species in OIL is $5e-4$ m²/yr.

For a cell with only one diffusive connection to another cell with a different fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,OIL,s}/K_{OIL,WATER,s})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,OIL,s}/K_{OIL,WATER,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{cs} (-P_{1,WATER,e} m_{1s} + P_{2,OIL,e} m_{2s}/K_{OIL,WATER,s})$$

$$M_{2s} = D_{cs} (P_{1,WATER,e} m_{1s} - P_{2,OIL,e} m_{2s}/K_{OIL,WATER,s})$$

This is a linear system of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.58E-1	9.11E-2	4.44
time = 1000	2.53E-1	8.91E-2	4.35
time = 10,000	2.09E-1	7.38E-2	3.60

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	6.25E-4	2.208E-4	1.08E-2
time = 1000	6.12E-3	2.16E-3	1.05E-1
time = 10,000	4.97E-2	1.75E-2	8.55E-1

CT_Cells3 -03 - Simple Diffusion With Multiple Connections

This problem is identical to CT_Cells3-01, except that two diffusive connections to a second cell are defined:

	diffusive length (m)	tortuosity	porosity
Connection 1			
Cell 1	0.02	0.1 (SAND)	0.3 (SAND)
Cell 2	0.02	0.15 (CLAY)	0.4 (CLAY)
Connection 2			
Cell 1	0.04	0.1 (SAND)	0.3 (SAND)
Cell 2	0.04	0.15 (CLAY)	0.4 (CLAY)

The diffusive area for the first connection is 10 m²; the diffusive area for the second connection is 20 m².

For a cell with two diffusive connections to another cell through the same fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{1s} (-c_{1,WATER,s} + c_{2,WATER,s}) + D_{2s} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{1s} (c_{1,WATER,s} - c_{2,WATER,s}) + D_{2s} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{1s} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s}) + D_{2s} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s})$$

$$M_{2s} = D_{1s} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s}) + D_{2s} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3 -04 - Simple Diffusion With Multiple Connections to Two Cells

This problem is identical to CT_Cells3-03, except that two diffusive connections to two different cells are defined. The connection settings are identical to those in CT_Cells3-03, but the mass and volume of the four media in the two receiving cells (Cells 2 and 3) are half of those in Cell 1.

For a cell with two diffusive connections to two other cells through the same fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{1s} (-c_{1,WATER,s} + c_{2,WATER,s}) + D_{2s} (-c_{1,WATER,s} + c_{3,WATER,s})$$

$$M_{2s} = D_{1s} (c_{1,WATER,s} - c_{2,WATER,s})$$

$$M_{3s} = D_{2s} (c_{1,WATER,s} - c_{3,WATER,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{1s} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s}) + D_{2s} (-P_{1,WATER,e} m_{1s} + P_{3,WATER,e} m_{3s})$$

$$M_{2s} = D_{1s} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s})$$

$$M_{3s} = D_{2s} (P_{1,WATER,e} m_{1s} - P_{3,WATER,e} m_{3s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

Sink2

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3 -05 - Diffusion with Particulates

This problem is identical to CT_Cells3-01, except that a portion of each of the two solids is suspended in each of the two fluids. The suspended solid concentrations are listed below:

Solid	Concentration in WATER (kg/m³)	Concentration in OIL (kg/m³)
SAND	0.1	0.2
CLAY	0.01	0.02

The diffusivity of the solids in the two fluids are listed below:

Solid	diffusivity in WATER (m²/year)	diffusivity in OIL (m²/year)
SAND	2e-3	1e-3
CLAY	5e-3	2e-3

The governing equations for each species are (assuming no decay):

$$\begin{aligned}
 M_{1s} = & D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s}) \\
 & + D_{c,SAND} (-c_{1,SAND,s}*CP_{1,WATER,SAND} + c_{2,SAND,s}*CP_{2,WATER,SAND}) \\
 & + D_{c,CLAY} (-c_{1,CLAY,s}*CP_{1,WATER,CLAY} + c_{2,CLAY,s}*CP_{2,WATER,CLAY})
 \end{aligned}$$

$$\begin{aligned}
 M_{2s} = & D_{cs} (c_{1,WATER,s} - c_{2,WATER,s}) \\
 & + D_{c,SAND} (c_{1,SAND,s}*CP_{1,WATER,SAND} - c_{2,SAND,s}*CP_{2,WATER,SAND}) \\
 & + D_{c,CLAY} (c_{1,CLAY,s}*CP_{1,WATER,CLAY} - c_{2,CLAY,s}*CP_{2,WATER,CLAY})
 \end{aligned}$$

This is a linear system of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.71E-1	9.55E-2	4.66
time = 1000	2.26E-1	7.97E-2	3.89
time = 10,000	1.40E-1	4.93E-2	2.41

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	6.20E-3	2.19E-3	1.07E-1
time = 1000	5.09E-2	1.80E-2	8.76E-1
time = 10,000	1.37E-1	4.84E-2	2.36

CT_Cells3 -06 - Diffusion with Particulates into a Pipe

This problem is identical to CT_Cells3-05, except that the first cell is connected to a pipe, rather than a cell. As a result, the diffusive resistance in the second half of the connection is zero. Note that the governing equations shown below assume an infinitely large pathway such that the pathway concentration approaches zero.

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{c,s} (-c_{1,WATER,s}) + D_{c,SAND} (-c_{1,SAND,s} * c_{p1,WATER,SAND}) \\ + D_{c,CLAY} (-c_{1,CLAY,s} * c_{p1,WATER,CLAY})$$

This is a linear system of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.67E-1	9.44E-2	4.60
time = 1000	1.96E-1	6.93E-2	3.38
time = 10,000	8.87E-3	3.13E-3	1.53E-1

Additional test: The test problem has an expression called TotalMass that computes the sum of the mass in the original cell plus the mass in the Sink downstream of the pipe pathway. Confirm that all of the mass that originates in the original cell ends up in the sink, by checking that the mass in TotalMass at the end of the simulation equals the amount at the beginning of the simulation.

CT_Cells3 -07 - Diffusion with Particulates into a Cell with Zero Particulate Concentration

This problem is identical to CT_Cells3-05, except that the second cell has zero particulate concentrations.

The governing equations for each species are (assuming no decay):

$$\begin{aligned}
 M_{1s} = & D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s}) \\
 & + D_{c,SAND} (-c_{1,SAND,s} * c_{p1,WATER,SAND}) \\
 & + D_{c,CLAY} (-c_{1,CLAY,s} * c_{p1,WATER,CLAY})
 \end{aligned}$$

$$\begin{aligned}
 M_{2s} = & D_{cs} (c_{1,WATER,s} - c_{2,WATER,s}) \\
 & + D_{c,SAND} (c_{1,SAND,s} * c_{p1,WATER,SAND}) \\
 & + D_{c,CLAY} (c_{1,CLAY,s} * c_{p1,WATER,CLAY})
 \end{aligned}$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.71E-1	9.55E-2	4.66
time = 1000	2.25E-1	7.93E-2	3.87
time = 10,000	1.24E-1	4.36E-2	2.13

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	5.81E-3	2.05E-3	1.00E-1
time = 1000	4.87E-2	1.72E-2	8.39E-1
time = 10,000	1.43E-1	5.06E-2	2.46

CT_Cells3 -08 - Intermedia Diffusion with Particulates

This problem is identical to CT_Cells3-02, except that a portion of each of the two solids is suspended in each of the two fluids, as in CT_Cells3-05. Because intermedia particulate diffusion is not allowed, the solution is similar to the solution for CT_Cells3-02, because the same amount of mass should diffuse to the sink. Note that results are not expected to match the very small exact results at time 10,000 with high precision

CT_Cells3 -09 - Diffusion With Multiple Connections from Multiple Media

This problem is identical to CT_Cells3-01, except that two diffusive connections to a second cell are defined:

	transport medium	diffusive length (m)	tortuosity	porosity
Connection 1	WATER			
Cell 1		0.02	0.1 (SAND)	0.3 (SAND)
Cell 2		0.02	0.15 (CLAY)	0.4 (CLAY)
Connection 2	OIL			
Cell 1		0.04	0.1 (SAND)	0.3 (SAND)
Cell 2		0.04	0.15 (CLAY)	0.4 (CLAY)

The diffusive area is for the first connection is 10 m²; the diffusive area for the second connection is 400 m².

For a cell with two diffusive connections to another cell, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{1s} (-c_{1,WATER,s} + c_{2,WATER,s}) + D_{2s} (-c_{1,OIL,s} + c_{2,OIL,s})$$

$$M_{2s} = D_{1s} (c_{1,WATER,s} - c_{2,WATER,s}) + D_{2s} (c_{1,OIL,s} - c_{2,OIL,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{1s} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s}) + D_{2s} (-P_{1,OIL,e} m_{1s} + P_{2,OIL,e} m_{2s})$$

$$M_{2s} = D_{1s} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s}) + D_{2s} (P_{1,OIL,e} m_{1s} - P_{2,OIL,e} m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 10,000	1.33E-1	4.70E-2	2.29

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 10,000	1.26E-1	4.43E-2	2.16

CT_Cells3-10 - Intermedia Diffusion with Zero Partition Coefficient for Fluid in Second Cell

This problem is identical to CT_Cells3-02, except that the partition coefficient from WATER to OIL is zero. As a result, no diffusive transport occurs, and the mass and concentration in the first cell stay constant. The concentrations in WATER for Am-241, Am-242 and Am-243, are, respectively, 2.60E-1, 9.17E-2, and 4.47.

CT_Cells3-11 - Diffusion with Zero Length in Receiving Cell

This problem is identical to CT_Cells3-01, except that the diffusive length in the second cell is zero. This modifies the value of D_{cs} .

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{cs} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s})$$

$$M_{2s} = D_{cs} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.52E-1	8.89E-2	4.34
time = 1000	2.05E-1	7.24E-2	3.53
time = 10,000	1.30E-1	4.59E-2	2.24

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	6.72E-3	2.37E-3	1.16E-1
time = 1000	5.34E-2	1.89E-2	9.20E-1
time = 10,000	1.29E-1	4.54E-2	2.21

CT_Cells3-12 - Diffusion with No Porous Media

This problem is identical to CT_Cells3-01, except that no porous media is specified in either cell for the diffusive connections. This modifies the value of D_{cs} .

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{cs} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s})$$

$$M_{2s} = D_{cs} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	1.83E-1	6.44E-2	3.14
time = 1000	1.29E-1	4.57E-2	2.23
time = 10,000	1.29E-1	4.57E-2	2.23

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	7.61E-2	2.69E-2	1.31
time = 1000	1.29E-1	4.56E-2	2.23
time = 10,000	1.29E-1	4.57E-2	2.23

CT_Cells3-13 - Diffusion with Solubility Constraint

This problem is identical to CT_Cells3-01, except that the solubility limit is exceeded for Am (the solubility limited being specified as 0.25 g/m³) in the first cell (and is never exceeded in the second cell).

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s} + c_{2,WATER,s})$$

$$M_{2s} = D_{cs} (c_{1,WATER,s} - c_{2,WATER,s})$$

Substituting for the concentration terms, expanding for all three species in both cells, and recalling that solubility limit is exceeded, the above equations become:

$$M_{11} = D_{c1} (-P_{1,WATER,e} * msat_{1e} * m_{11} / mt_{1e} + P_{2,WATER,e} * m_{21})$$

$$M_{21} = D_{c1} (P_{1,WATER,e} * msat_{1e} * m_{11} / mt_{1e} - P_{2,WATER,e} * m_{21})$$

$$M_{12} = D_{c2} (-P_{1,WATER,e} * msat_{1e} * m_{12} / mt_{1e} + P_{2,WATER,e} * m_{22})$$

$$M_{22} = D_{c2} (P_{1,WATER,e} * msat_{1e} * m_{12} / mt_{1e} - P_{2,WATER,e} * m_{22})$$

$$M_{13} = D_{c3} (-P_{1,WATER,e} * msat_{1e} * m_{13} / mt_{1e} + P_{2,WATER,e} * m_{23})$$

$$M_{21} = D_{c3} (P_{1,WATER,e} * msat_{1e} * m_{13} / mt_{1e} - P_{2,WATER,e} * m_{23})$$

$$mt_{1e} = m_{i1} + m_{i2} + m_{i3}$$

This is a non-linear systems of equations (solved using MATLAB). The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	1.35E-2	4.75E-3	2.32E-1
time = 1000	1.35E-2	4.75E-3	2.32E-1
time = 10,000	1.35E-2	4.75E-3	2.32E-1

Sink

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.37E-4	8.38E-5	4.08E-3
time = 1000	2.19E-3	7.74E-4	3.78E-2
time = 10,000	1.12E-2	3.95E-3	1.93E-1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells3-14 - Two Cells Diffuse to Equilibrium

This problem is similar to CT_Cells3-01, except that each of the two cells has an initial inventory with a different isotope of a single element. Cell1 initially has 100 g of Am-241 and Cell2 initially has 100 Ci of Am-243. The cells should diffuse until equilibrium is reached.

For a cell with only one diffusive connection to another cell through the same fluid, the governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-C_{1,WATER,s} + C_{2,WATER,s})$$

$$M_{2s} = D_{cs} (C_{1,WATER,s} - C_{2,WATER,s})$$

Substituting for c_{ims} , the above equations become:

$$M_{1s} = D_{cs} (-P_{1,WATER,e} m_{1s} + P_{2,WATER,e} m_{2s})$$

$$M_{2s} = D_{cs} (P_{1,WATER,e} m_{1s} - P_{2,WATER,e} m_{2s})$$

This is a linear systems of equations. The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-243 (g/m ³)
WATER		
time = 100	2.54E-1	7.77E-2
time = 1000	2.20E-1	6.66E-1
time = 10,000	1.33E-1	2.16

Sink

Medium	Am-241 (g/m ³)	Am-243 (g/m ³)
WATER		
time = 100	4.52E-3	4.37
time = 1000	3.87E-2	3.79
time = 10,000	1.26E-1	2.29

CT_Cells3-15 - Diffusion with Particulates into a Pathway, with a Solubility Constraint

This problem is identical to CT_Cells3-06, except that a solubility constraint (of 0.25g/m³) is imposed in the cell.

The governing equations for each species are (assuming no decay):

$$M_{1s} = D_{cs} (-c_{1,WATER,s}) + D_{c,SAND} (-c_{1,SAND,s} * cp_{1,WATER,SAND}) \\ + D_{c,CLAY} (-c_{1,CLAY,s} * cp_{1,WATER,CLAY})$$

Substituting for the concentration terms, expanding for all three species, and recalling that the solubility limit is exceeded, the above equation becomes:

$$M_{11} = (m_{11} / mt_{1e}) \{ D_{cs} (-P_{1,WATER,e} * msat_{1e}) \\ + D_{c,SAND} (-cp_{1,WATER,SAND}) [P_{1,SAND,e} * msat_{1e}] \\ + D_{c,CLAY} (-cp_{1,WATER,CLAY}) [P_{1,CLAY,e} * msat_{1e}] \}$$

$$M_{12} = (m_{12} / mt_{1e}) \{ D_{cs} (-P_{1,WATER,e} * msat_{1e}) \\ + D_{c,SAND} (-cp_{1,WATER,SAND}) [P_{1,SAND,e} * msat_{1e}] \\ + D_{c,CLAY} (-cp_{1,WATER,CLAY}) [P_{1,CLAY,e} * msat_{1e}] \}$$

$$M_{13} = (m_{13} / mt_{1e}) \{ D_{cs} (-P_{1,WATER,e} * msat_{1e}) \\ + D_{c,SAND} (-cp_{1,WATER,SAND}) [P_{1,SAND,e} * msat_{1e}] \\ + D_{c,CLAY} (-cp_{1,WATER,CLAY}) [P_{1,CLAY,e} * msat_{1e}] \}$$

$$mt_{1e} = m_{i1} + m_{i2} + m_{i3}$$

This set of equations must be solved by MATLAB. The resulting effective concentrations are as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 100	1.44E-2	5.09E-3	2.48E-1
time = 1000	1.44E-2	5.09E-3	2.48E-1
time = 10,000	1.44E-2	5.09E-3	2.48E-1
OIL			
time = 100	1.35E-3	4.75E-4	2.32E-2
time = 1000	1.35E-3	4.75E-4	2.32E-2
time = 10,000	1.35E-3	4.75E-4	2.32E-2
SAND			
time = 100	9.55E-1	3.37E-1	1.64E1
time = 1000	9.39E-1	3.32E-1	1.62E1
time = 10,000	7.77E-1	2.74E-1	1.34E1
CLAY			
time = 100	1.02	3.60E-1	1.76E1
time = 1000	1.00	3.54E-1	1.73E1
time = 10,000	8.41E-1	2.97E-1	1.45E1

Note: the MATLAB solution assumes that the mass (not molar) solubility is identical for all three isotopes. This creates a small error in the calculated results, of less than 1%. The verifier should therefore accept a small difference between GoldSim's results and the MATLAB results reported above.

CT_Cells3-16 – Diffusion with Inaccessible Porosity

This problem is identical to CT_Cells1-07, except a second cell is added, with a diffusive connection between the two cells (WATER to WATER). In addition, the particulates are removed from both cells, and no solubility constraint is imposed. The second cell contains 10 m³ of water, 5 m³ of oil, 75,000kg of sand, and 30000kg of clay,

Both cells contain all four media, and the diffusive connection properties are as listed below:

	diffusive length (m)	porous medium	Tortuosity
Cell 1	0.02	SAND	0.10
Cell 2	0.02	CLAY	0.15

The diffusive area is 20 m² and the diffusivity for all species in water is 1e-3 m²/yr. Note that when inaccessible porosity is specified, it has two impacts: 1) it modifies the effective volume of fluids (as discussed in CT_Cells1-07); and 2) it modifies the diffusive conductance for the connection as follows:

$$D_{cs} = \frac{A_c}{\frac{L_{ci}}{d_{ms} \cdot t_{Pci} \cdot n_{Pci} \cdot f_{Pcis}} + \frac{L_{cj}}{d_{ns} \cdot t_{Pcj} \cdot n_{Pcj} \cdot f_{Pcjs} \cdot K_{nms}}}$$

where:

$$A_c = \text{the area of diffusive connection } c \text{ [m}^2\text{];}$$

- L_{ci} = diffusive length for connection c in cell i [m];
 L_{cj} = diffusive length for connection c in cell j [m];
 d_{ms} = diffusivity for species s for fluid m (in cell i) [m²/yr];
 d_{ns} = diffusivity for species s for the fluid n (in cell j) [m²/yr];
 tp_{ci} = tortuosity for the porous medium defined for connection c in cell i (≤ 1);
 tp_{cj} = tortuosity for the porous medium defined for connection c in cell j (≤ 1);
 fp_{cis} = fraction of available porosity for species s for the porous medium defined for connection c in cell i (≤ 1);
 fp_{cjs} = fraction of available porosity for species s for the porous medium defined for connection c in cell j (≤ 1);
 np_{ci} = porosity for the porous medium defined for connection c in cell i ;
 np_{cj} = porosity for the porous medium defined for connection c in cell j ; and
 K_{nms} = partition coefficient between fluid medium n (in cell j) and fluid medium m (in cell i) for species s [m³ medium m / m³ medium n].

In this problem, the accessible porosity in each solid is defined as a variable, taking on the following values:

	f_{clay}	f_{sand}
Cell 1	.5	.9
Cell 2	.3	.7

This results in a linear system of equations (similar to those presented in CT_Cells3-01). The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.44	8.61E-1	4.20E+1
time = 1000	1.61	5.68E-1	2.77E+1
time = 10,000	1.45	5.11E-1	2.49E+1

Cell 2

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.63E-1	9.27E-2	4.52
time = 1000	1.25	4.42E-1	2.15E+1
time = 10,000	1.45	5.11E-1	2.49E+1

CT_Cells3-17 – Unsaturated Diffusion

This test is designed to test unsaturated diffusion between cells. The test contains two Cell elements. In Cell1 the Aq species has a concentration of 1 in water and 0 in air. The Air species has a concentration of 1e-6 in water and 1 in air.

The amounts of the two fluids vary with time; initially Aq is 90% saturated and Air is 10%, until time > 50s, when Aq is 10% saturated and Air is 90%.

The porous medium has a porosity of 0.3, so for a 100% saturated fluid the diffusive flux would be 0.3 g/sec.

The verifier should confirm that the Aq species, diffusing through the water medium, initially diffuses at a rate of 90% * 0.3 g/sec = 0.27 g/sec, and subsequently at 10% * 1 g/sec = 0.03 g/sec. The Air species, diffusing through the air medium, should have the opposite pattern. This result can be confirmed by ensuring that the Fluxes plot corresponds with the plot in Figure CT_Cells3-17a below.

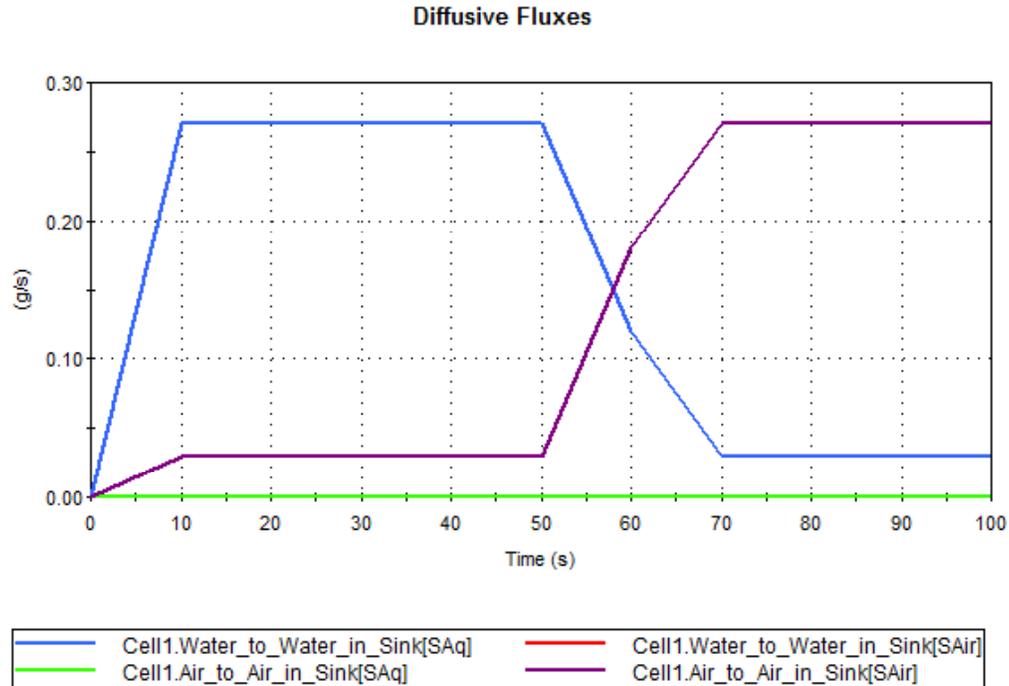


Figure CT_Cells3-17a

CT_Cells4 – Decay Calculations in Cells

These test problems are specifically targeted at verifying the radioactive decay algorithms in RIP. All problems in this group are run with radioactive decay. A 100 yr timestep is used for all problems unless otherwise specified

CT_Cells4-01: Radioactive Decay in a Cell

In this problem, the decay chain starting with Am-241 is examined. The problem is simply looking at decay over the first 1,000 yr. Am-241 decays to Np-237. To test split decay, two daughters are specified for Np-237, each receiving 50% of the mass. U-233a and U-233b each have identical properties. The analytical solutions for Am-241, Np-237 and U-233 are as follows (note that decay in the containers is a function of the timestep, with smaller timesteps producing more accurate results. A 2 year timestep is used in this case to exactly reproduce the analytical solution:

$$M(\text{Am-241}) = M_0(\text{Am-241}) e^{-k_1 t}$$

$$M(\text{Np-237}) = \frac{M_0(\text{Am-241}) \frac{AW(\text{Np-237})}{AW(\text{Am-241})} k_1 A_2}{(k_2 - k_1) A_1} [e^{-k_1 t} - e^{-k_2 t}]$$

$$M(\text{U-233}) = \frac{A_3 k_1 k_2 M_0(\text{Am-241}) \frac{AW(\text{U-233})}{AW(\text{Am-241})}}{A_1} \times$$

$$\left[\frac{e^{-k_1 t}}{(k_2 - k_1)(k_3 - k_1)} + \frac{e^{-k_2 t}}{(k_1 - k_2)(k_3 - k_2)} + \frac{e^{-k_3 t}}{(k_1 - k_3)(k_2 - k_3)} \right]$$

where:

- k_1 = decay rate for Am-241 = $1.603\text{E-}03 \text{ yr}^{-1}$,
- k_2 = decay rate for Np-237 = $3.238\text{E-}07 \text{ yr}^{-1}$,
- k_3 = decay rate for U-233a and b = $4.372\text{E-}06 \text{ yr}^{-1}$,
- $M_0(\text{Am-241})$ = Curies of Am-241 at TIME 0 = 10,000,
- AW = atomic weight (amu), taken as 241, 237 and 233 respectively,
- A_1 = specific activity of Am-241 = 3.44 Ci/g,
- A_2 = specific activity of Np-237 = $7.06\text{E-}04 \text{ Ci/g}$, and
- A_3 = specific activity of U-233 = $9.69\text{E-}03 \text{ Ci/g}$.

Using $t = 1,000 \text{ yr}$ and the above constants, the results are 2,013 Ci for Am-241, 1.613 Ci for Np-237, and $4.423\text{E-}03 \text{ Ci}$ for U-233. Since the U-233 portion is split evenly between two daughters, U-233a and U-233b each receive $2.2116\text{E-}3 \text{ Ci}$.

CT_Cells4-02: Radioactive Decay in a Cell with Solubility Limit

This problem is identical to T9P5, but a solubility constraint is imposed such that initially the cell is saturated. After some decay has taken place, it drops below the solubility limit.

Am-241 is given a solubility limit of $1,000 \text{ g/m}^3$ in water. The concentration of Am-241 in the cell is in excess of this limit until sometime between 600 and 700 years.

CT_Cells4-03: Competing Decay Rates

In this problem, species A decays to species B, and species B decays to species A. This simulates an equilibrium between two species. The magnitude of the decay rates determines the ratio of species present in the cell. The stoichiometry of the reaction is that $A \rightleftharpoons B$.

To solve for the actual concentration of each species over time, the following equations can be used:

$$m_A(t) = -k_f * m_A(t) + k_r * (A_{WA}/A_{WB}) * m_B(t)$$

$$m_B(t) = -k_r * m_B(t) + k_f * (A_{WB}/A_{WA}) * m_A(t)$$

where:

- k_f = the forward reaction rate = 0.001 (1/yr);
- k_r = the reverse reaction rate = 0.0005 (1/yr);
- A_{WA} = the atomic weight of species A = 200 (g/mole);
- A_{WB} = the atomic weight of species B = 200 (g/mole);
- $m_A(0)$ = the initial mass of species A = 0 (g);
- $m_B(0)$ = the initial mass of species B = 400 (g).

The resulting masses should be:

Time, yr	A	B
100	18.6	381.4
1,000	103.6	296.4
10,000	133.3	266.7

CT_Cells4-04: Stoichiometry

In this problem, species A decays to species B. The stoichiometry of the reaction is that $A \Leftrightarrow 2B$. There are initially 400g of A in the cell, with a decay rate of 0.001/yr.

To solve for the actual concentration of each species over time, the following equations can be used:

$$m_A(t) = m_A(0) \exp(-k_f * t)$$

$$m_B(t) = m_B(0) + (b/a) * m_A(0) * (1 - \exp(-k_f * t))$$

The resulting masses should be:

Time, yr	A	B
100	361.9	76.1
1,000	147.2	505.7

10,000	0.0182	800
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CT_Cells4-05: Time-varying Decay Rate

In this problem, species A decays to species B. The decay rate is specified as a function of both time and local environment, as follows:

$$\text{Decay} = \text{IF}(\text{Time} < 500, \text{Var}, 0)$$

The cell environments are specified as follows:

Environment	Var	Cell Used
ENVT1	0.01	Cell 2
ENVT2	0.001	Cell 3
NONE (default)	0	Cell 1

An initial mass of 1 gram is defined in each of the three cells and each cell has a volume of 1 m³. To solve for the actual concentration of each species over time, the following equations can be used:

$$m_A(t) = m_A(0) \exp(-k_f * t)$$

\Default\Cell1:

There is no decay in Cell1.

\ENVT1\Cell2:

$$m(100) = 1 * e^{-0.01 * 100} = 3.68E-1 \text{ g}$$

$$m(500) = 1 * e^{-0.01 * 500} = 6.74E-3 \text{ g}$$

$$m(1000) = m(500)$$

\ENVT2\Cell3:

$$m(100) = 1 * e^{-0.001 * 100} = 9.05E-1 \text{ g}$$

$$m(500) = 1 * e^{-0.001 * 500} = 6.07E-1 \text{ g}$$

$$m(1000) = m(500)$$

CT_Cells4-06: Time-varying Decay Rates, Stoichiometry, Four Daughters

In this problem, species A1 decays to species A2, A3, A4 and A5. The decay of A1 does not start until time 10 seconds, and ceases at 70 seconds. During the decay period, the stoichiometry is varied so that A2 is the daughter during 10 – 20 seconds, A3 is the daughter during 30 – 40 seconds, and so on. Starting at 70 seconds, all of the daughters decay rapidly back into A1.

In the array-view result elements the final concentration values should be negligible for all but species A1. The values should be: Water total concentration 2 g/l, dissolved concentration 1 g/l. Non-suspended solid concentration 8 g/kg, suspended-solid concentration 1 g/kg, and PrecipMass 0.7g

The time histories should show A1 decaying starting at 10 seconds, with the daughter product switching successively through the other species. Starting at 70 seconds, all of the daughters should decay back into A1.

CT_Cells5 - Time Variable Partitioning and Mass Transfer

In these problems, parameters controlling partitioning and mass transfer are time variable.

CT_Cells5-01 - Time Variable Partitioning Between Media in a Cell

This problem is identical to CT_Cells1-01, but at 5000 years, the partition coefficients change as follows:

Medium	Partition Coefficient relative to WATER (m^3/m^3) for fluids; (m^3/kg) for solids
WATER	1
OIL	0.2
SAND	0.4
CLAY	10

The resulting concentrations, before and after the change, are as follows:

Medium	Am-241 (g/m ³) or (g/kg)	Am-242 (g/m ³) or (g/kg)	Am-243 (g/m ³) or (g/kg)
WATER			
time = 4,900	2.59E-1	9.13E-2	4.45
time = 5,100	1.35E-1	4.78E-2	2.33
OIL			
time = 4,900	2.59E-2	9.13E-3	4.45E-1
time = 5,100	2.71E-2	9.56E-3	4.66E-1
SAND			
time = 4,900	5.17E-2	1.83E-2	8.90E-1
time = 5,100	5.41E-2	1.91E-2	9.32E-1
CLAY			
time = 4,900	1.29	4.57E-1	2.23E+1
time = 5,100	1.35	4.78E-1	2.33E+1

CT_Cells5-02 - Time Variable Advection

This problem is identical to CT_Cells3-01, but at 5000 years, the flow rate is reduced from 0.1 m³/yr to 0.01 m³/yr.

The concentration in WATER in Cell 1 over time is shown in the following table. Note that a lower precision than normal is acceptable for the small final values at time 10,000:

Medium	Am-241 (g/m ³)	Am-242 (g/m ³)	Am-243 (g/m ³)
WATER			
time = 100	2.37E-1	8.35E-2	4.07
time = 1000	1.06E-1	3.75E-2	1.83
time = 10,000	1.95E-3	6.87E-4	3.35E-2

CT_Cells5-03 - Time Variable Diffusion

This problem is identical to T6P3-1, but at 5000 years, the diffusive lengths, area, tortuosities and porosities change as follows:

	transport medium	diffusive length (m)	tortuosity	porosity
Connection 1	WATER			
Cell 1		0.01	0.2 (SAND)	0.6 (SAND)
Cell 2		0.01	0.3 (CLAY)	0.8 (CLAY)

The diffusive area changes to 10 m². The diffusivity changes from 1E-3 m²/yr to 2E-3 m²/yr.

The resulting concentrations are as follows:

Cell 1

Medium	Am-241 (g/m³)	Am-242 (g/m³)	Am-243 (g/m³)
WATER			
time = 100	2.54E-1	8.97E-2	4.37
time = 1000	2.20E-1	7.76E-2	3.79
time = 6,000	1.31E-1	4.61E-2	2.25

Sink

Medium	Am-241 (g/m³)	Am-242 (g/m³)	Am-243 (g/m³)
WATER			
time = 100	4.52E-3	1.59E-3	7.77E-2
time = 1000	3.87E-2	1.37E-2	6.66E-1
time = 6,000	1.28E-1	4.52E-2	2.20

Precision and Algorithm tests: Rerun CT_Cells5-03 specifically testing the medium and low accuracy options as selected in the Model/Options dialog. Confirm that the results are equivalent.

CT_Cells5-03 – Changing Volume

This test verifies that when the volume of water changes at a time step, the Cell uses an effective amount equal to 3/8 of the previous amount plus 5/8 of the new amount.

The initial outflow rate from Cell1 of 1e-6 m³/s should give a fraction released of 1e-6 per timestep, or approximately 1g per timestep.

At 10s the Cell1's volume changes from 1 to 2 m³, so the weighted average is 13/8 m³. The fraction released for that time step should be $8/13 = 0.615 \text{ e-6}$, or 0.615g released.

From then up to 19s the fraction released should be 0.5e-6 or 0.5 g per step.

At 20s Cell1's volume changes from 2 m³ to 1 m³, so the weighted average is 11/8 m³. The fraction released for that time step should be $8/11 = 0.727 \text{ e-6}$, or 0.727g released.

The tester should run the model and confirm that the flux rates match these values, which are summarized in Table CT_Cells5-04-1 below.

Time/Time Range	Expected Release
0-9s	1g
10s	0.615g
11s-19s	0.5g
20s	0.727g
21s-100s	1g

Table CT_Cells5-04-1

CT_Cells6 – Pseudo-Reference Fluids and Multiple Cell Nets

In these problems, GoldSim's capability to apply multiple solubilities within a given cell network and to diffuse mass among multiple cell networks is verified.

CT_Cells6-01 – Pseudo-Reference Fluids

This problem verifies that pseudo-reference fluids function properly within GoldSim's Cell Pathways. The problem consists of three Cells connected by diffusive pathways and each having a different reference fluid. Two species, A and B, exist initially in Cell1. The solubility limit for each species is different in each cell. The following tables summarizes the problem setup and initial conditions:

Cell	Reference Fluid	Volume (m ³)	Diffusive connections to:
Cell1	Sol_1_50 (pseudo)	1.0	Cell2
Cell2	Sol_10_50	1.0	Cell1, Cell3
Cell3	Sol_10_100 (pseudo)	1.0	Cell2

Species	Solubility Limit in Cell (mg/l):			Original Amount and Location
	Cell1	Cell2	Cell3	
A	1	10	10	100g in Cell1
B	50	50	100	100g in Cell1

This test uses 'pseudo-reference fluids' to define variable solubility within a single cell network.

Species A has sufficient mass to reach the solubility limits of 1, 10, 10 g/m³ in the three cells. The remaining 79g should stay as precipitate in Cell1.

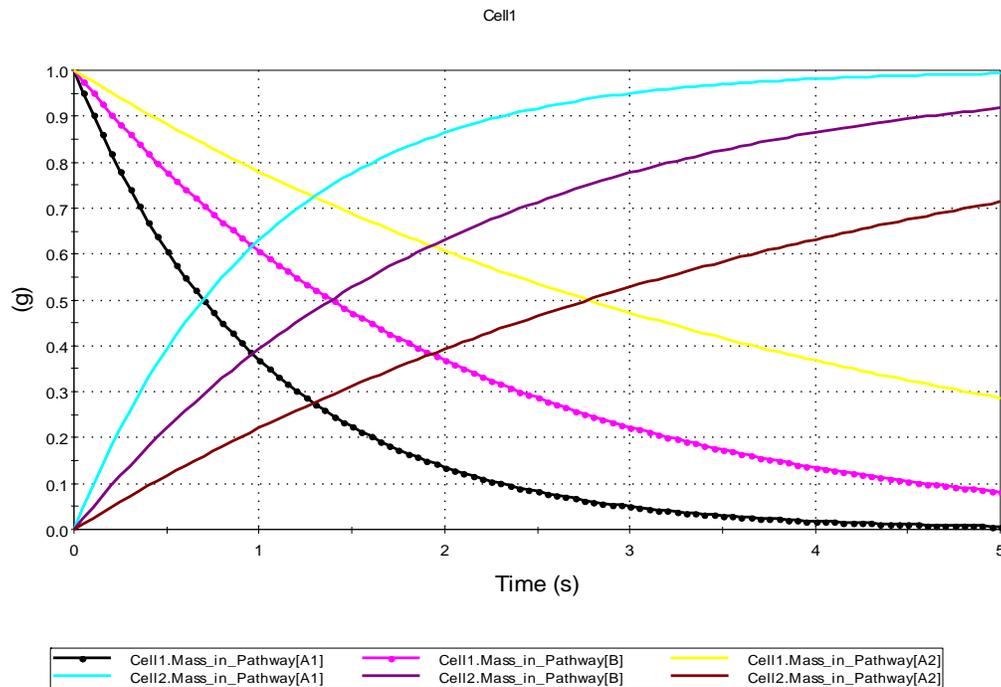
Species B has only enough mass to reach half of the solubility limits in the cells: 25, 25, and 50 g/m³ respectively.

Check that when the model is run, the dissolved concentrations and precipitate mass converge to the correct values.

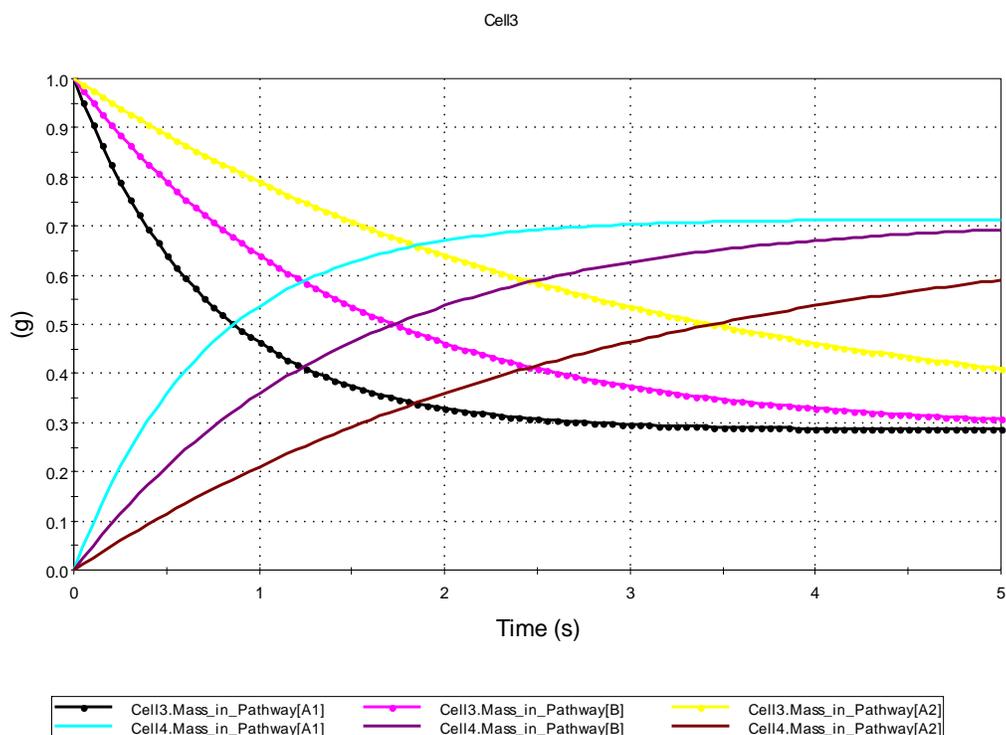
CT_Cells7-01 – Cell Outflows using Direct Transfer Rates

In this problem two pairs of Cells are linked using direct transfer rate flux links. There are three species, and simulations are run in two ways: once using distinct species, and once having the first and third species act as isotopes.

For the distinct species case, the transfer of mass between Cell1 and Cell2 should be exponentially-decaying, with the transfer rates being 1 sec⁻¹, 0.5 sec⁻¹, and 0.25 sec⁻¹ for each species:



The transfer between Cell3 and Cell4 is two-way, so while these Cells initially behave identically as the amount of mass in Cell4 builds up the system approaches equilibrium. Nearing equilibrium the mass in Cell3 should approach 0.29g, and Cell4 should approach 0.71g:



CT_Cells7-02 – Cell Outflows using Precipitate and Filter Transfer Rates

In this test problem Container FilterTest contains a small model that tests the capabilities of the 'Fraction of inflows' filter-type flux link, and Container PrecipTest contains a small model that tests the capabilities of the 'Precipitate transfer' flux link.

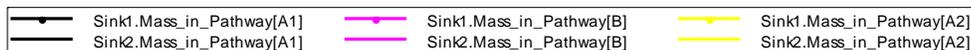
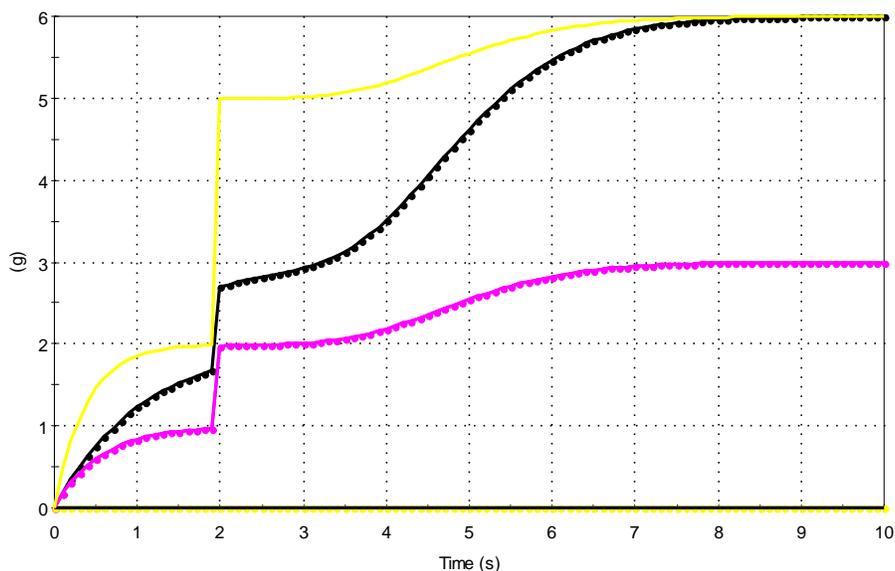
Run the model, and then compare the results in each Container to those shown in the model (and below). The results should be as follows.

FilterTest:

The total amount of mass added to Sink1 is 6g of each species. Of this, 0% of A1, 50% of B, and 100% of A2 should be intercepted and sent to Cell Sink2. Check the total masses in Sink1 and Sink2 at the end of the simulation to confirm this.

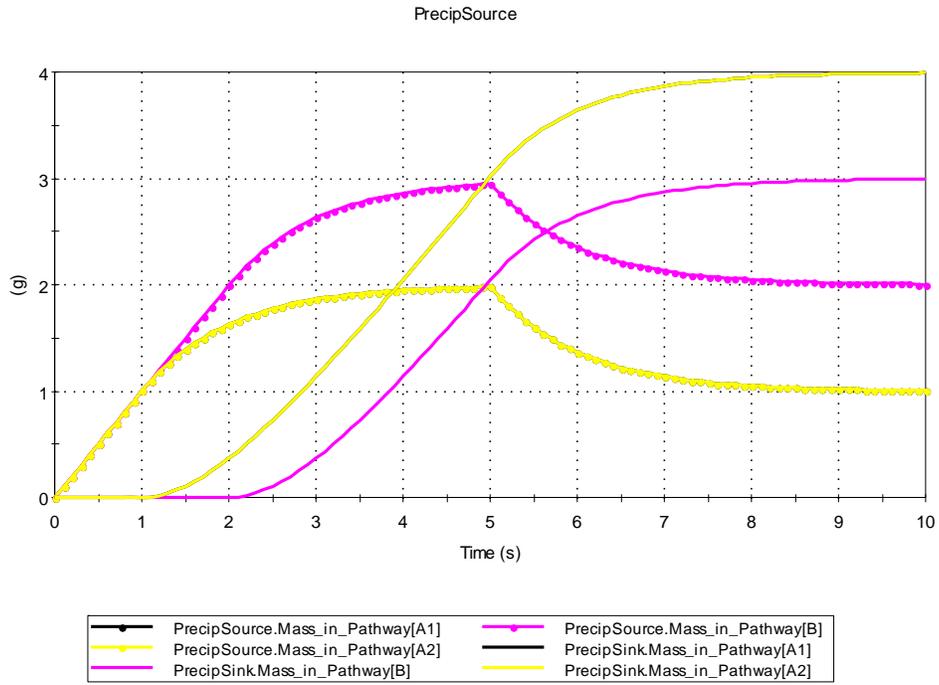
The time-history record should look like this:

Total Masses in Cell Elements

PrecipTest:

Species A1 & A2 reach their solubility limit at 1s, and their precipitate is gradually moved to PrecipSink. Species B reaches its limit at 2s. After the external input stops at 5s, the remaining excess precipitate should be flushed into PrecipSink. At the end, PrecipSource should contain 1g, 2g, 1g of the species (A1, B, A2). PrecipSink should contain 4g, 3g, 4g.

The time-history record should look like this:



4.3 EXTERNAL PATHWAY TESTS

CT_ExtPath-01

This test uses a simple external pathway function XF002 inside the test dll file cfstubs.dll. It has a single input and output. Two species are input using the cumulative input field, with species A being constant at 3 g/day, and species B being 3 g/day from 6 to 10 days, and 0 at all other times.

In order to test the ability of the external pathway to return an error message, set the Multiplier input from its normal value of 3 to a value of 0, and run the model. You should see an error message indicating that the multiplier is not positive.

Repeat both tests with the external pathway element set to run as a separate process.

Repeat the complete test with 64-bit versions of the test file and DLL (CT_ExtPath-0164.gsm and cfstubs64.dll).

CT_ExPath-02

This test uses the same external pathway, but with two input and two output connections from low-volume cells. One cell loads at the same rate as the cumulative input in CT_ExtPath-01, the other loads at twice the rate.

The external function merges all inputs, and triples them. Thus each output should have three times the input concentrations, which average 1.5, so the output concentrations are 4.5.

Repeat the complete test with 64-bit versions of the test file and DLL (CT_ExtPath-0264.gsm and cfstubs64.dll).

CT_ExtPath-03

This is the same as CT_ExtPath-02, but the inputs are combined and the outputs are split. The external element splits the outputs in proportion to their flow rates. The resulting mass-fluxes should be 3 for the first output, and 6 for the second.

Repeat the complete test with 64-bit versions of the test file and DLL (CT_ExtPath-0364.gsm and cfstubs64.dll).

4.4 NETWORK PATHWAY TESTS

CT_Net-01

This test replicates CT_Pipes-01 using three different series combinations of network-pipes to substitute for the original pipe elements. All three networks should give the same result (Ogata and Banks) as CT_Pipes-01.

CT_Net-02

This test replicates CT_Pipes-01 using three different combinations of network-pipes to substitute for the original pipe elements.

It is similar to CT_Net-01, but tests different combinations of merging inputs and splitting outputs. The three networks do the following:

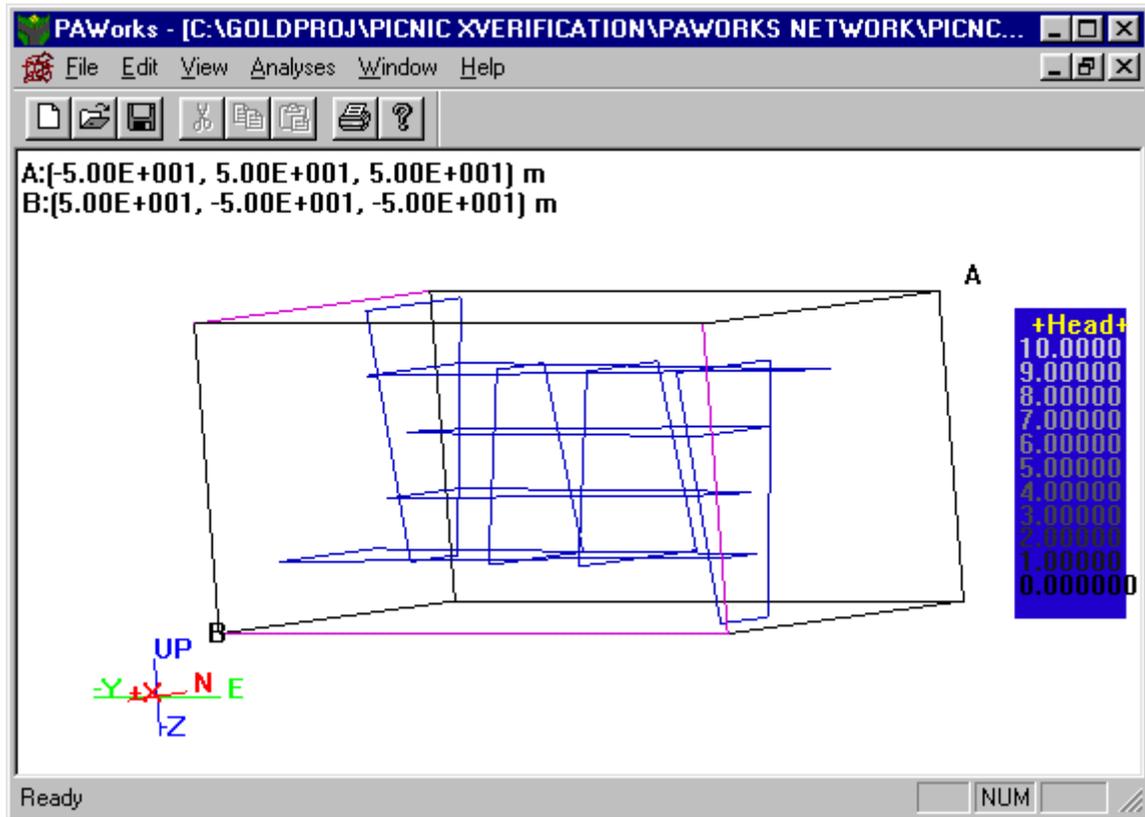
- The first network has a set of three short pipes in series, in parallel with a single full-length pipe.
- The second network has three pipes in parallel, each with the properties from Pipe_40m_Retarded in CT_Pipes-01.
- The third network has five pipes, with two converging into a single pipe which splits into two more. The effective properties of each segment are equivalent to the original pipe in CT_Pipes-01, so again the resulting concentration history should be the same.

CT_Net-03: Fracture Network with Diffusion into Immobile Zones

Formerly RIP verification test T8P7-1, this test problem is designed to verify the fracture network pathway. No analytic solutions to complex fracture systems are available; therefore the GoldSim results are verified against the results of an independent code developed by Barten and Robinson (1996) of the Swiss Paul Scherrer Institute (PSI), called PICNIC (Barten. (1996b).

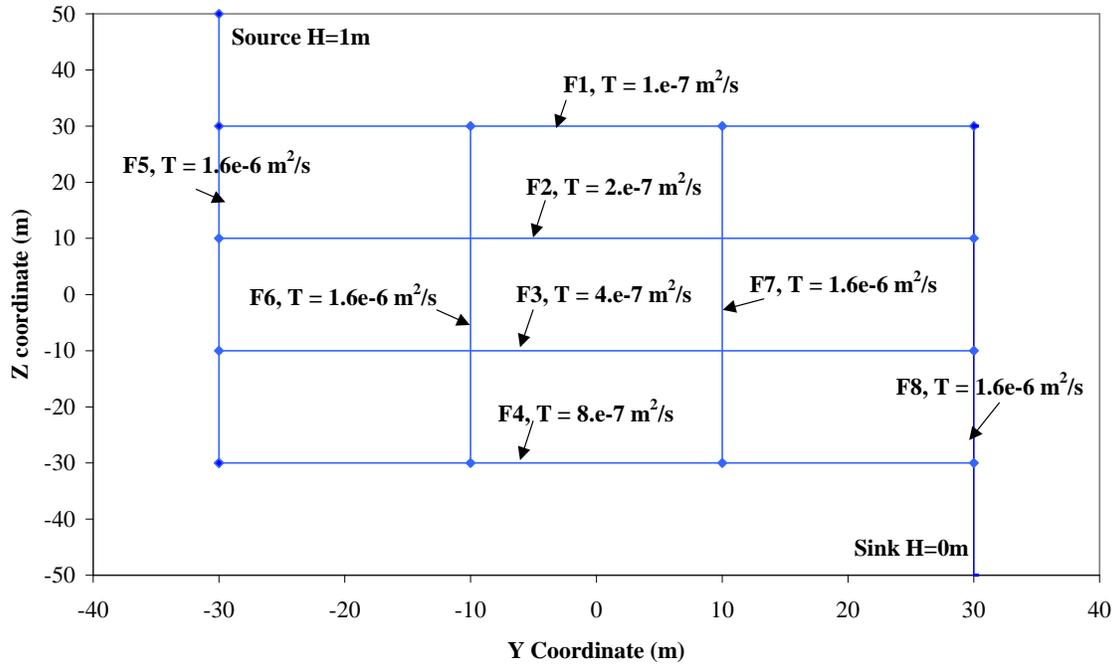
This “grid” network simulation uses a 3x3 fracture network, with differing immobile zone properties attached to each of the fractures. The fracture network is shown below. The fractures vary in width along their length, so that every pipe has a different flow wetted surface. The boundary conditions, transmissivities (T), and fracture numbers (F) are shown in the following figures.

Fracture Network for the 3x3 "Grid" Cross Verification Tests

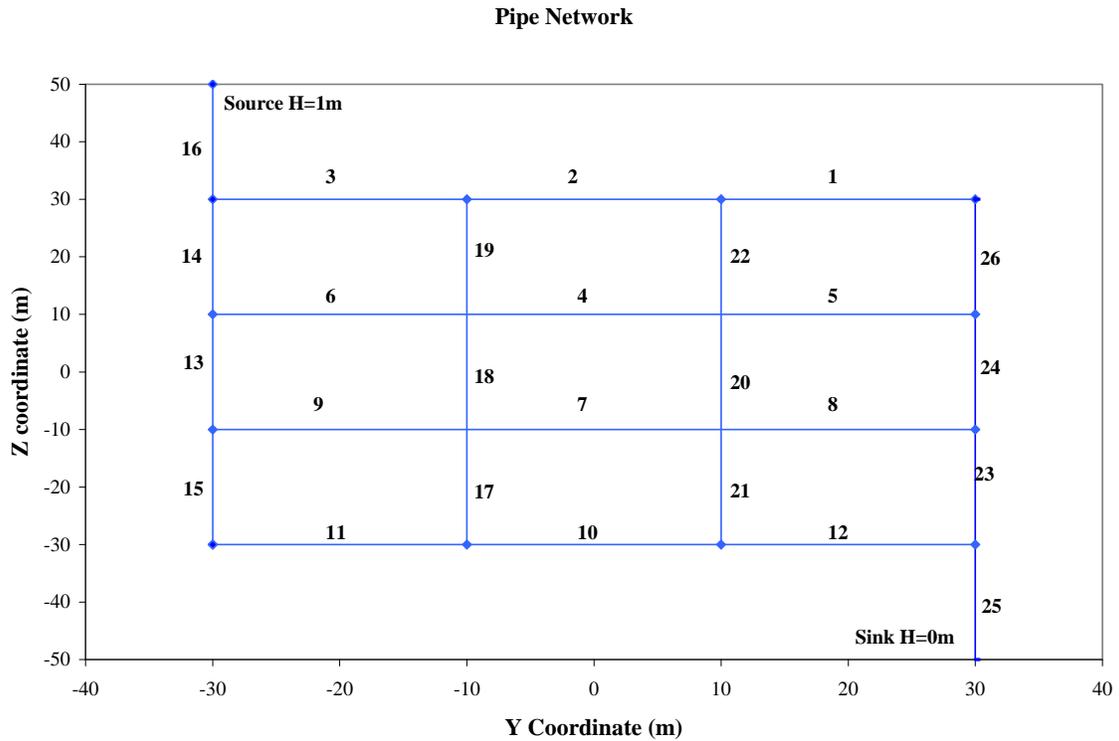


Fracture Properties and Boundaries for “Grid” Cross Verification Test

Pipe Network



Pipe Numbers for “Grid” Cross Verification Test



The aperture (a) of each pipe is related to the fracture transmissivity through the relationship:

$$a = 2T^{0.5}$$

Flow in all pipes is downward and to the right. The velocity and flow area for each of the 26 pipes is given in the following table. The dispersion length (α) is equal to 1.0m and the free water diffusion coefficient (D_0) is equal to $10^{-9} \text{ m}^2/\text{s}$.

Pipe Properties for Test Case PNG1

Pipe	Velocity (m/yr)	Area (m ²)
1	84.93	0.00965
2	68.83	0.01278
3	74.93	0.01746
4	97.07	0.01789
5	120.65	0.02366
6	98.84	0.01212
7	136.33	0.02530
8	175.28	0.01714
9	127.54	0.03058
10	191.41	0.03818
11	172.17	0.04047
12	266.92	0.02508
13	76.66	0.14176
14	66.73	0.18080
15	38.40	0.18144
16	44.79	0.29856
17	1.76	0.19288
18	0.69	0.16000
19	2.88	0.14840
20	6.61	0.16000
21	4.44	0.13784
22	0.35	0.17328
23	80.73	0.08272
24	22.96	0.16000
25	109.25	0.12240
26	5.11	0.16032

In this simulation, two immobile zones are defined. The first immobile zone is attached to fractures 1, 2, 3, 6 and 7 (see above figure for fracture numbering) and is identical to that used in the preceding example.

The second immobile zone is attached to fractures 4, 5 and 8. The porosity of this zone is 0.001, the tortuosity is 1.0, the maximum diffusion distance is 1.0m, and the rock density is 2500 kg/m³. The immobile zone properties for all fractures are given below (note that for this non-decaying example, only the retardation for species 1 is used).

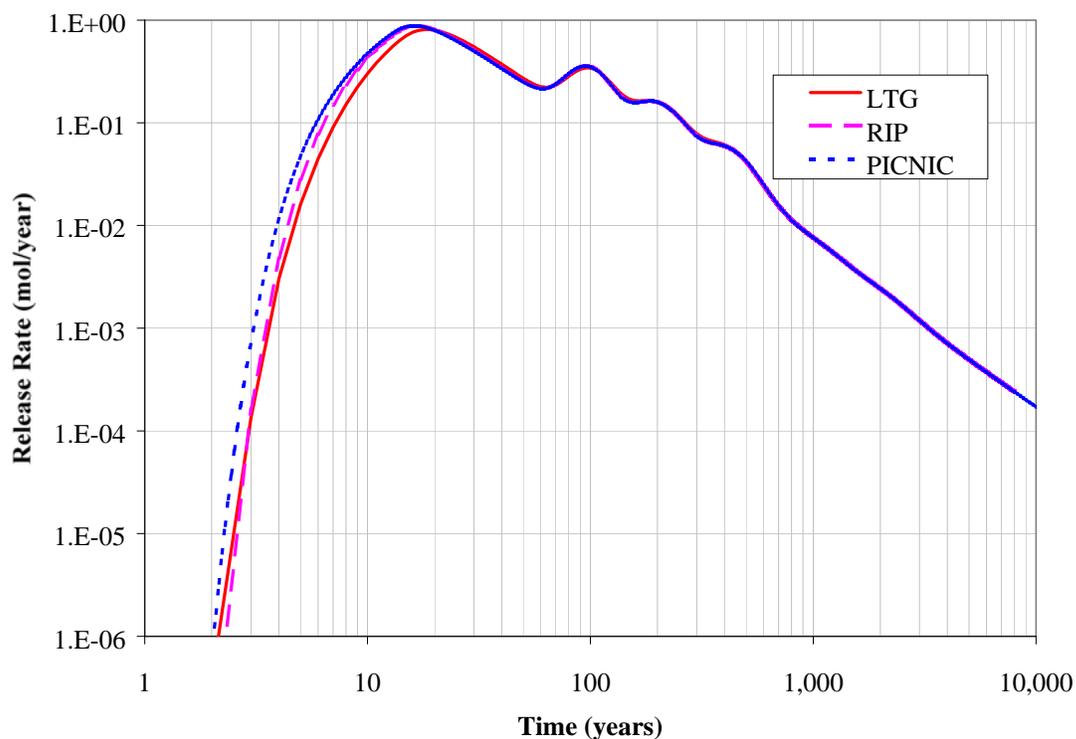
Immobile Zone Properties

Pipe (-)	Porosity (-)	Perimeter (m)	Max. Diff. Dist. (m)	Tort. (-)	Retardation (-)
1	0.1	30.5	0.05	1	26
2	0.1	40.42	0.05	1	26
3	0.1	55.2	0.05	1	26
4	0.1	40	0.05	1	26
5	0.1	52.9	0.05	1	26
6	0.1	27.1	0.05	1	26
7	0.1	40	0.05	1	26
8	0.1	27.1	0.05	1	26
9	0.1	48.34	0.05	1	26
10	0.001	42.68	1	1	2501
11	0.001	45.24	1	1	2501
12	0.001	28.04	1	1	2501
13	0.001	35.44	1	1	2501
14	0.001	45.2	1	1	2501
15	0.001	45.36	1	1	2501
16	0.001	74.64	1	1	2501
17	0.1	48.22	0.05	1	26
18	0.1	40	0.05	1	26
19	0.1	37.1	0.05	1	26
20	0.1	40	0.05	1	26
21	0.1	34.46	0.05	1	26
22	0.1	43.32	0.05	1	26
23	0.001	20.68	1	1	2501
24	0.001	40	1	1	2501
25	0.001	30.6	1	1	2501
26	0.001	40.08	1	1	2501

The input boundary condition is a Cauchy release (flux rate) equal to 10 moles per year for 10 years, falling to zero for the rest of the simulation.

The resulting downstream release with time for PICNIC is shown graphically in the following figure and table. The time history for total mass discharged (combined over all species, output "Totalflux") in the GoldSim model should essentially match these results.

PICNIC Results for Cross Verification Case PNG3



PICNIC Results for Case PNG3

Time (years)	PICNIC (mol/yr)
10	4.71E-01
45	2.88E-01
100	3.52E-01
450	5.22E-02
1,000	7.63E-03
4,500	5.86E-04

CT_Net-04: Network Watch Groups

This test case is based on CT_Net-03. Element Net3 has two watch groups that use the second (fracture-set property) method of defining Watch Groups. The second of these watches Set_4's output, which should match that of the overall network. Compare the first two outputs in element Compare to verify this, by ensuring that the two histories are identical.

The first Watch Group in Net2, defined using Method 1 (in the pipe table) should match the first Watch Group in Net3, which uses Method 2. This represents a set of internal pipes that contribute to the total discharge. Compare the outputs 3 and 4 in element Compare to verify that they are identical, and that their outputs are smaller than and initially arrive later than those of the first two outputs.

CT_Net-05: Multiple Network Watch Groups

This test case is also based on CT_Net-03. Element Net3 has multiple watch groups that are specified within a .ltx file. Edit the network table and import file CT_Net-05.ltx.

The test compares three different calculations of the total discharge from the last pipe (Pipe 25). One of these is the actual network pathway discharge, and the other two are separate watch groups both associated with Pipe 25.

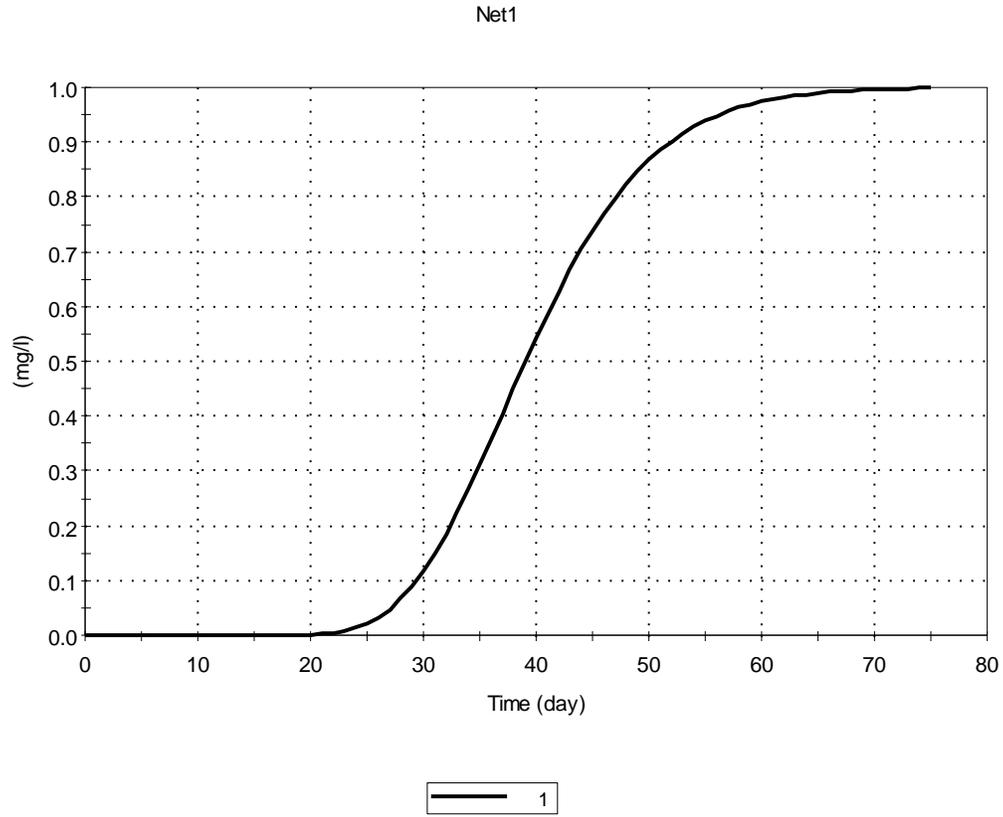
1. Edit the fracture network table in element Net1. Delete several pipes randomly. Then import file CT_Net-05.ltx.
2. Run the model.
3. Display the history table in element WatchGroups. Confirm that all three results are identical. The results should match those in the table image shown on-screen.

Time (yr)	Net1.Water_to_BG2[Am241] [g/yr]	Net1.Watch25[Am241] [g/yr]	Net1.Watch99[Am241] [g/yr]
0	0	0	0
10	0.3302	0.3302	0.3302
45	0.2037	0.2037	0.2037
100	0.1383	0.1383	0.1383
1000	3.857e-07	3.857e-07	3.857e-07
4500	0	0	0

CT_Net-06: Local Property “Length” in Dispersivity Input Field

This test case is based on a simple pipe subdivided into three segments.

Run the model twice, using two values for the dispersivity in the fracture set element: “1m” and “1m + ~Length * 025”. Confirm that the results for the 1m value match those shown below. Confirm that the results for the higher dispersivity show significantly increased dispersion.



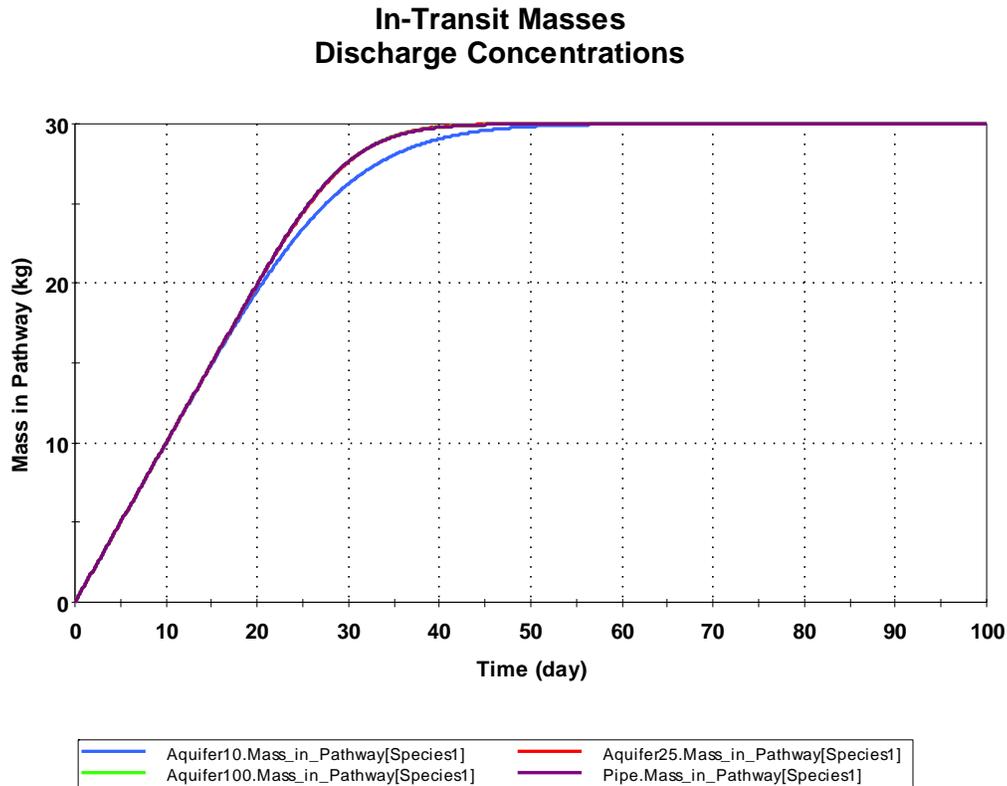
Time (day)	Net1.Concentration[A1] [mg/l]
18	0.00017
19	0.0004483
20	0.001052
21	0.002233
22	0.004351
23	0.007865
24	0.01332
25	0.02131
26	0.03242
27	0.04718
28	0.06601
29	0.08916
30	0.1167
31	0.1486
32	0.1844
33	0.2238
34	0.2661
35	0.3107
36	0.3569
37	0.4039
38	0.451

39	0.4975
40	0.5428

4.5 AQUIFER PATHWAY TESTS

CT_Aquifer_01 Dispersion Tests

In this test an aquifer with a length of 100 m and dispersivity of 2 m is simulated using Aquifer element with 100 cells, 25 cells, and 10 cells. In addition to the Aquifer elements, this model sets up a Pipe element with the same flow properties to use as an analytical verification. The tester should run the model and zoom in on the Mass_Concs and Outfluxes graphs to confirm that the three aquifer elements give similar results to the Pipe element, with the results of the aquifer of 100 cells most closely aligning with the Pipe's results. In addition, the tester should enter the Mass_Balance_Verification container and confirm that the elements Percent_Error10, Percent_Error25, and Percent_Error100 all have very small absolute values ($<1e-6\%$). These elements confirm that the integral of mass loading into the aquifers equals the integral of outflux from the aquifer plus the mass stored in the aquifer.



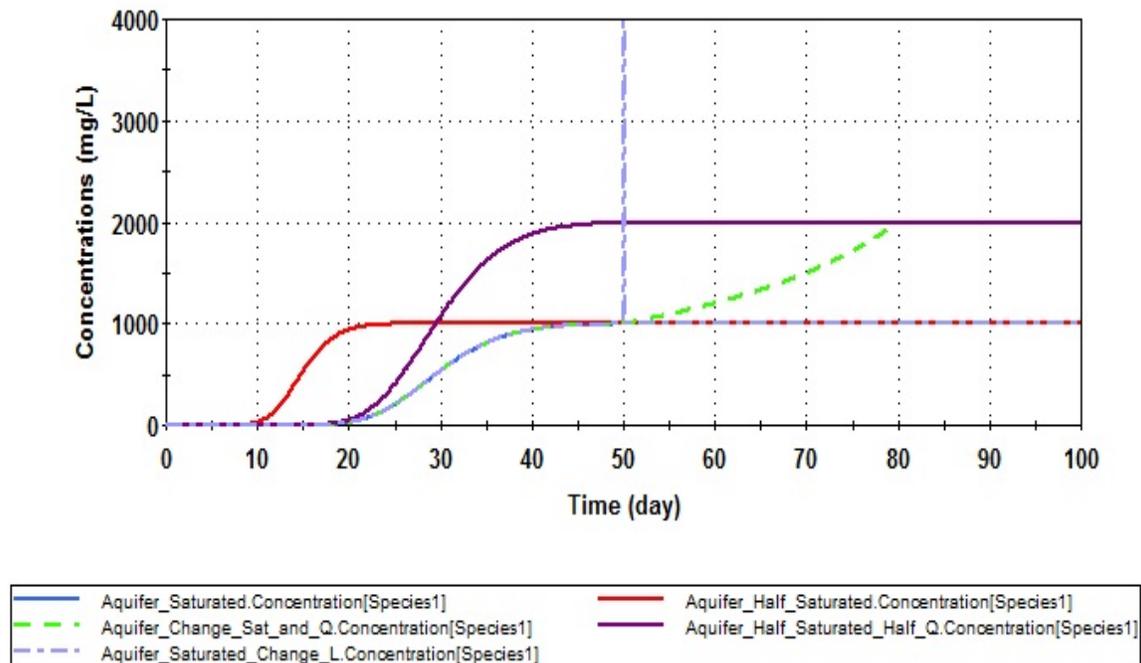
CT_Aquifer_02 ChangingProperties

This test qualitatively examines the effect of saturation, flow rate, and aquifer length on breakthrough curves, including a test of length, flow rates and saturation that change during the simulation. All other aquifer properties are held constant.

The tester should run the model and confirm the graphs (Mass_Concs and Outfluxes) match the images of graphs pasted beside them. The tester should also enter the Mass_Balance_Verification container and confirm the element Maximum_Continuity_Pcent_Error is a very small percentage ($<1e-6\%$).

In the Mass_Concs graph, the blue line, the fully saturated aquifer with an outflow rate of 1 m³/day, should reach its steady state breakthrough concentration at about 45 to 50 days. The half saturated aquifer with the same flow rate (red line) should come to steady state at about 22 to 25 days (half the time). The purple line on the graph, i.e. the aquifer with half saturation and a flow rate of 0.5 m³/day, i.e., should have a breakthrough at the same time as the saturated aquifer but the breakthrough concentration should be twice as high. The aquifer with a changing flow rate and saturation level (green line) should have the same concentration output as the saturated aquifer for the first ~50 days, as it is also fully saturated with a flow rate of 1 m³/day during this period. Between 50 and 80 days, the aquifer with changing saturation and flows rates changes these parameters linearly from 1 and 1 m³/day, respectively, to 0.5 and 0.5 m³/day, respectively. By 80 days, the aquifer with changing flow rate and saturation level (green line) should have the same outflow concentration as the purple line, i.e. the aquifer with saturation and flow rates of 0.5 and 0.5 m³/day, respectively. The violet line on the graph is an aquifer that is the same as the saturated aquifer (blue line), except that the length changes from 100 to 99 m at 50 days. The tester should verify a spike in concentration and mass loading occurs in the violet line at day 50 when the length changes.

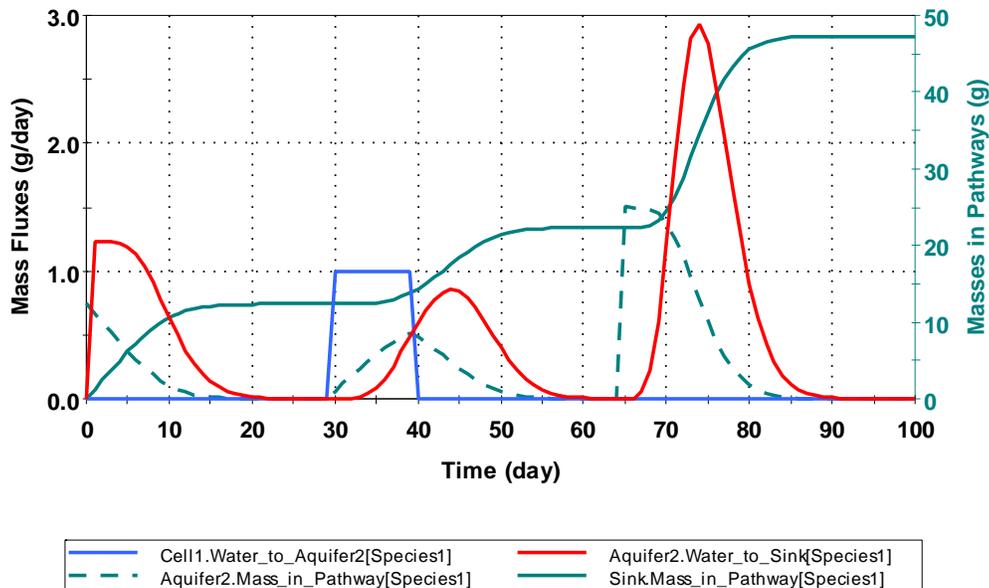
Mass_Concs graph from CT_Aquifer_02_ChangingProperties



CT_Aquifer_03 Changing Boundary Conditions

This file tests the aquifer element under changing boundary conditions. It tests specification of different boundary conditions, changing inflow concentrations, discrete changes. The tester should run the model and compare the graphs to the graph images in the model and shown below. In addition the tester should verify that the final mass in the first sink is 47.34 g and 15 g in the other sinks.

Masses and fluxes graph from CT_Aquifer_03 first test:



4.6 RECEPTOR TESTS

CT_Recept-01 Impact to a Receptor

Test CT_Recept-01 computes the impact to a receptor in terms of hazard index, dose, and risk. Over the simulation, the concentration of S1 goes from 1 to 0, while S2 goes from 0 to 1.

The allowable concentration for S1 is 0.1g/m³, for S2 it is 0.2g/m³. Thus S1's HI should change from 10 down to 0, while S2's changes from 0 to 5.

The risk/concentration ratio for S1 is 1.0{(yr-1)/(g/m³)}; S2's is twice as much. Thus, the risk due to S1 should start at 1/yr and diminish to 0, while that for S2 should start at 0 and increase to 2/yr.

The Dose is calculated using a dose-conversion factor of 1e7(Sv/yr)/(g/m³) for S1, and twice as great for S2. The dose due to S1 should thus start at 1e7Sv/r and diminish to 0, while that due to S2 should start at 0 and increase to 2e7Sv/yr.

4.7 SOURCE TESTS

These problems test all aspects of the Sources, including associated cells linked to a source.

Basic Source Term Functionality

These test problems are specifically targeted at verifying the basic source term functionality, including distributing and releasing mass to specified associated cells, sources in localized containers, and simple release from associated cells. In all cases the test problem files are set up with a single, non-decaying species. Each of 10,000 packages is assigned an inventory of 1 g.

Distributing and Releasing Mass

These test problems verify that GoldSim distributes mass to and releases mass from specified associated cells.

CT_SourceBasic-01: Distribute Mass to Multiple Parallel Cells

In this problem, the mass at the source is exposed immediately and distributed evenly (in parallel) to four associated cells. Each of these cells in turn discharges to a different unassociated cell. The links between cells are all advective with very high flow rates small cell volumes and infinite solubility cell solubility limits, insuring immediate release.

The cumulative release from the source to each of the cells should be equal to 2500g. The final mass in each of the unassociated cells should equal 2500 g.

CT_SourceBasic-02: Distribute Mass to a Single Cell

This problem is identical to CT6-1, but the mass is only distributed to the first of the four associated cells.

The cumulative release to the first cell should be 10,000g. The final mass in the first unassociated cell should be 10,000g, and 0g in the other unassociated cells.

CT_SourceBasic-03: Distribute Mass to Four Cells in a Series

In this problem, the mass in the source is exposed immediately and distributed evenly to four associated cells, which are connected in series. Each of the associated cells is connected to a separate unassociated cell. Each of the first three associated cells releases half of its output to the next associated cell in series, and half to its unassociated cell. The final associated cell in the series releases all of its mass to its unassociated cell. The connections between cells are all advective with very high flow rates, small cell volumes and an infinite cell solubility limit, ensuring immediate release.

The mass in each of the four unassociated cells should be as follows:

$$\text{Cell1: } (0.5)(2500) = 1250 \text{ g}$$

$$\text{Cell2: } (0.5)(2500 + 1250) = 1875 \text{ g}$$

$$\text{Cell3: } (0.5)(2500 + 1875) = 2187.5 \text{ g}$$

$$\text{Cell4: } 2500 + 2187.5 = 4687.5 \text{ g}$$

CT_SourceBasic-04: Distribute Mass to First Cell in a Series

In this problem, the mass in the source is exposed immediately and distributed to a single associated cell. This cell discharges to three other associated cells connected in series. Each of the associated cells is connected to a separate unassociated cell. Each of the first three associated cells releases half of its output to the next associated cell in series, and half to its unassociated cell. The final associated cell in the series releases all of its mass to its unassociated cell. The connections between cells are all advective with very high flow rates, small cell volumes and an infinite cell solubility limit, insuring immediate release.

The mass in each of the four unassociated cells should be as follows:

$$\text{Cell1: } (0.5)(10,000) = 5000 \text{ g}$$

$$\text{Cell2: } (0.5)(5000) = 2500 \text{ g}$$

$$\text{Cell3: } (0.5)(2500) = 1250 \text{ g}$$

$$\text{Cell4: } 1250 \text{ g}$$

Releases from Associated Cells

CT_SourceBasic-05: Simple Advective Release from Associated Cells

In this problem a source discharges to a single associated cell. It tests the scaling of advective fluxes from associated cells. The source contains 10,000 packages which fail uniformly over 50 years. The cell contains 10 m³ of water, which discharges at a rate of 4 m³/yr. The solubility is specified as very small (such that release is linearly controlled by the advective release, which is in turn scaled by the number of failed containers). The simulation is run for 100 years. The time history of the source release rate should increase linearly with time, and become constant at 50 years.

The release rate from the source, $M(t)$ [g/yr], at time t for an associated cell with a single media and a concentration above the saturation limit is computed as follows:

$$M(t) = Q * C_{\text{sat}} * N_{\text{Fail}}(t)$$

where:

Q = the flow rate of the advective connection [m³/yr] = 4;

C_{sat} = the saturation concentration for species A1 [g/ m³] = 1E-6;

$N_{\text{Fail}}(t)$ = the rate of container failure [-]
 = 10,000/50*t = 200*t for 0 <= t <= 50;
 = 10,000 otherwise.

$$M(10) = (4 \text{ [m}^3\text{/yr]}) * (1\text{E-}10 \text{ [g/ m}^3\text{]}) * (200 * 10) = 8.0\text{E-}7 \text{ g/yr}$$

$$M(20) = (4 \text{ [m}^3\text{/yr]}) * (1\text{E-}10 \text{ [g/ m}^3\text{]}) * (200 * 20) = 1.6\text{E-}6 \text{ g/yr}$$

$$M(50) = (4 \text{ [m}^3\text{/yr]}) * (1\text{E-}10 \text{ [g/ m}^3\text{]}) * (200 * 50) = 4.0\text{E-}6 \text{ g/yr}$$

Note that GoldSim results may be off at the third decimal place, since when a solubility limit is reached, the solubility can be fixed at 0.999 of the solubility limit.

CT_SourceBasic-06: Simple Diffusive Release from Associated Cells

This problem is similar to CT_BasicSource-5, but the associated cell is linked to a pipe diffusively. It tests the scaling of diffusive fluxes from associated cells. The diffusion parameters are defined such that the diffusive flux is small. The solubility is also specified as being small. As shown below, the time history of release from the associated cell should increase linearly with time, and become constant at 50 years.

For a diffusive link through a common fluid (with no porous media) from a cell to a pipe, the total mass flux can be calculated as follows, assuming that the cell concentration is above the solubility limit :

$$M(t) = D * C_{\text{sat}} * N_{\text{Fail}}$$

$$D = \frac{A_c d}{L}$$

where:

d = the diffusivity for the species in water [$\text{m}^2\text{/yr}$] = 0.03156;

A_c = the diffusive area [m^2] = 1;

L = diffusive length in cell [m] = 0.1;

C_{sat} = the solubility for the species [g/ m^3] = $1\text{E-}10$;

$N_{\text{Fail}}(t)$ = the rate of container failure [-]
 = $10,000/50 * t = 200 * t$ for $0 \leq t \leq 50$
 = 10,000 otherwise.

$$M(10) = (0.3156 \text{ m}^3\text{/yr}) * (1\text{E-}10 \text{ g/ m}^3) * (200 * 10) = 6.312\text{E-}8 \text{ g/yr}$$

$$M(20) = (0.3156 \text{ m}^3\text{/yr}) * (1\text{E-}10 \text{ g/ m}^3) * (200 * 20) = 1.262\text{E-}7 \text{ g/yr}$$

$$M(50) = (0.3156 \text{ m}^3\text{/yr}) * (1\text{E-}10 \text{ g/ m}^3) * (200 * 50) = 3.156\text{E-}7 \text{ g/yr}$$

Note that GoldSim results may be off at the third decimal place, since when a solubility limit is reached, the solubility can be fixed at 0.999 of the solubility limit.

CT_SourceBasic-07: Scaling of Volumes and Masses in Associated Cells, High Solubility

This problem tests the scaling of media volumes and masses in associated cells. The source contains 100 packages, each containing a single gram of mass. A single associated cell contains 10 m^3 of water and 10 kg of sand. The partition coefficient between sand and water is equal to 1, such that the mass is partitioned equally between the two media. The solubility limit is equal to 0.5 g/ m^3 .

The containers fail uniformly over 50 years. Hence, after 50 years, 100 g of mass is partitioned equally between $10 \times 100 \text{ m}^3$ of water and $10 \times 100 \text{ kg}$ of sand (since the media volumes and masses are scaled with the number of failed packages). Similarly, after n years ($n < 50$), n g of mass is partitioned equally between $10 \times n \text{ m}^3$ of water and $10 \times n \text{ kg}$ of sand.

Because the associated cells are scaled, the solubility limit is not exceeded. The concentration in the water should be $0.5 \text{ g} * n / 10 \text{ m}^3 * n = 0.05 \text{ g/ m}^3$, and the concentration in the sand should be $0.5 \text{ g} * n / 10 \text{ kg} * n = 0.05 \text{ g/kg}$.

CT_SourceBasic-08: Scaling of Volumes and Masses in Associated Cells, Low Solubility

This problem is similar to CT_BasicSource-7, except that a very low solubility limit ($1\text{E-}10 \text{ g/ m}^3$) is imposed. As a result, the concentration in the water in the associated cell should always be fixed at $1\text{E-}10 \text{ g/ m}^3$. All of the precipitated mass is assumed to be part of the solid. Hence, the concentration in the sand should be $1 \text{ g} * n / 10 \text{ kg} * n = 0.1 \text{ g/kg}$.

CT_SourceBasic-09: Scaling of Volumes and Masses in Associated Cells, Excluded Cells

This problem ensures that cells are located in a container with a source, but are specified to not be associated with the source do not have their properties scaled.

The file contains two sources. Both sources contain 100 packages with 1g of mass in each package. The packages fail immediately and are connected to a single associated cell with 10 m^3 of water. The solubility of the species is very low ($1\text{E-}10 \text{ g/ m}^3$).

In the first source(Source_A), the associated cell has two advective links: one to an unassociated cell in the source container, and a second to a cell outside the source container. Both of these cells have a very large volume ($1\text{E}6 \text{ m}^3$), such that the solubility limit is not reached. The advective flow rate is $2 \text{ m}^3/\text{yr}$. Hence, the flux to each cell is $(2 \text{ m}^3/\text{yr})(100 \text{ packages})(1\text{E-}10 \text{ g/ m}^3) = 2\text{E-}8 \text{ g/yr}$. The concentration in the two cells should behave identically, increasing linearly, reaching $(2\text{E-}6 \text{ g})/(1\text{E}6 \text{ m}^3) = 2\text{E-}12 \text{ g/ m}^3$ after 100 years (i.e., the unassociated cell in the source should not have it's volume scaled).

In the second source (Source_B), the associated cell has only a single link to an unassociated cell in the same container. This unassociated cell has a very small volume ($1\text{E-}10 \text{ m}^3$), such that it is immediately saturated. It then discharges to a cell outside of the source container at a rate of $2 \text{ m}^3/\text{yr}$. The flux rate from the unassociated cell in the source container should be $(1\text{E-}10 \text{ g/ m}^3)(2 \text{ m}^3/\text{yr}) = 2\text{E-}10 \text{ g/yr}$ (i.e., the flux should not be scaled).

CT_SourceBasic-10: Scaling of Volumes and Diffusive Area, No Solubility Constraint

In this problem, the barriers fail uniformly over 5000 years. A single associated cell is connected to a single unassociated cell. Since the release from the associated cell is diffusive, the release will continue to rise linearly until equilibrium is reached, at which time the release will remain constant. There is no solubility constraint, no porous medium, and no resistance in the unassociated cell.

The governing equations are listed below:

$$M_{1s} = D_{cs} * (-P_{1,Water,e} * m_{1s} + P_{2,Water,e} * m_{2s}) + N_{fail} \text{ (1g)}$$

$$M_{2s} = D_{cs} * (P_{1,Water,e} * m_{1s} - P_{2,Water,e} * m_{2s})$$

where

$$N_{Fail} = 2 \text{ yr}^{-1} \text{ for } 0 \leq t \leq 5,000 \text{ yr};$$

$$P_{1,Water} = 1/(1 * N_{Fail}) \text{ m}^{-3} \text{ for cell 1};$$

$$P_{2,Water} = 1/(1 * 10,000) = 1e-4 \text{ m}^{-3} \text{ for cell 2};$$

$$m_0 = 0 \text{ for both cell 1 and cell 2.}$$

The diffusive conductance, D_{cs} , increases linearly with time between 0 and 5000 years:

$$D_{cs} = \frac{N_{Fail} A_c d}{L}$$

where:

$$d = \text{the diffusivity for the species in water [m}^2/\text{yr}] = 0.03156;$$

$$A_c = \text{the diffusive area [m}^2] = 0.01;$$

$$L = \text{diffusive length in cell [m]} = 0.1;$$

The solution (reached using Matlab) is as follows:

Acell1

Medium	Am-241 (g/m ³)
WATER	
time = 100	8.59E-1
time = 1000	3.70E-1
time = 4000	4.59E-1
time = 10,000	5.00E-1

Cell 1

Medium	Am-241 (g/m³)
WATER	
time = 100	2.84E-3
time = 1000	1.26E-1
time = 4000	4.33E-1
time = 10,000	5.00E-1

Number of Packages**CT_BasicSource-11: Stochastic Number of Packages**

This test ensures that the number of packages can be specified stochastically, and that the number of packages can be specified as zero. In the test, all packages fail immediately. The number of packages is specified as a function. The function is defined as follows:

If(Packages>1, Packages, 0)

"Packages" is a stochastic, defined as a uniform distribution between -100 and 100. Hence, about half of the time, the number of packages will be 0. The remainder of the realizations will be between 1 and 100.

N_Packages should be compared to Failed_Packages. Failed_Packages should be a rounded version of N_Packages. Furthermore, the cumulative amount of mass exposed should be equal to zero for those realizations in which the number of packages is zero.

Barrier Failure***Simple Outer Barrier Failure***

All of these problems were run for 10,000 years, with 10,000 packages and 1 g of species in each package.

CT_SourceBarriers-1: Outer Barrier Failure with Multiple Weibull Modes

In this test, all of the mass is in the outer fraction, and there are three Weibull failure modes:

Mode	Probability	Mean Lifetime (yrs)	Slope
1	0.75	4000*0.8862	2
2	0.25	5000*0.8862	2
3	0.00	5000	2

The cumulative amount exposed should be:

$$\text{Exposed} = \text{NWP} * \left[1 - \prod_{i=1}^N \left(1 - P_i * F_i(10,000) \right) \right]$$

where:

- Exposed = cumulative amount of mass exposed (g),
- NWP = total number of packages,
- $F_i(10,000)$ = cumulative probability of failure mode i by time 10,000,
- P_i = fraction of packages which can fail by mode, and
- N = number of failure modes = 3.

$F_i(10,000)$ is simply the integral (from 0 to 10,000) of the failure distribution for mode i . For the purposes of this verification, this integration was computed by creating a Weibull stochastic, and viewing that Cumulative Probability at a level of 10,000. Note that since only an integral number of primary containers can fail, the value is rounded. In this case, the total exposed mass is equal to 8103g (10,000 – 8103).

CT_SourceBarriers-2: Outer Barrier Failure with Multiple Uniform Modes

This test is identical to CT_SourceBarriers-1, except that it uses three uniform failure modes:

Mode	Probability	Duration (yrs)
1	0.75	5000
2	0.25	6000
3	0.00	6000

The total exposed mass is equal to 8125 g.

CT_SourceBarriers-3: Outer Barrier Failure with Multiple Exponential Modes

This test is identical to CT_SourceBarriers-1, except that it uses three exponential failure modes:

Mode	Probability	Expected Lifetime (yrs)
1	0.75	4000
2	0.25	5000
3	0.00	5000

The total exposed mass is equal to 7558 g.

CT_SourceBarriers-4: Outer Barrier Failure with Multiple Degenerate Modes

This test is identical to CT_SourceBarriers-1, except that it uses three degenerate failure modes:

Mode	Probability	Start Time (yrs)
1	0.75	4000
2	0.25	5000
3	0.00	5000

The total exposed mass is equal to 8125 g.

CT_SourceBarriers-5: Outer Barrier Failure with Mixed Modes: Weibull and Exponential

This test is identical to CT_SourceBarriers-1, except that it uses two mixed failure modes:

Mode	Type	Probability	Mean Lifetime (yrs)	Slope
1	Weibull	0.75	4000*0.8862	2
2	Exponential	0.25	4000	NA

The total exposed mass is equal to 8063 g.

CT_SourceBarriers-6: Outer Barrier Failure with Mixed Modes: Uniform and Exponential

This test is identical to CT_SourceBarriers-1, except that it uses two mixed failure modes:

Mode	Type	Probability	Mean Lifetime (yrs)	Duration (yr)
1	Exponential	0.75	4000	NA
2	Uniform	0.25	5000	NA

The total exposed mass is equal to 7663 g.

Simple Inner Barrier Failure**CT_SourceBarriers-7: Inner Barrier Failure with Multiple Weibull Modes**

This test is identical to CT_SourceBarriers-1, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

Note that because inner barriers are not discretized, the result is not truncated. The total exposed mass is equal to 8102.63g .

CT_SourceBarriers-8: Inner Barrier Failure with Multiple Uniform Modes

This test is identical to CT_SourceBarriers-2, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

The total exposed mass is equal to 8125 g .

CT_SourceBarriers-9: Inner Barrier Failure with Multiple Exponential Modes

This test is identical to CT_SourceBarriers-3, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

Note that because inner barriers are not discretized, the result is not truncated. The total exposed mass is equal to 7557.86 g .

CT_SourceBarriers-10: Inner Barrier Failure with Multiple Degenerate Modes

This test is identical to CT_SourceBarriers-4, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

Note that because inner barriers are not discretized, the result is not truncated. The total exposed mass is equal to 8125 g.

4.8 SOURCE TESTS: ADVANCED OUTER AND INNER BARRIER FAILURE

CT_SourceBarriers-11: Outer Barrier Failure with Start Time

In this problem, all of the mass is in the outer fraction, and the outer barrier has a single uniform failure mode with a duration of 10,000 years (the same as the simulation length). The effective time is defined such that the failure mode does not start until 1050 years:

$$\text{Effective Time} = \text{Max}(0\{\text{yrs}\}, \text{Time}-1050\{\text{yrs}\})$$

This should result in the failure of 8950 packages, and a total of 8950g of exposed mass.

CT_SourceBarriers-12: Outer Barrier Failure with Accelerated Failure Rate

In this problem, all of the mass is in the outer fraction, and the outer barrier has a single uniform failure mode with a duration of 10,000 years (the same as the simulation length). The failure rate is accelerated between years 1000 and 3000 by defining the effective time as follows:

$$\text{Effective Time} = \text{Cumulative_Time}$$

where Cumulative_Time is a Integrator, with an initial value of 0 yrs, and a rate defined as:

$$\text{Rate of Change} = \text{If}(\text{time}<1000\{\text{yrs}\} \text{ OR } \text{time}>3000\{\text{yrs}\}, 1, 2)$$

This should result in a time history of failure in which 1000 packages have failed by 1000 years, 4900 have failed by 3000 years, and all of the packages have failed by 8000 years.

CT_SourceBarriers-13: Inner Barrier Failure Linked to Outer Barrier Failure

This problem is identical to CT_SourceBarriers-11, except all of the mass is assigned to the inner fraction, the outer barrier fails according to a degenerate distribution at 1050 yrs, and the inner barrier failure is linked to the outer barrier. This should result in a total of 8950g of exposed mass.

CT_SourceBarriers-14: Inner Barrier Failure with Start Time, Exposure Delayed by Outer Barrier

This problem is identical to CT_SourceBarriers-13, except that the inner barrier is not linked to the outer barrier, and is assigned a start time of 0. As a result, at time = 1100 yrs (the next timestep after the outer barrier fails), the cumulative amount of mass exposed is 1100g. It then increases linearly, such that at 5000 yrs, 5000 g have been exposed, and at 10,000 yrs, 10,000g have been exposed.

CT_SourceBarriers-15: Inner Barrier Failure with Start Time

This problem is similar to CT_SourceBarriers-14, except that the inner barrier is not linked to the outer barrier, and is assigned a start time of 1050yrs. The outer barrier fails immediately. This should result in a total of 8950g of exposed mass.

User-Defined Outer and Inner Barrier Failure***CT_SourceBarriers-16: Outer Barrier Failure with Multiple User-Defined Modes***

This problem is identical to CT_SourceBarriers-2, except that the uniform failure rate is specified using a User-Defined failure mode. The fraction failed is specified as follows:

$$\text{Fraction Failed} = \text{If}(\text{time} \leq \text{Duration}, \text{time}/\text{Duration}, 1)$$

The total exposed mass should be the same as in CT_SourceBarriers-2 (8125 g).

CT_SourceBarriers-17: User-Defined Outer Barrier Failure Defined by a Table

In this problem, all of the mass is in the outer fraction, and the outer barrier has a single user-defined failure mode. The failure mode is defined using a 1D Table as follows:

Time	Fraction Failed
0	0
1000	0
6000	0.5
10000	1

The cumulative release should be 0 at time = 1000 yrs, 5000g at time = 6000 yrs, and 10,000 g at time = 10,000 yrs.

CT_SourceBarriers-18: Inner Barrier Failure with Multiple User-Defined Modes

This test is identical to CT_SourceBarriers-16, except that all mass is placed inside the inner barrier, the failure distributions are defined for the inner barrier, and the outer barrier fails immediately.

The total exposed mass is equal to 8125 g.

CT_SourceBarriers-19: User-Defined Inner Barrier Failure Linked to Outer Barrier Failure

This problem is identical to CT_SourceBarriers-13 (in which the outer barrier fails at 1050 yrs), except that the uniform failure rate for the inner barrier is specified using a User-Defined failure mode. The fraction failed is specified as follows:

$$\text{Fraction Failed} = \text{If}(\text{time} \leq 10000, \text{time}/10000, 1)$$

Theoretically, this should result in a total of 8950g of exposed mass. However, because user-defined distributions are only computed at the discrete timesteps, the barriers are assumed to fail over the entire timestep, rather than just a fraction of a timestep. Hence, 9000 g of mass are exposed.

CT_SourceBarriers-20: User-Defined Inner Barrier Failure Not Linked to Outer Barrier, but Exposure Delayed by Outer Barrier

This problem is identical to CT_SourceBarriers-19, except that the inner barrier is not linked to the outer barrier, and hence begins failing immediately. As a result, at time = 1100 yrs (the next timestep after the outer barrier fails), the cumulative amount of mass exposed is 1100g. It then increases linearly, such that at 5000 yrs, 5000 g have been exposed, and at 10,000 yrs, 10,000g have been exposed.

CT_SourceBarriers-21: User Defined Inner Barrier Failure Not Linked to Outer Barrier

In this problem, the outer barrier fails immediately, and the user-defined inner barrier failure rate is defined as follows:

$$\text{Fraction Failed} = \text{If}(\text{time} < 1050, 0, (\text{time} - 1050)/10000)$$

This should result in a total of 8950g of exposed mass.

CT_SouceBarriers-22: Uniform Outer Barrier Failure with Rounding/Truncating Failure Times

In this problem, the outer barriers of ten packages fail uniformly over 100 years according to a uniform distribution. The user should test the option (Model/Options/Mass Transport) to round versus truncate the failure times.

With rounding the packages should fail at 5, 15, 25... 95 years. With truncation they should fail at 10, 20, 30... 100 years.

CT_SouceBarriers-23: Outer Barrier Failure with Multiple Weibull Modes and Disruptive Event

This test is identical to CT_SourceBarriers-01, except that there is a defined disruptive event which occurs and fails 1,000 packages suddenly at 2,000 years.

The Tester should confirm that both the number of failed packages and the cumulative mass exposed jump by 1,000 at 2,000 years.

Sampled Failure Modes

CT_SourceSampledFailure-1: Uniform Outer Barrier Failure with Random Failures

In this problem, the outer barriers of 10,000 packages fail uniformly over 100 years according to a uniform distribution. Failure is simulated by assuming a random failure time. Five realizations are carried out.

All five realizations for the time history of the number of failed packages (Failed_Packages) should have nearly the same shape: a relatively straight line from 0 to 10,000. Table view, however, should indicate that the curves are not identical.

Failure Using an External Table

All of these problems were run for 100 years with 100 packages and 1 g of species in each package. They all use an external table defined as follows:

time(yr)	fraction
1	0
2	0.01
5	0.1
10	0.2
25	0.3
50	0.5

CT_SourceTableFailure-01: Outer Barrier Failure using an External Table

In this test, all mass is in the outer fraction, and there is a single external table outer failure mode. The probability of failure is 0.5.

The cumulative amount exposed should be $50 \text{ g} \times 0.5 = 25 \text{ g}$ at time 50 yrs.

CT_SourceTableFailure-02: Inner Barrier Failure using an External Table

In this test, all mass is in the inner fraction, and there is a single external table inner failure mode. The probability of failure for the inner barrier is 0.5. The outer barrier fails immediately (probability of failure = 1.0).

The cumulative amount exposed should be 25 g at time 50 yrs.

CT_SourceTableFailure-03: Outer Barrier Failure using an External Table with a Start Time

This test is identical to CT_SourceTableFailure-01, except that the failure mode does not begin until 20 years:

$$\text{Effective Time} = \text{Max}(0\{\text{yrs}\}, \text{ETime} - 20\{\text{yrs}\})$$

The cumulative amount of mass exposed should be 25 g at time 69 yrs.

CT_SourceTableFailure-04: Outer Barrier Failure using an External Table with Decelerated Failure

This test is identical to CT_SourceTableFailure-01, except that the failure mode is decelerated after 25 years as follows:

$$\text{Effective Time} = \text{Cumulative_Time}$$

where Cumulative_Time is a Integrator, with an initial value of 0 yrs and a rate defined as:

$$\text{Rate of Change} = \text{if}(\text{Time} < 25 \text{ \{yrs\}}, 1, 0.5)$$

At time 25 yrs, the amount of exposed mass is (fraction from table)(original mass)(probability of failure) = (0.3)(0.5)(100) = 15 g. After time 49 yrs, the amount exposed is 15g + (0.5)[(0.5-0.3)*100g] = 25g.

CT_SourceTableFailure-05: Inner Barrier Failure using an External Table with Inner Linked to Outer

This test is similar to CT_SourceTableFailure-02, except that the probability of inner failure is 1 and the inner barrier failure is linked to outer barrier failure. The outer barrier fails immediately at 50 years.

Under these conditions, GoldSim would actually start the failure in the middle of the previous timestep (i.e., at 49.5 years). This results in 50.5 years of failure. During the first years of the distribution, 50 g are exposed. During the last 50 years, 0.4g/yr is exposed. As a result, 50.5 years of failure results in a total of 50.4 g being exposed. The verifier should ensure that the cumulative amount to Cell A1 is 50g at 100 years.

CT_SourceTableFailure-06: Inner Barrier Failure using an External Table with Inner Delayed by Outer

This test is identical to CT_SourceTableFailure-05, except that rather than being linked to the outer barrier, the inner failure mode starts immediately. The outer barrier, however, does not fail until 50 years. At Time = 50 yrs, 50 g should be exposed immediately.

CT_SourceTableFailure-07: Outer Barrier Failure using an External Table with Random Failures

This test is identical to CT_SourceTableFailure-01, except that failure is simulated assuming a random failure time. Five realizations are carried out.

All five realizations should have roughly the same shape, and approximately 25 g (say, between 22 and 28g) should be exposed by 50 yrs. The curves, however, should not be identical (due to the random sampling).

Source Term Exposure Rates

CT_SourceExposure-1: Bound Exposure with Slow Degradation Rate

In this problem, all mass is assigned to the bound fraction, and the outer and inner containers fail immediately. Exposure is therefore controlled by the matrix degradation rate. Analytically, the release rate can be computed as follows:

$$\text{cumulative release} = \int_{t=0}^{10,000} N_c \times M_{uu}(t) \times k \times I_b(t) dt$$

where:

- N_c = number of containers = 10,000;
- $I_b(t)$ = bound inventory of a single container = 1 g;
- $M_{uu}(t)$ = fraction of unprotected, unaltered matrix; and
- k = fractional degradation rate of the matrix = 4.75E-5 yrs-1.

In this example, since all of the containers fail instantaneously, $M_{uu}(t)$ can be expressed as follows:

$$M_{uu}(t) = \exp(-kt)$$

GoldSim assumes that degenerate failures occur in the middle of the timestep (i.e., the barriers cannot fail at time = 0). Hence, the matrix only degrades for 9950 years. The cumulative release is:

$$\text{cumulative release} = -N_c \times e^{-kt} \times I_b \Big|_0^{9950} = 3766 \text{ g}$$

CT_SourceExposure-2: Bound Exposure with Delayed Inner Barrier Start Time

This problem is identical to CT_SourceExposure-1, except that the inner barrier does not fail until TIME = 2,050 yr. This results in 7950 yrs of release. The analytical solution for the problem is:

$$\int_0^{8,000} M_{uu}(k) (I) (N_c) = -(I) (N_c) e^{-kt} \Big|_0^{7950} = 3,145 \text{ g}$$

CT_SourceExposure-3: Bound Exposure with Uniform Outer Failure Distribution

This problem is similar to CT_SourceExposure-1, except that rather than failing the primary containers immediately, they all failed uniformly over 10,000 yr. Under these circumstances, the solution for for $M_{uu}(t)$ is as follows:

$$M_{uu}(t) = \frac{g}{k} (1 - e^{-kt})$$

The term g is the rate at which the matrix becomes unprotected (equal to a constant value of 1/10,000 in this problem).

Hence, the cumulative release is:

$$\int_0^{10,000} \text{Muu}(k) (I) (Nc) = (I) (Nc) \left(g t + \frac{g}{k} e^{-kt} \right) \Big|_0^{10,000} = 2040 \text{ g}$$

CT_SourceExposure-4: Multiple Inventory Exposure

The outer containers for this test fail uniformly over 500 to 1,500 years, and the inner fail uniformly over 500 years, starting when the outer containers fail. There are four inventories, with each having a total of 1,000g of a unique species:

1. The first inventory is 'free', and so is simply released uniformly as the outer containers fail, over 500 to 1,500 years.
2. The second inventory is bound in a waste matrix, in the 'outer' region. Its decay rate is 0.00139/year (half-life of 500 years). The release curve for this inventory should start at time 500, and follow inventory 1 but lagging with a half-life of 500 years.
3. The third inventory is in the 'gap', should start to be exposed at 1,500 years, and should lag inventory one by a variable amount never greater than 2,000 years, the time for all inner containers to fail.
4. The fourth inventory is bound in a matrix within the inner container. The matrix decays at 0.000693/year. The release curve for this inventory should lag that of the third inventory, with a half-life of 1,000 years.

The Verifier should display a time-history of releases plot, and confirm visually that each inventory's pattern matches the description above.

CT_SourceExposure-5: Congruent Dissolution of the Waste Matrix

10% of the matrix mass (100g) should be dissolved when the container fails, at 10+ years. After that the balance should dissolve at 100g/yr over 9 years until it is all dissolved. The concentration will then start to drop exponentially as the Cell is flushed.

The contaminant should follow the same path, but with one thousand times lower values. Some overshoot of the dissolved concentration is expected at early times, by a few percentage points, because slightly more matrix is 'dissolved' than the minimum required to reach the solubility limit.

The verifier should run the model and compare the results in the MatrixResults and ContResults plots to Figure CT_SourceExposure-5a and CT_SourceExposure-5b below.

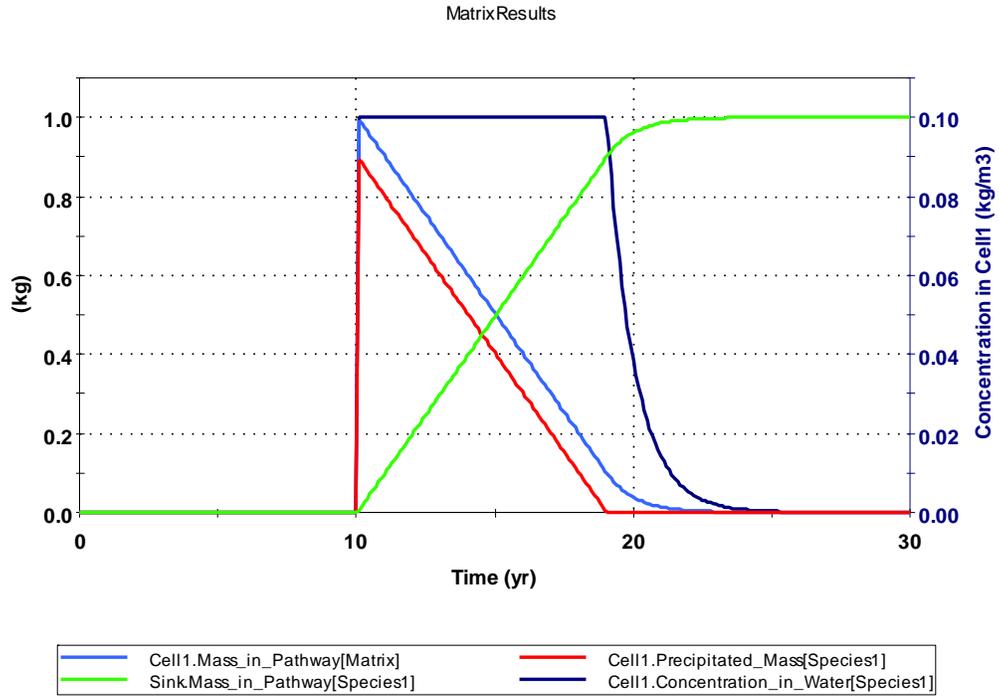


Figure CT_SourceExposure-5a

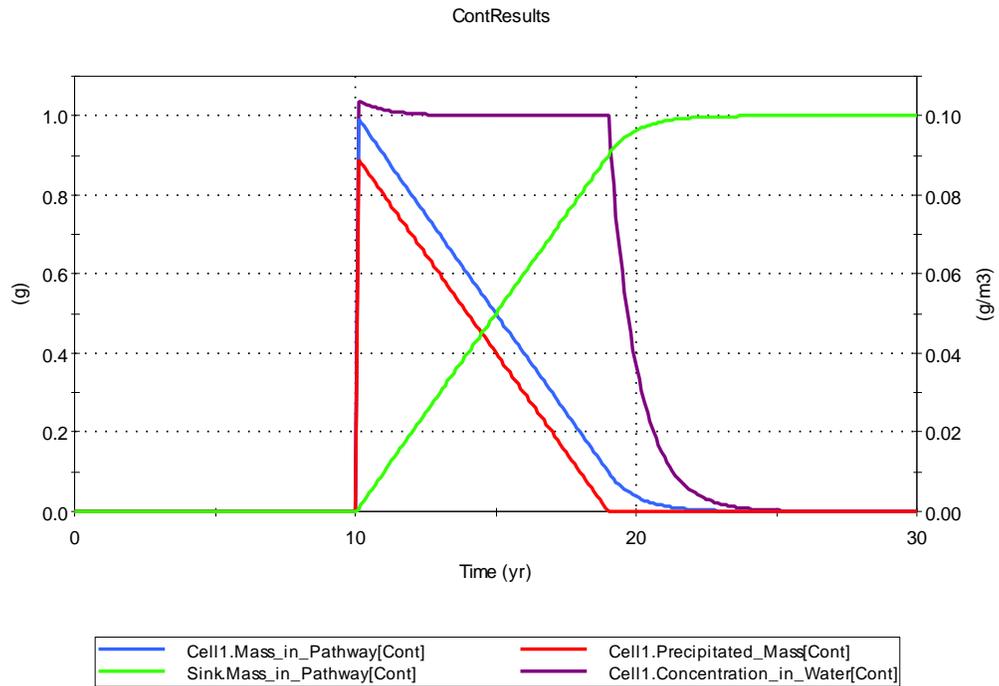


Figure CT_SourceExposure-5b

Decay Within Sources and Associated Cells

CT_SourceDecay-1: Decay within a Source

In this problem, the decay chain starting with Am-241 is examined. Mass is exposed and then released instantaneously from the containers at TIME = 1,000. Therefore, the problem is simply looking at decay within the source over the first 1,000 yr. Am-241 decays to Np-237. To test split decay, two daughters are specified for Np-237, each receiving 50% of the mass. U-233 and V-233 each have identical properties.

The analytical solutions for Am-241, Np-237, U-233 and V-233 are as follows:

$$M(\text{Am-241}) = M_0(\text{Am-241}) e^{-k_1 t}$$

$$M(\text{Np-237}) = \frac{M_0(\text{Am-241}) \frac{AW(\text{Np-237})}{AW(\text{Am-241})} k_1 A_2}{(k_2 - k_1) A_1} \left[e^{-k_1 t} - e^{-k_2 t} \right]$$

$$M(\text{U-233}) = \frac{A_3 k_1 k_2 M_0(\text{Am-241}) \frac{AW(\text{U-233})}{AW(\text{Am-241})}}{A_1} \times$$

$$\left[\frac{e^{-k_1 t}}{(k_2 - k_1)(k_3 - k_1)} + \frac{e^{-k_2 t}}{(k_1 - k_2)(k_3 - k_2)} + \frac{e^{-k_3 t}}{(k_1 - k_3)(k_2 - k_3)} \right]$$

where:

- k1 = decay rate for Am-241 = 1.603E-03 yr⁻¹,
- k2 = decay rate for Np-237 = 3.238E-07 yr⁻¹,
- k3 = decay rate for U-233a and b = 4.372E-06 yr⁻¹,
- M₀(Am-241) = Curies of Am-241 at TIME 0 = 10,000,
- AW = atomic weight (amu), taken as 241, 237 and 233 respectively,
- A1 = specific activity of Am-241 = 3.44 Ci/g,
- A2 = specific activity of Np-237 = 7.06E-04 Ci/g, and
- A3 = specific activity of U-233 = 9.69E-03 Ci/g.

Note that within the source, the mass that is released during a timestep is only decayed for half of that timestep. A 10 year timestep is used in this case. Using t = 995 yr and the above constants, the results for "exposed mass" are 2,029 Ci for Am-241, 1.610 Ci for Np-237, and 2.194E-03 Ci for U-233 and V-233. The associated cell, however, decays the mass for the balance of the timestep in which it is received (990 to 1000yrs). As a result, the mass in the cell at 1000 yrs should equal the exact solution of 2,012.9 Ci for Am-241, 1.613 Ci for Np-237, and 2.212E-03 Ci for U-233 and V-233.

This model should be run in two ways. In the first run, U233 should have no daughters. Run the test and confirm the results are close to the exact results.

In the second run, make Am241 a daughter of U233, with a stoichiometry factor of zero. Repeat the test. (This tests the full-matrix iterative solver).

4.9 SOURCES AFFECTED BY DISRUPTIVE EVENTS

CT_SourceEvent-01

This file ensures that Source Elements function properly when waste-container failure is induced by a disruptive event. The file contains four tests:

Test Containers Test1 and Test1a - 500 waste containers fail normally at 10 days, and 450 more due to the disruptive Discrete Change at 15 days. The first 500 containers release 500 grams gradually over 3 days as their inner barriers fail uniformly. The disruptive Discrete Change should immediately release an additional 450 g from the disrupted inner barriers. The total mass released is 950g. Note that the difference between the tests in Containers 1 and 1a is simply that in Test1 a condition-triggered Discrete Change Element is used to disrupt the Source, whereas in Test1a a Timed Event is used to trigger the Discrete Change Element. The results for both test Containers should be essentially identical.

Test Containers Test2 and Test2a - 500 waste containers fail normally at 10 days, and 450 more due to the disruptive Discrete Change at 15 days. There is no release due to the initial failures, as the inner barriers do not fail unless disrupted. The Discrete Change should immediately cause the release of 900 grams from the inner containers of the failed packages. Note that the difference between the tests in Containers 2 and 2a is simply that in Test2 a condition-triggered Discrete Change is used to disrupt the Source, whereas in Test2a a Timed Event is used to trigger the Discrete Change. The results for both test Containers should be essentially identical.

4.10 MISCELLANEOUS CONTAMINANT TRANSPORT TESTS

CT_Clone3: Cloned CT Models

The purpose of this file is to ensure that cloned environmental elements work properly. This file contains a simple model made up of Source, Pipe, Cell, and Receptor Elements. The original model is contained in Buried_Drum_Example. The entire model has been cloned and is contained in Buried_Drum_Example_1. Tests include the following:

1. First, run the model to see results. The dose received by Receptor1 is of interest. The time history of the dose for the cloned receptor should be the same for the original model (it is assumed that the calculated results are accurate based on separate verification tests for the contaminant-transport elements). Expected results for this test are shown in Figure CT_Clone3.1.

2. Next, in one version of the model (either the original or the clone), change/edit an element (e.g., the number of source packages;). Re-run the model. Results for the original model and the clone should still be identical, although the results will likely be different from the previous model run(s). Repeat by changing several more elements.
3. Make sure to undo changes, then re-save the model file.

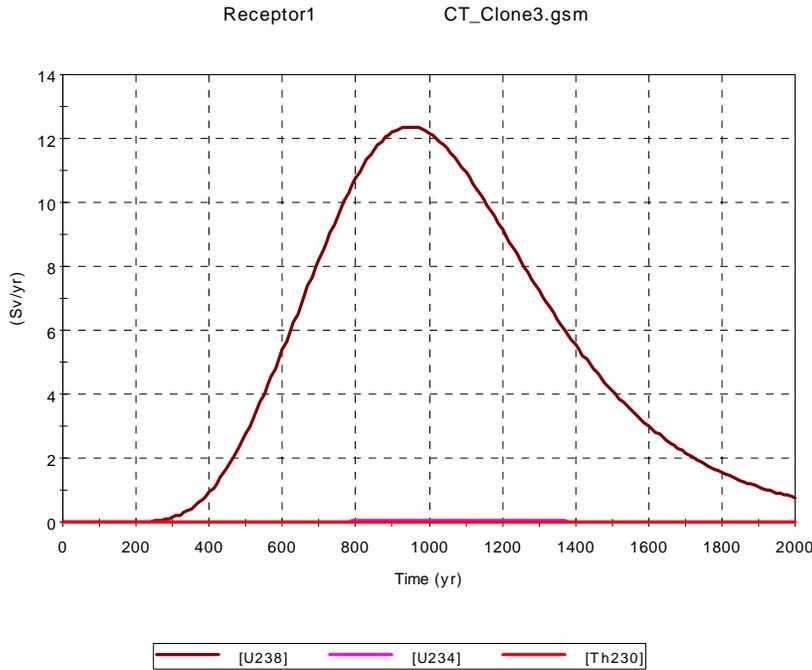


Figure CT_Clone3.1. Expected results for Receptor1 for the initial test.

CT_Timestep: Variable Timesteps for CT Elements

This file verifies that GoldSim models containing contaminant-transport elements run correctly when variable timesteps are used. Run the model to see results. Expected outputs are obtained by running the same models with uniform timesteps. The results using uniform timesteps are assumed to be accurate based on separate verification of the Cell and Pipe Pathway Elements. Tests include the following:

1. A test to verify that a model based on cell pathways within a container runs properly when variable timesteps are defined. The timestep phases are 0 - 1000 days (0.938-day step); 1001 - 10000 days (1.88-day step); and 10000 - 30000 days (15-days step). Model_with_Cells is the model of interest. Expected results for the Pond and Outflow_Stream elements are shown in a table in the file and in Table CT_TIMESTEP.1.
2. A test to verify that a model based on a pipe pathway within a container still functions properly when variable timesteps are used. Model_with_Pipe is the model of interest. Expected results for the GW_Discharge element is shown in a table in the file and in Table CT_TIMESTEP.2.

Table CT_TIMESTEP.1 (Elements Pond and Outflow_Stream)

Day	Pond	Outflow_Stream
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	Mass of Species A (g)	Concentration of Species A (mg/l)	Mass of Species A (g)	Concentration of Species A (mg/l)
1	10	1×10^{-5}	0	0
3,615			6.6×10^{-2}	6.6×10^{-4}
30,000	0	0	0	0
	Declines exponentially with time		Curve shape resembles a lognormal distribution with peak at 3615 days	

Table CT_TIMESTEP.2 (Element GW_Discharge)

Day	Mass of Species A (g)	Concentration of Species A (mg/l)
2,750	2.0×10^{-4}	2.0×10^{-7}
6,400	151	0.151
30,000	2.7×10^{-1}	2.7×10^{-4}
	Curve shape resembles a lognormal distribution with peak at 6375 days	

CT_Conditionality1: CT elements inside conditional containers

This file verifies that environmental elements function properly inside of conditional containers. An environmental model resides inside Container1, which is an unconditional container. The same model has been cloned and placed inside of Container2, which is a conditional container that activates at a time of 100 years. Run the model. The time history for the result element CiPlot should be identical for both models, but the time history for the model in Container2 should be delayed by 100 years.

CT_Plume

This file verifies the plume function. The test problem considers several combinations of source and aquifer geometry for a dissolved-contaminant groundwater plume. Other input parameters for the plume function are contained in the test file. GoldSim's plume function is verified by comparing results to those obtained from TPlume (Golder 1991), which uses the Domenico and Robbins (1985) solution.

The test proceeds as follows. Run the model. View the results shown in **Table CT_PLUME_FUNCTION_1** below and ensure that the results match the expected GoldSim results.

Table CT_PLUME_FUNCTION_1

Container	Element	Expected GoldSim output at 1,000 days (g/m^3)	TPlume value at 1,000 days (g/m^3)
PointSource_ThickAquifer	XConc	0.0154	0.0154
PointSource_ThinAquifer	XConc	0.0461	0.0477
AreaSource_ThickAquifer	XConc	0.0154	0.0153
AreaSource_ThinAquifer	XConc	0.0462	0.0478

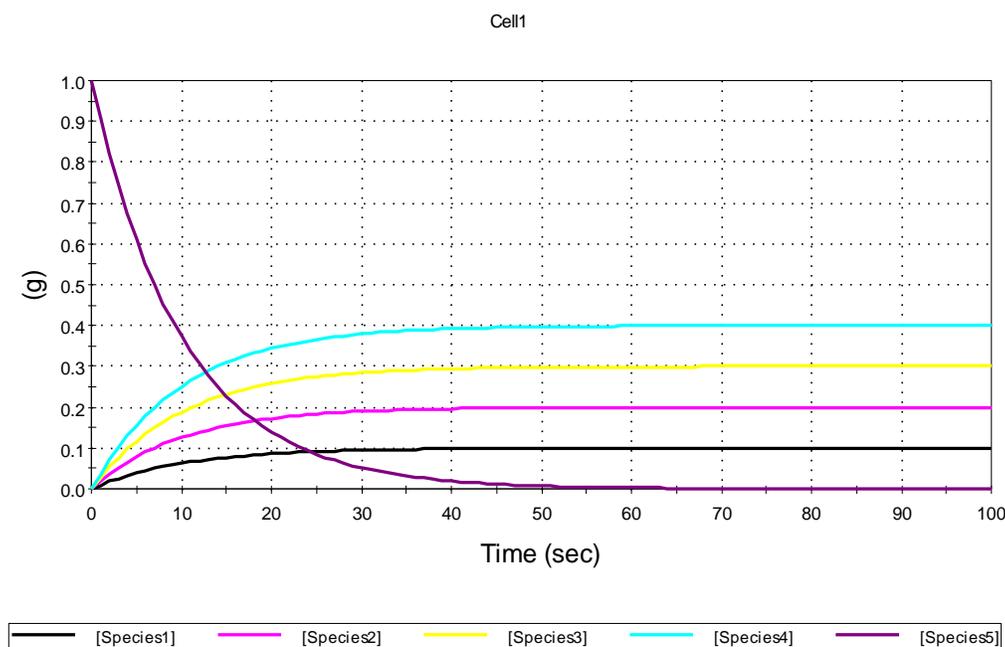
The verifier should also ensure that the Vector_Check Expression element replicates the results from each container in a vector format (it performs an identical calculation by combining the source thickness, source width, aquifer thickness and concentration into vector inputs to a vector-type plume function).

Notes:

1. GoldSim differs from TPlume for the thin-aquifer case because GoldSim has a more accurate solution for thin aquifers (i.e., reflections vs. assumed vertical mixing).
2. The assumed source geometry is a point source at the groundwater table (PointSource), or a vertical rectangle with a depth equal to half the width, oriented perpendicular to the flow direction, and with the top at the groundwater table.
3. The observation point for the concentration is 50 m downgradient from the source, 25 m off the plume centerline horizontally, and 10 m below the groundwater table (i.e., $x = 50\text{m}$, $y = 25\text{m}$, and $z = 10\text{m}$).
4. This verification includes no decay or retardation.

CT_Decay_4: Four Daughter Products for CT Species

This file verifies that four daughter products are correctly produced by the decay calculations in the Cell and in the Pipe element. The parent is Species5, and the four daughters are produced at the same rate (0.1 sec^{-1}) but with different stoichiometry. The resulting mass-time charts should look like the following figure:



CT_Locking_and_Sealing

This file verifies that CT elements behave properly inside sealed or locked containers. This file does not verify sealed and locked containers (see the GoldSim User Interface test). The test proceeds as follows:

1. Seal the container named CT_Elements.

2. Enter CT_Elements. Open the properties dialog for each element, and then click in each field and try to edit the field. Be sure to open each tab and click each expansion button in the properties dialog. Each time, a message box should appear stating that the container is sealed, and asking if you want to continue and break the seal. Click “No” to cancel the action each time. Note if any fields are alterable.
3. Remove the seal and then lock the container CT_Elements.
4. Enter CT_Elements. Open the properties dialog for each element. Within each, explore all of the properties tabs and expansion buttons. None of the fields should be active (i.e., they should all be “greyed out”). The only active button on any dialogs should be the Close button. Note if any fields are active.
5. The inputs and outputs for each CT element should also be inactive. Verify this by trying to access them via the element’s input and output ports (Exception: you should be able to invoke the link cursor from an output and make a link to the input of an element outside the container CT_Elements. Try this by attempting to link to Data4 outside the container).
6. Unlock the container and save the file.

CT_MeshGenerator

This file verifies the correct functioning of the CT CellNet Generator. There are four mesh tests, and the verifier should follow this procedure for the four CellNet Generator elements in the test:

1. Delete any existing cell elements in the container housing the CellNet Generator.
2. Open the property dialog for the CellNet Generator being tested and click the “Generate Cells” button.
3. Verify that the generated network corresponds with the expected characteristics pasted in the container. Repeat the test with the orientation of the generated cells rotated (so that the direction that was horizontal is now vertical). Confirm the result again with the rotated network.

CT_Species_Import_Elements

This test verifies that the Species spreadsheet import functions are working correctly, and also checks to ensure that the Elements array label set functions correctly.

There are four spreadsheet import functions - Replace All, Update Only, Add & Update, and Add Only.

To run the test open the CT_Species_Import.gsm file and proceed through the following steps:

1. Go to the Species element. Delete all of the species except for the first (Ag). Go to the Array Labels dialog and ensure that the Elements list has been updated so that it only shows Ag. Import species information from CT_Species_Import.xls. Select Replace All. View the Elements array label set again, and ensure it has been updated to show Ag, Am, Np, and Pu. Exit the Species element’s property dialog and run the model.
2. Change to edit mode and go to the Species element. Delete all of the species except for the first (Ag). Import species information from CT_Species_Import.xls. Select Add Only. Exit the Species element’s property dialog and run the model.
3. Return to edit mode and reopen the Species element. Edit all of the species - change the Isotope flag, daughter products, molecular weights, decay rates and daughter products. Import species data from Excel using an Update only operation (the Replace All, Add Only and Add &

Update import options should be greyed out). Exit the Species element's dialog and run the model.

4. Change to edit mode and open the Species element and delete the two Americium species. Check that this is reflected in the Elements array label set. Edit the remaining species - change the Isotope flag, daughter products, molecular weights, decay rates and daughter products. Import species information from CT_Species_Import.xls (select the Update Only option). No species should be added and the verifier should ensure the Elements array label set is unchanged. Close the dialog and run the model .
5. Return to edit mode and reopen the species element. Import species information from CT_Species_Import.xls (select the Add Only option). The two Americium species should be added to the Species list and Am should be added to the Elements list. Close the Species element's dialog and run the model.
6. Change to edit mode, open the Species element and delete the two Americium species. Edit the remaining species - change the Isotope flag, daughter products, molecular weights, decay rates and daughter products. Import species information from CT_Species_Import.xls (select the Add and Update option). The two Americium species should be added to the species list and Am should be added to the Elements list.
7. Return to edit mode, open the species element and attempt to import CT_Bad_Import_Data.xls. GoldSim should not crash, but you should be prevented from running the model.

CT_Species_Import_Export

This test verifies the correct export and import of species data to and from Microsoft Excel. The test is in two parts: the first verifies that these features function correctly for species data specified using decay rates, and the second verifies that the features function correctly for species data specified using half-lives.

1. Open the file called CT_Species_Import_Export_Decay.gsm. Open the Species element's property dialog and export species data to a new spreadsheet called Export_Decay.xls. To verify that the data was correctly exported, import the data (using an Update All operation) back into the species element. Run the model and ensure the Cell1_Plot and Cell2_Plot correspond with the graphs pasted in the model.
2. Return to edit mode. Switch the drop down in the species element so that decay is now specified using half-lives. Try to run the model. The model should not run.
3. Open the file called CT_Species_Import_Export_HL.gsm. Open the Species element's property dialog and export species data to a new spreadsheet called Export_HL.xls. To verify that the data was correctly exported, import the data (using an Update All operation) back into the species element. Run the model and ensure the Cell1_Plot and Cell2_Plot correspond with the graphs pasted in the model.
4. Return to edit mode. Switch the drop down in the species element so that decay is now specified using decay rates. Try to run the model. The model should not run.

CT_Polymorphic

This test verifies the correct functioning of polymorphic inputs to media elements. It consists of four model files, with each model file defining media properties using a different combination of species/element property vectors and solubility units. Each model file should produce identical results.

The verifier should ensure that the Result element agrees with the plot in Figure CT_Polymorphic-1 below.

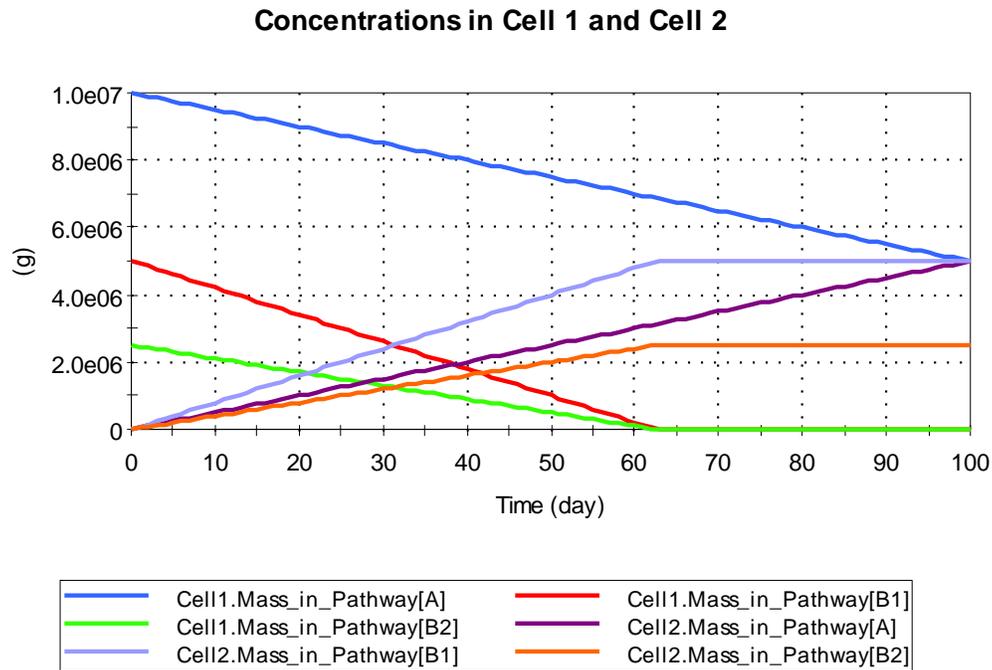


Figure CT_Polymorphic-1

The Verifier should then enter the Material container and ensure that the following outputs display the following expected values:

Element	Output	Expected Value
Water	Relative Diffusivity	[0.10 0.15 0.15]
Water	Solubility	[50 100 200] mg/L or [50 10 0.2] mol/m ³
Fluid_1	Partition Coefficients	[0.2 0.23 0.23]
Fluid_1	Relative Diffusivity	[0.07 0.10 0.10]
Fluid_2	Solubilities	[0.02 0.04 0.08] kg/m ³ [20 4 4] mol/m ³
Solid	Partition Coefficients	[2.0E-5 2.5E-5 2.5E-5] m ³ /kg
Solid	Porosities	0.3

CT_Inconsistent_Properties

This test checks that GoldSim identifies inconsistent properties between different isotopes of the same species.

The verifier should begin the test by opening the Water element. They should confirm that the Solubilities field is equal to Sol_Ref_Fluid_Species_Mass, and that the Relative Diffusivities field is set to Ref_Fluid_Diff_Fact_Species. In the Fluid_2 element they should ensure that the Solubilities field is set to Sol_Fluid_Species_Mass. Run the model - five warnings should be added to the run log. The Water element should warn that the Solubilities are inconsistent, while Fluid_1 should warn that Partition Coefficients are inconsistent, and Fluid_2 should warn that the specified Solubilities are inconsistent. Solid_1 should warn about its Partition Coefficients are inconsistent, and Solid_2 should report that the specified Porosities are inconsistent.

For the next step open the Water element and link the Solubilities field to Sol_Ref_Species_Mol. Link the Fluid_2 element to Sol_Fluid_Species_Mol. Rerun the model - the same five errors should be generated.

For the final step open the Water element and connect the Solubilities field to Sol_Ref_Fluid_Element_Mass, and the Relative Diffusivities field to Ref_Fluid_Diff_Fact_Species. Rerun the model. Again five errors should be generated, but the Water element should now warn that the Relative Diffusivities are inconsistent.

5. DASHBOARD AUTHORIZING MODULE TESTS <SUPERCEDED BY GS46>

6. RELIABILITY MODULE TESTS

General Tests

Note that because the Reliability component of GoldSim is a separate module, the user may have to use the File/Extension Modules menu to enable it.

The tester should verify that the “Insert Reliability Element” item is added to the Insert menu, and also to the context-sensitive menu in the graphics pane when the Reliability Module is enabled. After inserting a reliability element of the tester’s choosing, the user should deactivate the reliability module, and a warning message informing the user that any reliability elements will be removed should appear. Click yes to continue unloading the Reliability Module, and ensure that “Insert Reliability Element” no longer appears in the Insert menu or in the context-sensitive menu in the graphics pane.

RL_01_Failure_Modes

Open the test file RL_01_FailureModes. This file tests the functioning of all RL failure modes. This test file was designed to run 1000 realizations and to save time histories up to the 200th realization, as defined in the Model Simulation Settings dialog box.

To perform the test, first run the model. Then verify that the CCDF of result 1 matches that shown in **Figure RL01-1 (also reproduced in the model)**.

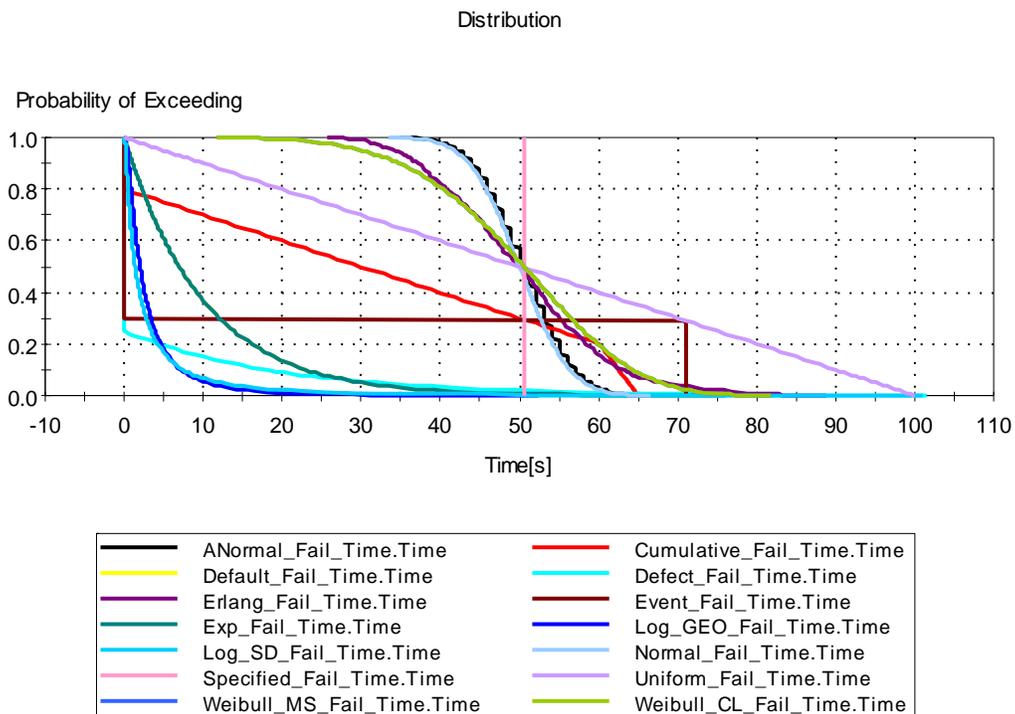


Figure RL01-1

The verification results are presented in **Table RL01-1**. A verifier should check that the MTTF of the specified failure times listed in **Table RL01-1** are within the range of 90% confidence value, from 5% to 95%, of those given by the result distribution elements in each distribution's container. Note: the 5% and 95% limits are confidence bounds *on the mean value*. Thus, for any of the test elements in Table RL01-1, there is a 10% chance that the MTTF will lie outside these bounds.

Comparing the test results to Figure 7-1 and Table 7.1 ensures that each of the failure modes that can reference time has the MTTF that would be expected, and that the dispersion of failure times for each of those failure modes is correct.

Test Element	Expected Result
ExpDefault	MTTF=10s
Exponential	MTTF=10 s
Uniform	MTTF=50 s
Normal	MTTF=50 s
Weibull	MTTF=50 s
Log_SD	MTTF=3.3 s
Log_GEO	MTTF=3.3 s
Cumulative	20% of the components should fail after the first timestep. By 60 s, 80% of components should have failed. All components should fail by 65 s.
Specified	Fails between 50 and 51 s
Event	30% failure at 70 s.
Anormal	MTTF between 50s and 51s (Triggered by an event that occurs once per second)
Defect	Only 25% fail, and for that 25%, mean failure time = 20 s (GoldSim will report a mean <i>operating time</i> of approximately 79 s [this can be viewed in the causal analysis result of the RL element] for the entire population; the CDF of the Fail_Result Result Distribution shows that 25% failed to operate for the full duration)
Erlang	Mean failure time = 50 s, standard deviation = 10 s.

Table 6-1

The verifier should then enter the Unreliable container and verify that the Time History of Result 2 corresponds directly with the graph in Figure RL01-2, and that the average Cum_Emitted at 100s is between 0.95 and 1.05. As the unreliable failure mode does not fail (it simply causes a triggered action to fail), this portion of the test verifies that the correct proportion of actions are unsuccessful when an Unreliable failure mode is specified. The Action element is triggered 20 times with and is 95% reliable, meaning that there should be 1 unreliable action per realization.

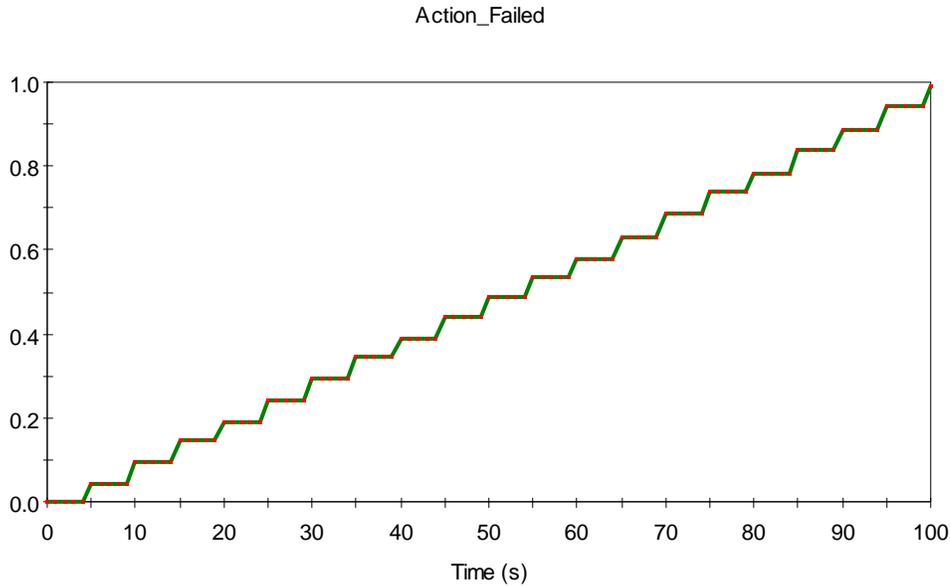


Figure RL01-2

The functioning of the Demand>Capacity failure mode should be verified by entering the Demand_Capacity container and ensuring that the 90 % confidence interval on the mean value of Reliability in the Performance Analysis section of the Results tab includes 0.209853.

This test verifies that an action element with a Demand>Capacity failure mode produces the failure rate that would be expected from a stochastic Demand (Normal distribution, mean 10, standard deviation 2) and stochastic Capacity (Normal distribution, mean 13, standard deviation 2) after the element has been triggered 10 times. Each action has a 0.144556 probability of failure, and since 10 actions are triggered, this means that the element should have a mean Reliability value of $(1-0.144556)^{10}=0.209853$.

RL_02_FMCV

This model verifies the correct functioning of the four different FMCVs available in GoldSim(Operating time since PM, Total time, Number of actions completed and User-defined FMCV). Each of these FMCVs is tested inside a normal container, a conditional container, and within a parent reliability element.

The Number of actions completed FMCV is driven by an action that occurs once per second. The User-defined FMCV is in meters, but is actually also proportional to time (it is equal to $ETime*20s$).

All elements have a specified value exceeded failure mode that occurs at 50s (for Op time and Total time FMCVs), at 50 actions for the Number of Actions mode, and at 1000m for the User-defined mode.

Each container has 5 RL elements, each with different initial ages and acceleration factors. These are:

Normal – no acceleration, new at the start of the simulation

Accelerated – new at the start of the simulation, accelerated by a factor of 2

Decelerated – new at the start of the simulation, accelerated by a factor of 0.5 (ages one half as fast as the normal case).

Initial – 20% aged at the start of the simulation

Initial_Acc – 20% aged at the start of the simulation, accelerated by a factor of 2.

To conduct the test, open and run the model entitled RL_02FMCV.gsm Enter the four containers inside the normal container, the conditional container, and the reliability element. Verify that the time history inside the container corresponds with the graph pasted in this document (and reproduced inside the model), and ensure that failure occurs at the times listed in each container.

Standard Conditions

Because they are in a standard container, and all age at the same rates, all of the FMCVs in the Standard_Conditions container should display the same behavior. The time history results should correspond with Figure RL02-1 below for all four FMCVs.

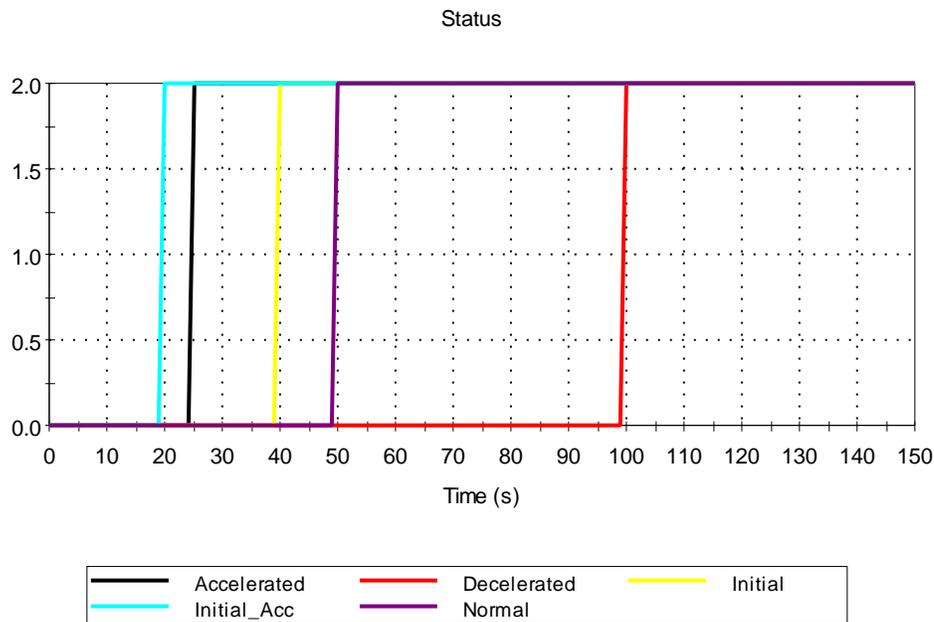


Figure RL02-1

Conditional Container

The same elements are now reproduced inside a conditional container that is activated at 10s,. Graphs should correspond with Figure RL02-2 ,RL02-3. and RL02-3b. Note that failure modes within conditional containers do not age until the container's first activation.

Operating Time, Total Time and User-defined

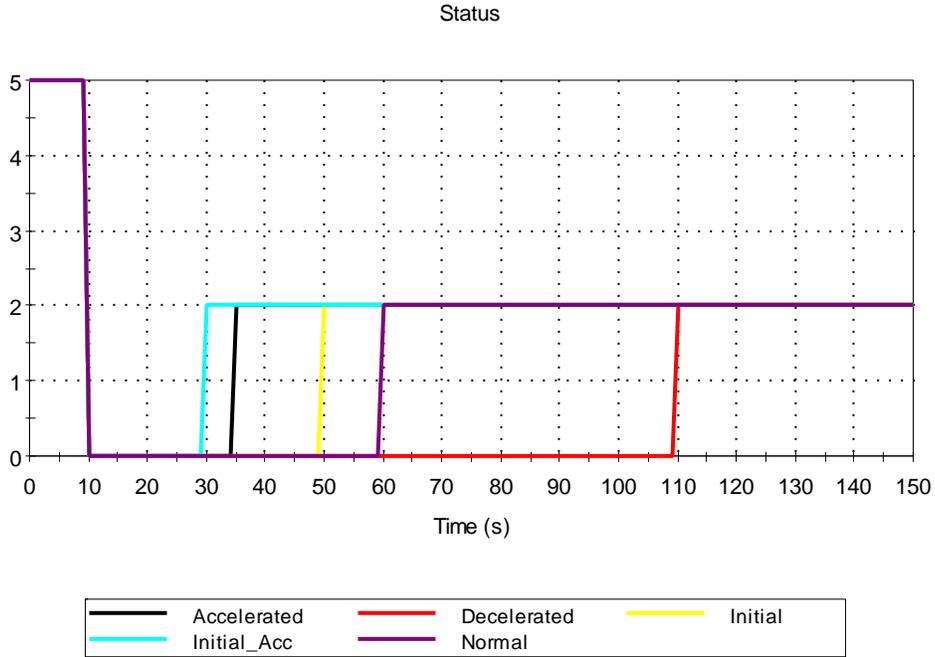


Figure RL02-2

Number of Actions Completed

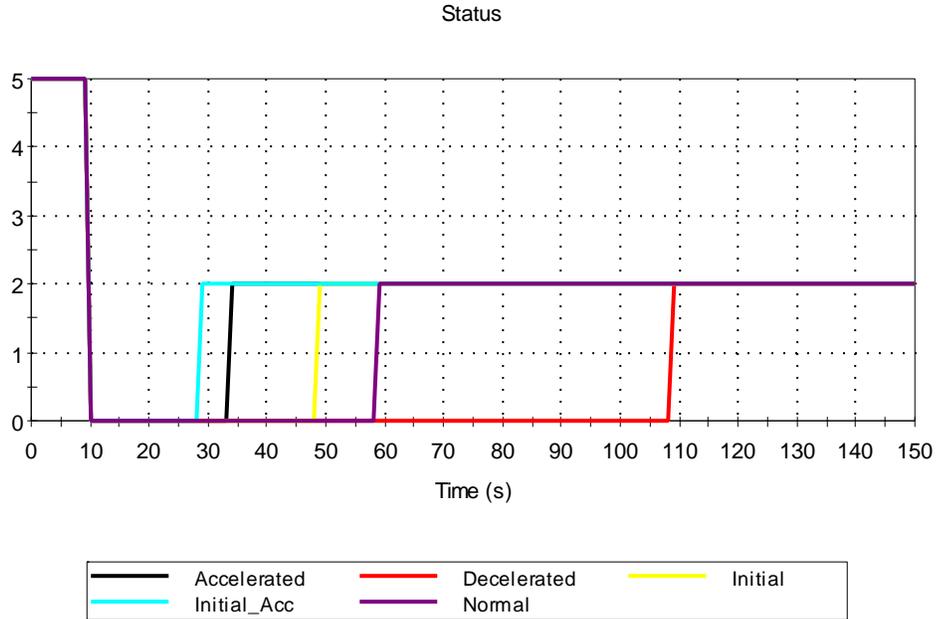


Figure RL02-3

Reliability Element

The same elements are now reproduced inside a reliability element that is activated at 10s, deactivated at 40s and reactivated at 50s. Graphs should correspond with Figure RL02-4, RL02-5 and RL03-5b.

Operating Time and User-defined

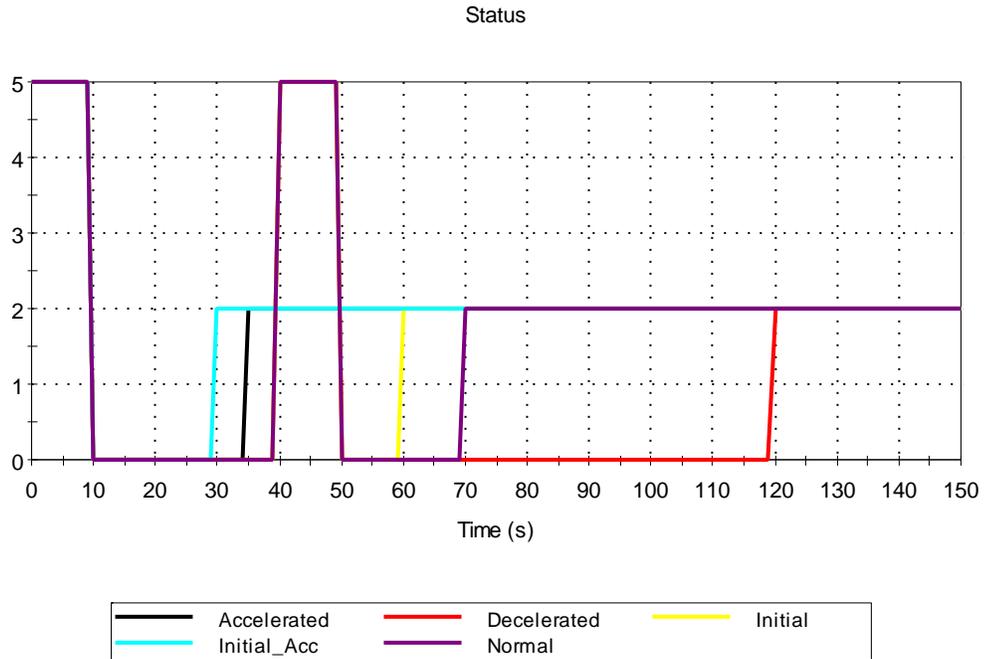


Figure RL02-4

Total Time

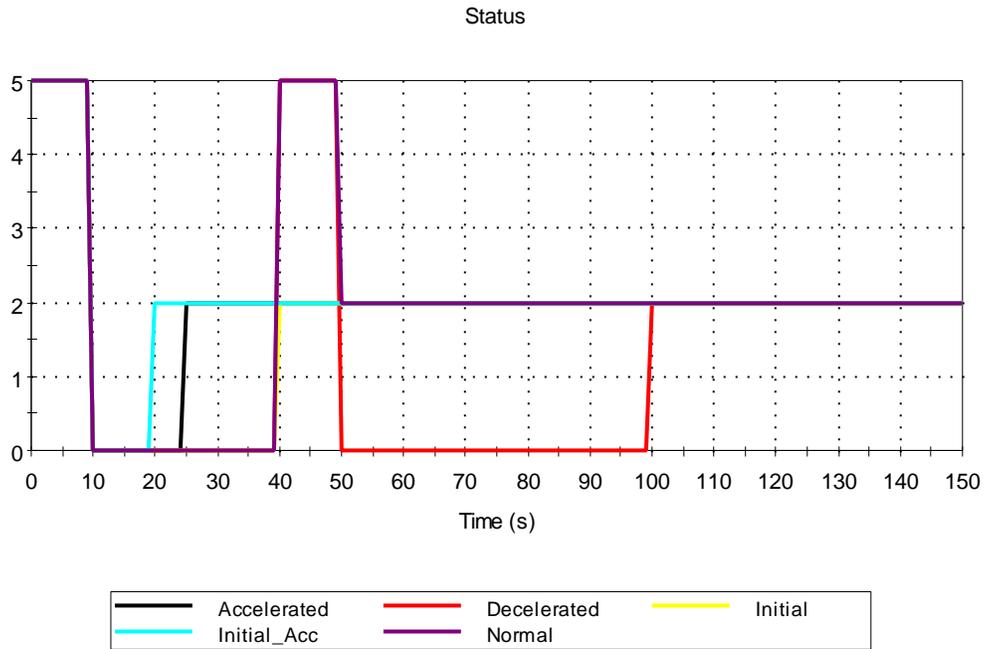


Figure RL02-5

Number of Actions Completed

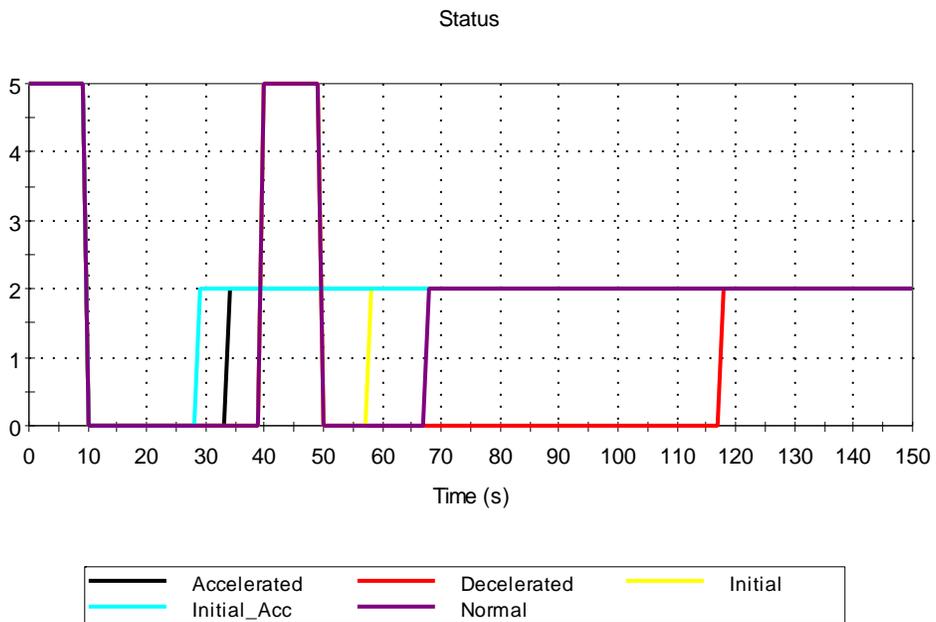


Figure RL02-5b

The final test involves verifying the correct functioning of the Uncertain initial value functionality. To conduct this test, open the file entitled RL_02b_UncertainInitialValue and run the model. Ensure that the graph of Result1 matches Figure RL02-6 (the graph is also reproduced inside the model).

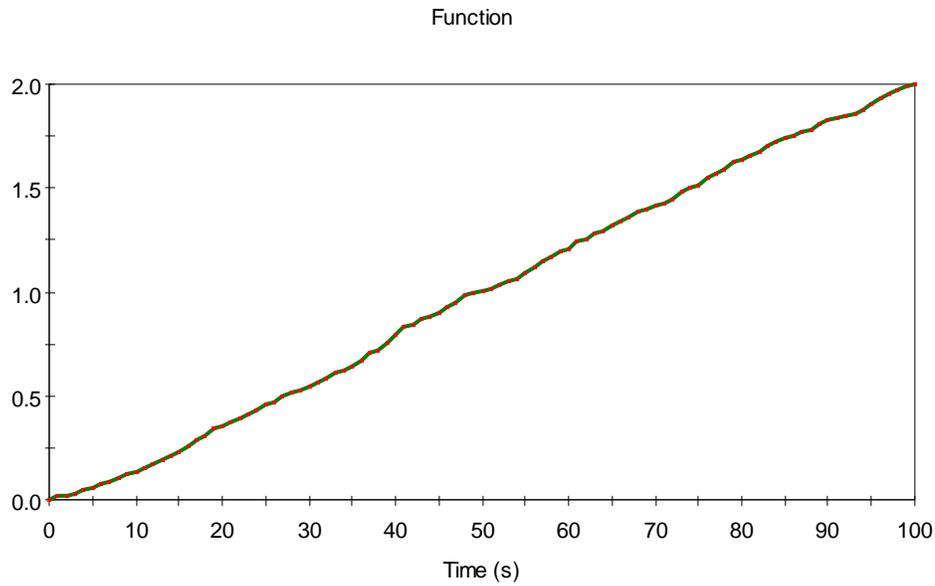


Figure RL02-6

This test uses a specified value exceeded failure mode that fails at 100s with an uncertain initial age value. When an uncertain initial value is selected, GoldSim selects an age value from a uniform distribution that ranges between new and failed. This is why the mean status increases linearly between 0 (operating) and 2 (failed) over the course of the simulation.

RL_03_Automatic_Repair_Distributions

The test is designed to verify that the ‘Automatically Repair Failure’ options and distributions are operating correctly by comparing them with the exact repair time distributions.

To perform the test, open and run the model entitled RL_03_Automatic_Repair_Distributions. Verify that the Reliable outputs of all four function elements drop to zero at time=50s (all are graphed in the RelHistories time history element and one of them should also be checked using its Results/Performance Analysis option), and that the Operating time history corresponds directly with the Figure RL03-1 pasted below and in the model.

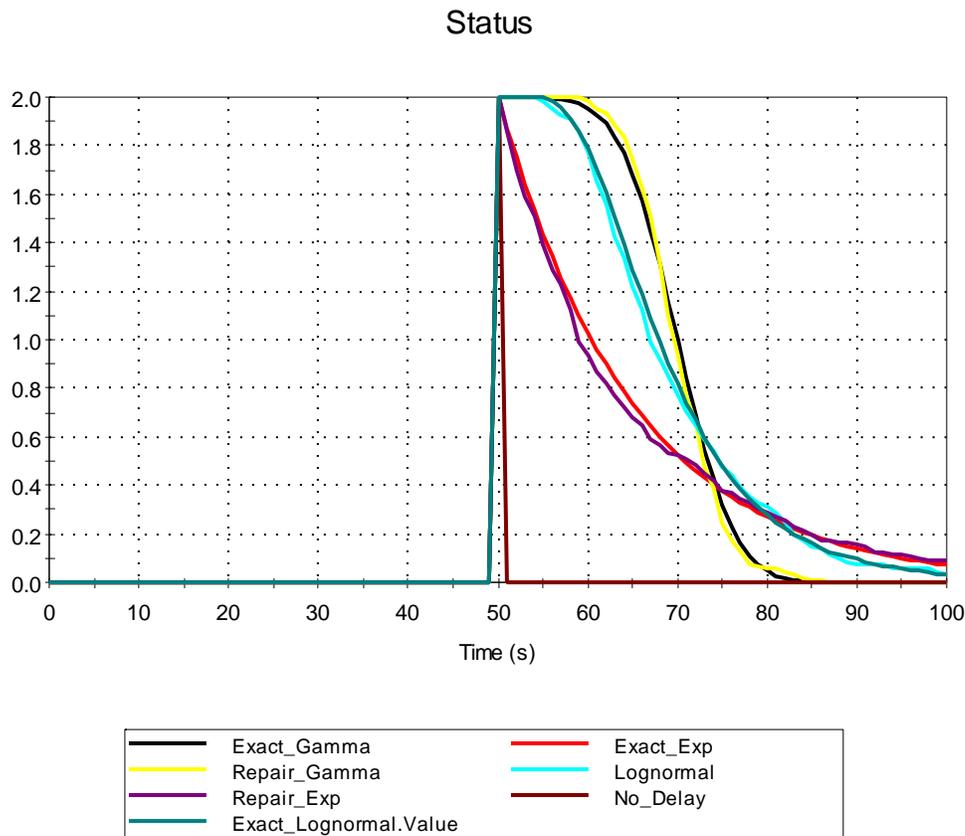


Figure RL03-1

RL_04_Outputs

This test is designed to verify the proper functioning of the reliability element outputs and local properties.

To conduct the test, open the file entitled RL_04_Outputs and run the model. Ensure that the Status graph corresponds with Figure RL04-1 below (also pasted below the element in the model).

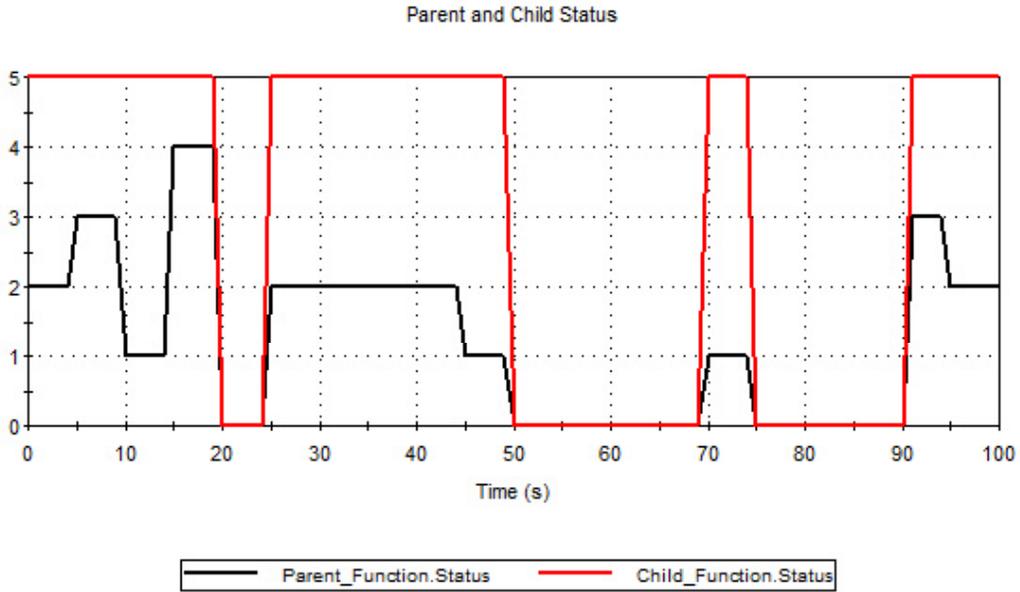


Figure RL04-1

Enter the Parent_Function RL element and ensure that Result3 corresponds with Figure RL04-2 below (also pasted to the right of the element in the model).

Local Property Tests

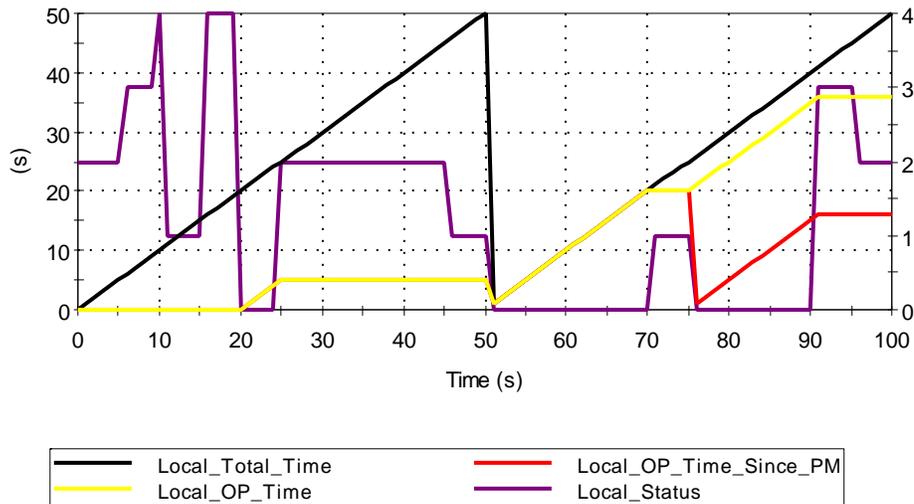


Figure RL04-2

Enter the Function container and ensure that Result1 corresponds with Figure RL04-3 below (also pasted to the right of the element in the model).

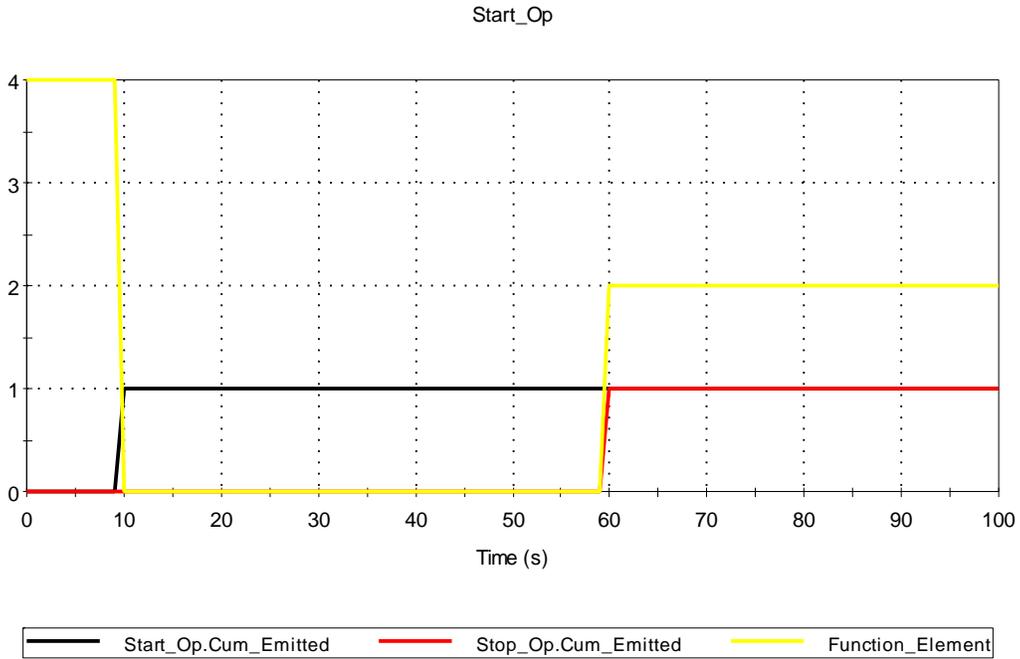


Figure RL04-3

Return to the top level of the model and enter the Action container. Ensure that Result1 corresponds with Figure RL04-4 and that Result2 corresponds with Figure RL04-5. Both graphs are also reproduced in the model.

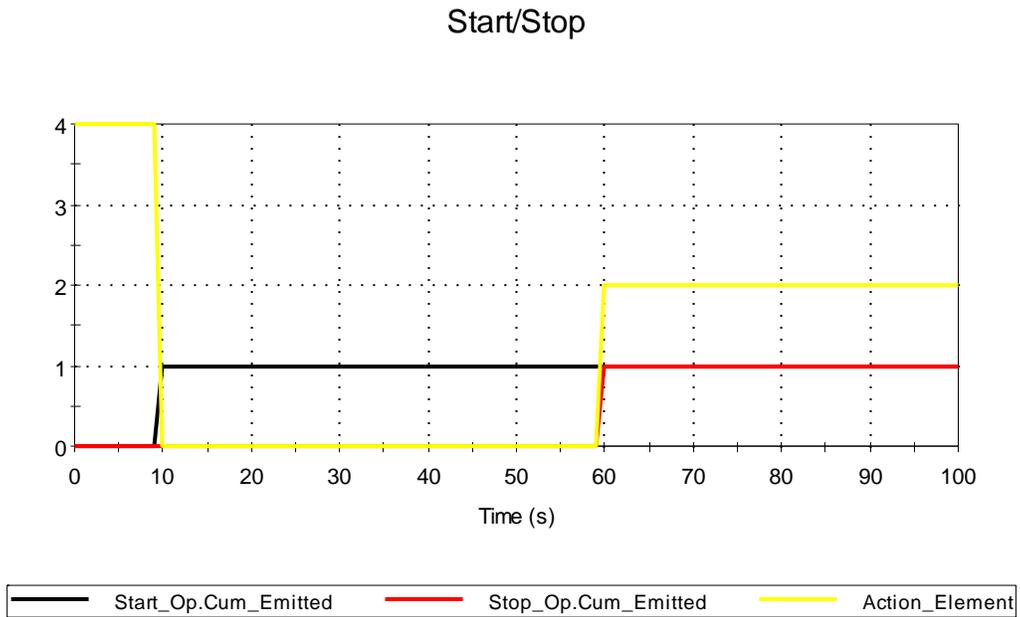


Figure RL04-4

Other Action Element Outputs

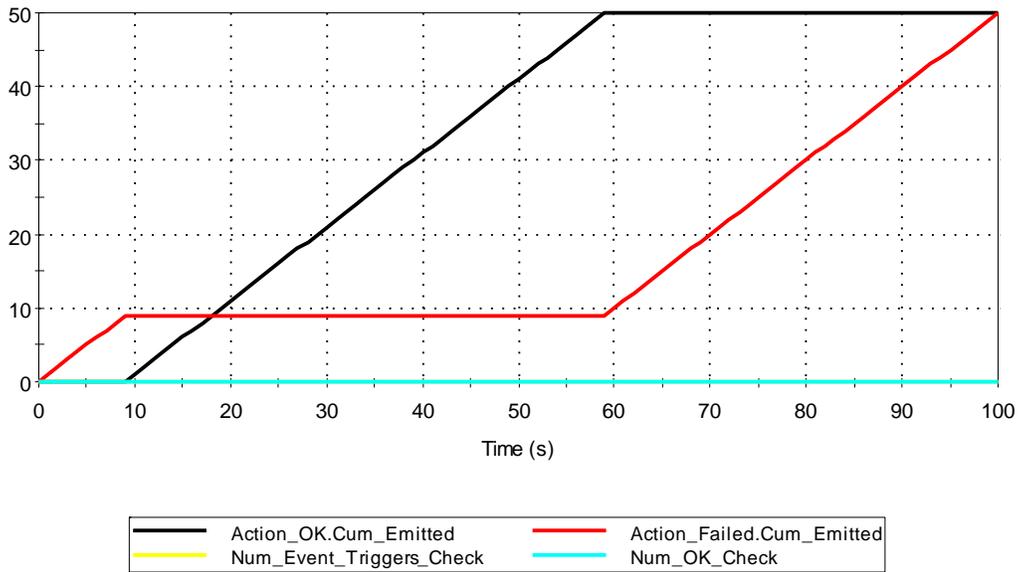


Figure RL04-5

Return to the top level of the model and enter the CustomOutputs container. Ensure that ExposedLocalProperties corresponds with Figure RL04-6 and that ExposedOutput corresponds with Figure RL04-7. Both graphs are also reproduced in the model.

Local Property Tests

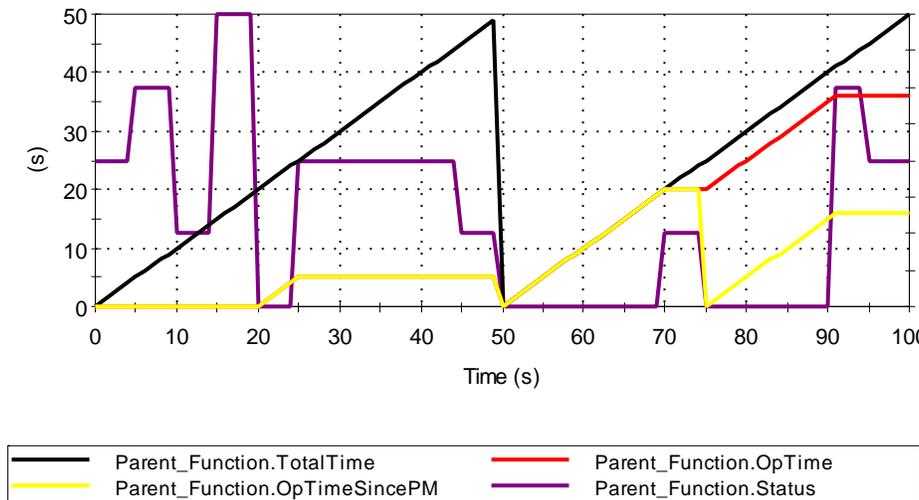


Figure RL04-6

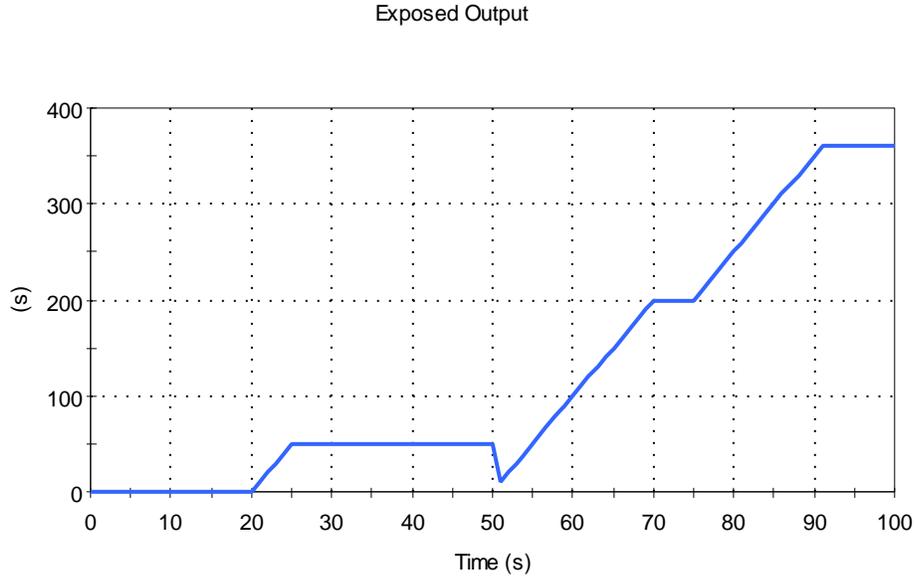
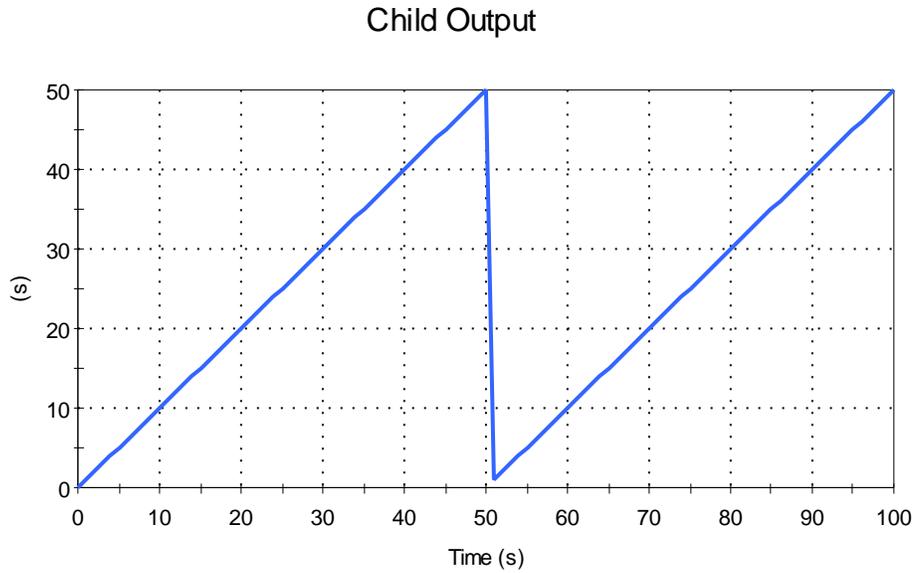


Figure RL04-7

Enter the Parent_Function element and ensure that the Child_Output plot matches Figure RL04-8 below:



RL_05_LogicTrees

This test verifies the proper functioning of the logic-tree nodes, and also the proper functioning of the conversion from one type of logic-tree to another.

To complete the test, open the file entitled RL_05_LogicTrees and run the model. Ensure that each reliability element starts functioning at $t = 50s$. Then enter each reliability element and change the logic tree type to fault-tree. Run the model again and check that the same result is obtained. Re-enter each reliability element and switch the logic-tree type back to a requirements-tree. Run the model and ensure that each element still starts operating at $t = 50s$.

RL_06_PMReplace

This test verifies the proper functioning of both types of PM failure modes and the replace trigger, along with their associated options.

There are three reliability elements in the top level: Function, Parent_Function, and Parent_Function_Replace.

Function and the two child elements in Parent_Function and Parent_Function_Replace have two failure modes – an Operating time since PM failure mode that fails at 41s, and a Total time failure mode that fails at 75s and is not repaired by when a PM:Preventive Maintenance event occurs. At 50s the first failure mode is repaired to an age of 25s by a PM:Preventive maintenance mode that takes 5s to complete. This failure mode is either directly triggered, or triggered by the parent.

Function, and Parent_Function are replaced at 95s by a PM:Replace that takes 5s to complete. Parent_Function_Replace is replaced by a Replace trigger at 100s.

To complete the test the verifier should run the model and ensure that the graph of Result1 corresponds with the graph pasted in Figure RL06-1 below (also reproduced in the model).

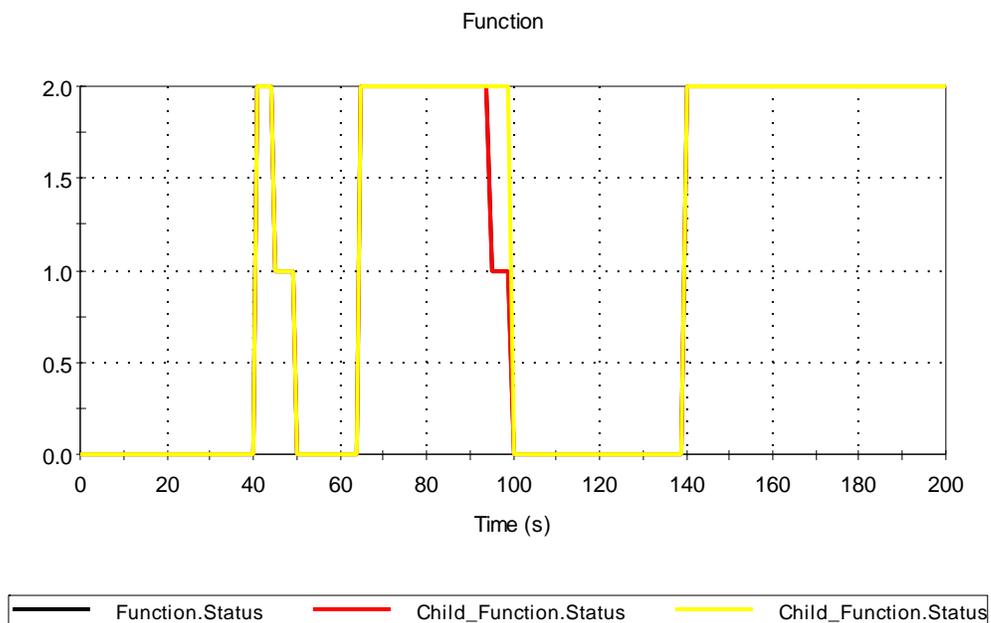


Figure RL06-1

RL_07_Combined_Failure_Modes

This test verifies that multiple failure modes operate correctly.

It uses a reliability element with three exponential failure modes, with mean failure rate of 0.01/s, 0.02/s and 0.07/s.

Because Poisson distributions are unaffected by aggregation, this means that the combined effect of these three failure modes would be equivalent to a Poisson failure mode with a mean failure rate of 0.1/s (corresponds with a mean time to failure of 10s).

To conduct the test, open the file entitled `RL_07_CombinedFailureModes` and run the model. It should be verified that the graph of the `Function_Element's` `Operating` parameter matches the shape of the analytical solution (exponential with mean failure rate of 0.1/s) in Result 1. The correct operation of the three failure modes should also be confirmed by verifying that the 90% confidence bound on the mean failure time in the result distribution includes the expected mean value (10s).

RL_08_Cloning

This test verifies that cloning works properly with the two types of reliability elements.

The verifier should open the file entitled `RL_08_Cloning` and make a number of changes to all of the settings of both `Function` and `Action`. The verifier should ensure that these changes are reflected in `Function_1` and `Action_1`. They should then make a number of changes to `Function_1` and `Action_1` and ensure they are reflected in `Function` and `Action`. Finally, the verifier should free `Function_1` and `Action_1` and make changes to `Function` and `Action`. They should ensure that none of these changes are reflected in `Function_1` and `Action_1`.

These changes should include:

- Switching back and forth between the simple failure mode and advanced failure modes
- Adding and deleting failure modes, changing FMCV and repair settings.
- Altering the logic tree (switching types, adding and deleting nodes, especially to other elements using the RL node browse functionality).

As part of the test, the verifier should create and run a valid model. The model should run successfully to completion and results should be available for all elements in the model.

The tester should also attempt to edit the tree of a child from the property dialog of its cloned parent. A message should be displayed stating that the child element's dialog must be edited locally. The tree of the child should be edited locally and the verifier should ensure that the changes are correctly reflected in the cloned child element.

The tester should also edit the requirements tree of `Function2` and confirm the changes appear in the cloned `Function2b`. One of the changes should be to add a `Not RL Component` for the child element `Function3`.

RL_09_Dynamic_Fields

This test verifies that dynamic fields in the reliability module respond as expected when their value changes.

The verifier should open the model entitled RL_09_DynamicFields and run the model. They should then confirm that the results graphs in each of the 6 containers correspond with the graphs pasted to the right of each result element.

In the first container (EXP_Dynamic), the function element EXP_Dynamic has a dynamic failure mode which has a failure rate of 0.05 1/s for the first 15s of the simulation, and then a failure rate of 0 1/s for the remainder of the simulation. Result 1 should correspond directly with Figure RL09-1 below.

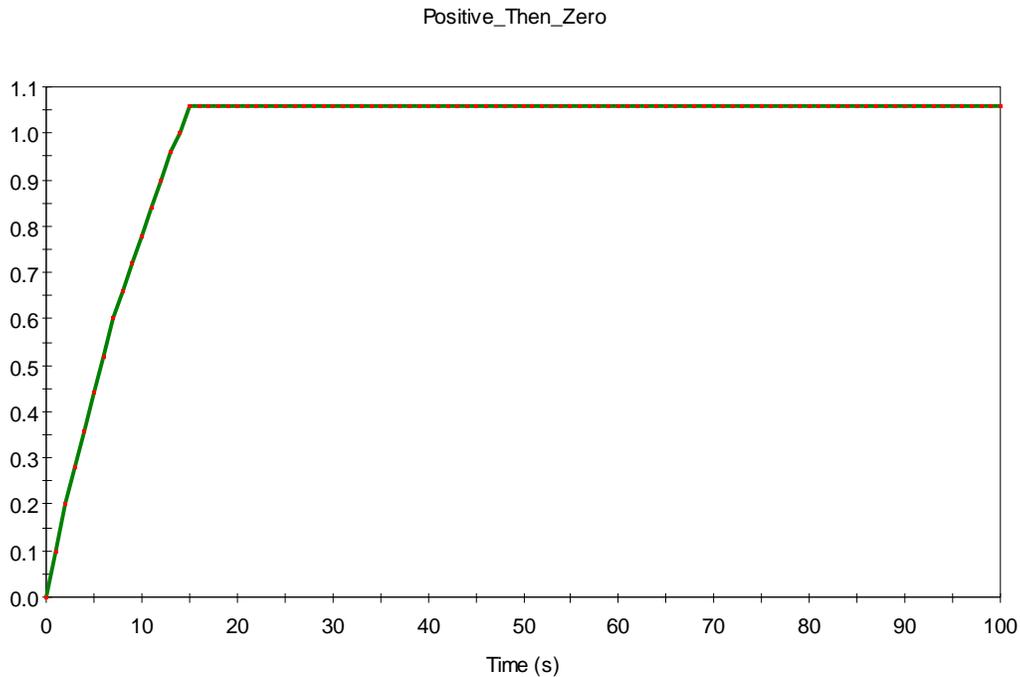


Figure RL09-1

The Engine element has a dynamic failure mode whose failure rate increases, then decreases as the simulation proceeds. The verifier should ensure that the Reliability Time History element corresponds with Figure RL09-1b below:

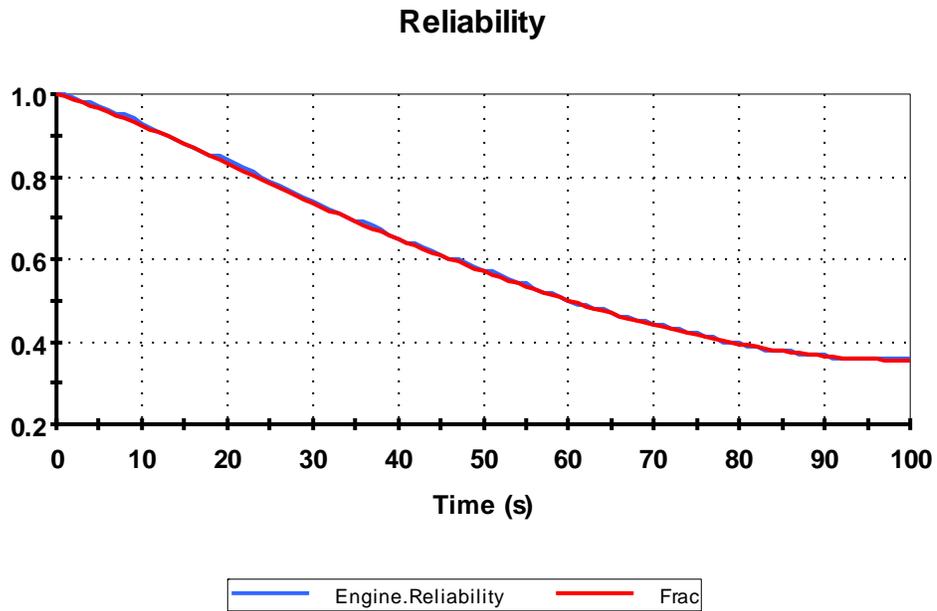


Figure RL09-1b

In Normal_Dynamic, the reliability element initially has a Normal failure mode with a mean time to failure of 10s and a standard deviation of 1s. For the rest of the simulation, the failure mode has a mean time to failure of 30s and a standard deviation of 5s. A successful test is indicated when Result1 corresponds with Figure RL09-2.

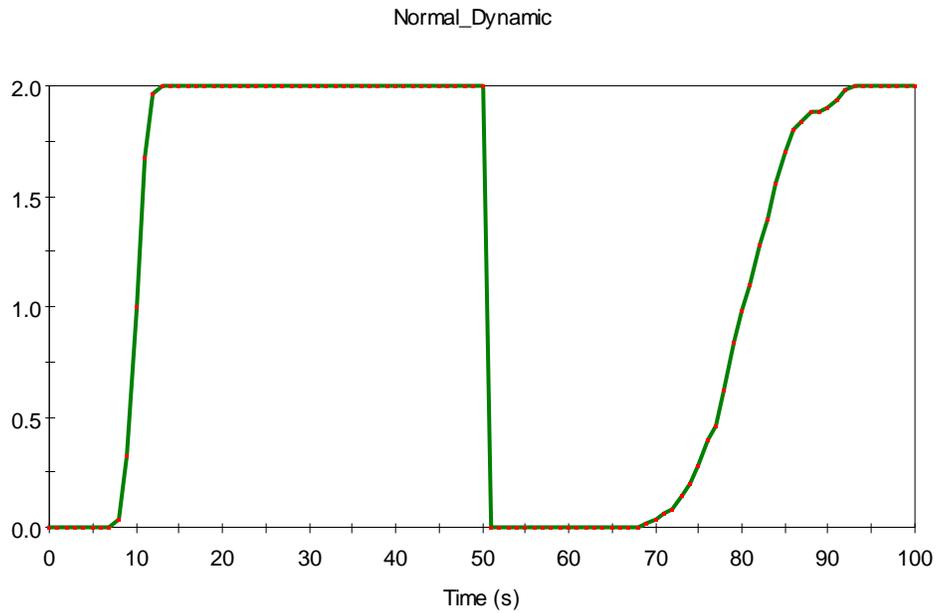


Figure RL09-2

In Gamma_Repair, the reliability element has a triggered failure at 0s and 50s. It is automatically repaired by a gamma repair distribution that initially has a mean 10s and a standard deviation of 5s, but which has a repair distribution with mean 30s and standard deviation 10s for the remainder of the simulation. A successful test is indicated when Result2 corresponds with Figure RL09-3.

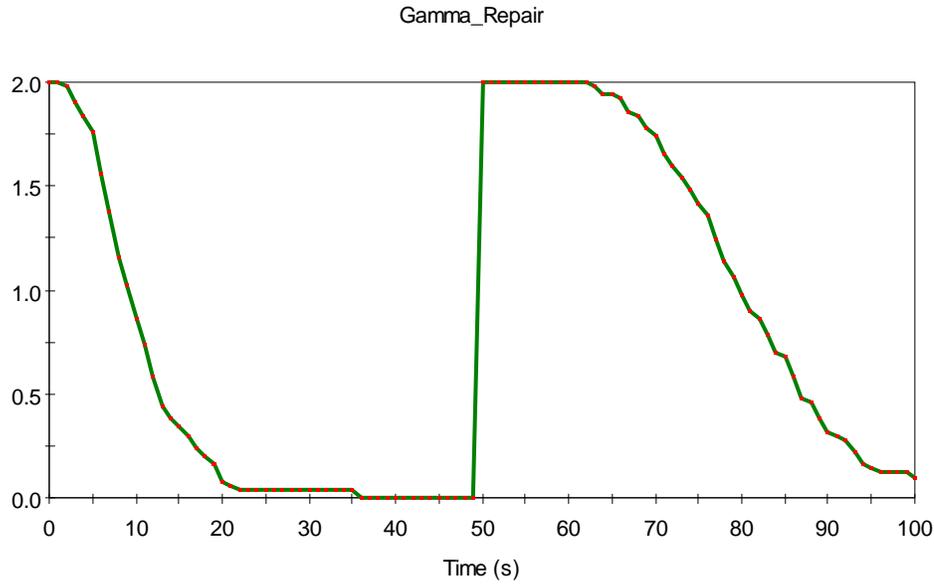


Figure RL09-3

In Repair_to_Age, the reliability element has a specified value exceeded failure mode that fails at 40s. It is repaired after 10s to an age of 20s, a process that takes 10s (gamma repair, 10s mean delay, no standard deviation), meaning it will still fail at an age of 40s. At 50s, it is repaired again (with a 10s delay), but this time to an age of 30s, meaning it will fail again at 70s. A successful test is indicated when Result3 corresponds with Figure RL09-4.

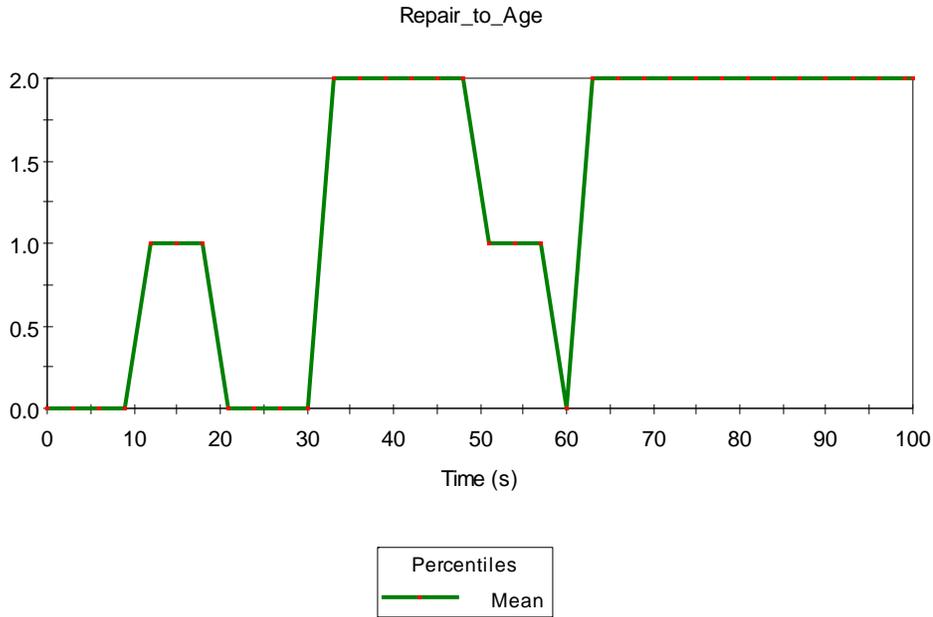


Figure RL09-4

In Repair_if_True, the reliability element has a uniform failure mode that fails between 10s and 20s. The reliability element also has a preventative maintenance mode, triggered at 40s and 80s, which takes 5s, and repairs the uniform failure mode if ETime is less than 50s. Therefore, the element would be expected to fail between 10s and 20s, be repaired at 45s, and then fail again between 55s and 65s. A successful test is indicated when Result4 corresponds with Figure RL09-5.

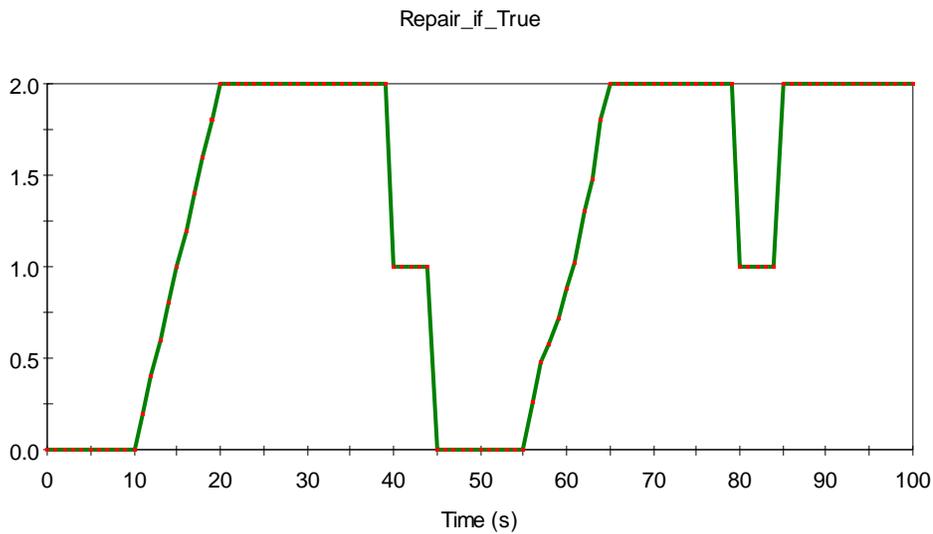
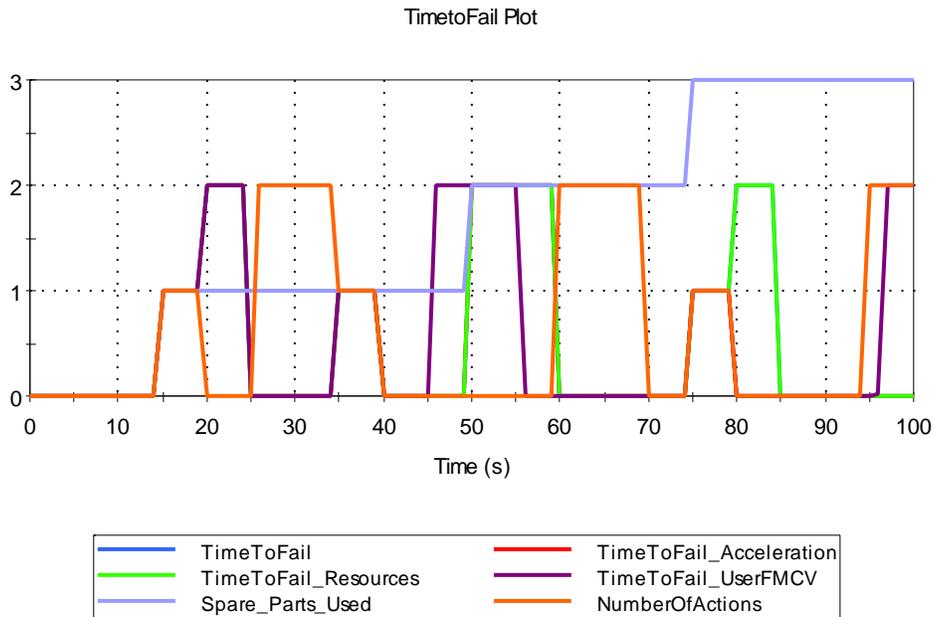


Figure RL09-5

There is an additional container within Repair_if_True (RL_TimeToFail) that tests the \sim RL_TimetoFail local property. The test consists of a number of RL elements, each with a specified value exceeded mode and a PM:Preventative Maintenance mode that repairs the specified value exceeded mode if the time to failure is 5 seconds or less. This is tested using various FMCVs, resources and acceleration. The verifier should ensure that the TimetoFail_Plot matches Figure RL09-6 below.



RL_10_Action_Delay

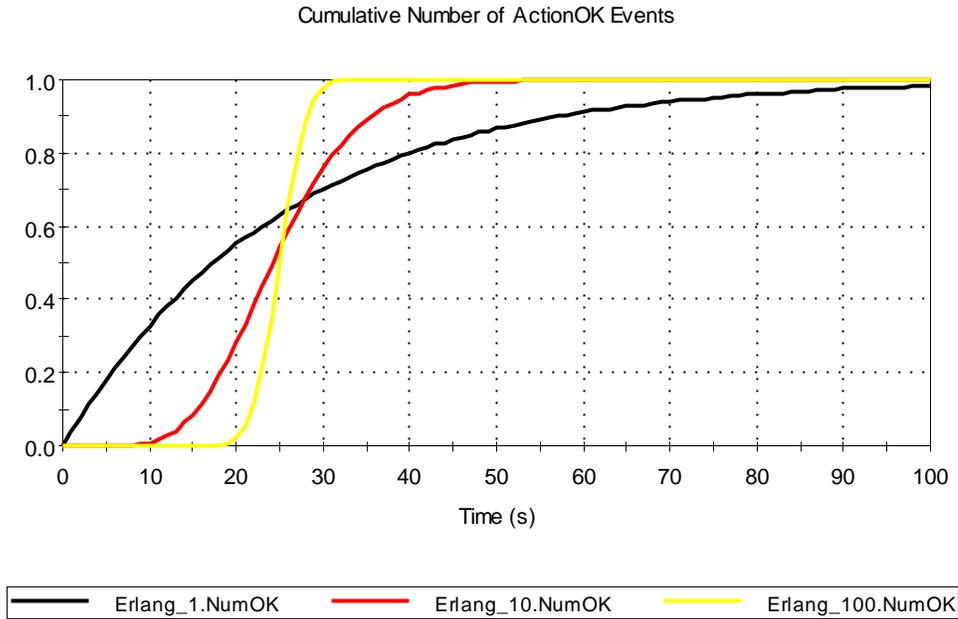
This test verifies the proper function of the Action element's delay features.

To perform the test the verifier should open the file called RL_10_ActionDelay and run the model. At least 250 run log errors should be generated, and the verifier should ensure that the run log contains entries stating that the Max_Events element has 500 action triggers left to process. After checking the run log, the verifier should ensure that the Result elements in the Specified_Delay, Parent_and_Child, Erlang, SD and Action_Failed containers and within the Action_Event system correspond with the graphs pasted in each container.

In the Specified_Delay container, the action element has a specified delay of 50s, and is triggered at the start of the simulation – the expected result is that the action event is emitted at 50s.

In the Parent_and_Child container, there is a parent element, triggered at the start of the simulation with a specified delay of 50s, and a child element with a specified delay of 20s. Therefore, the expected result is that the action events are emitted at 70s.

The Erlang container contains three action elements with Erlang delay dispersions, with shape factors of 1, 10 and 100. The graph inside the Erlang container should correspond with Figure RL10-1.



RL10-1

Figure

The SD container contains three action elements with standard deviation delay dispersions, with standard deviations of 0s, 5s and 10s. The graph inside the SD container should correspond with Figure RL10-2.

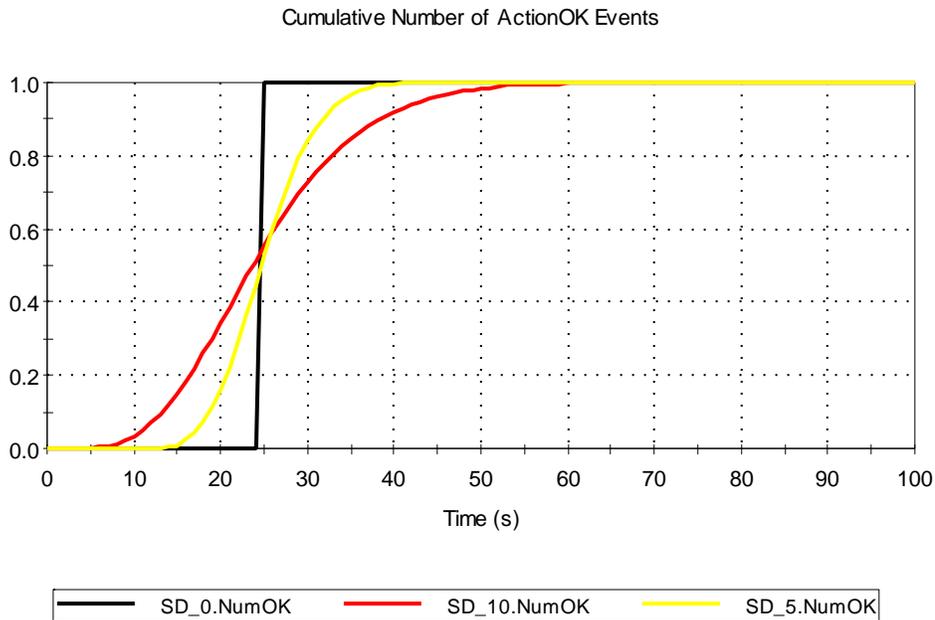


Figure RL10-2

Inside the Action_Failed container, there is a Action element which fails at the start of the simulation, and whose action is triggered at 10s. It should emit an ActionFailed output at 10s, and Result 1 should correspond with Figure RL10-3 below.

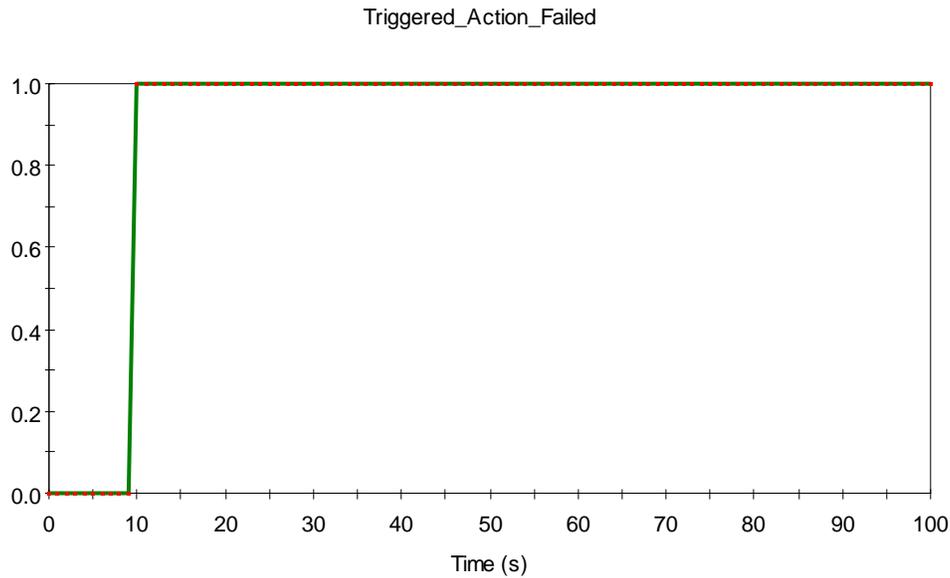


Figure RL10-3

Inside the `In_Process_Failure` container, there are two `Action` elements. The `In_Process_Fail` element is triggered at 10s, but fails at 25s (midway through the `Action`'s delay). An `Action_Failed` event should be issued at 25s, and an `ActionOK` event should never be issued. The `In_Process_Child` has no failures of its own, but handles the `Action` internally with an `Action` element with a delay that again fails after 25s. Again, an `Action_Failed` event should be issued at 25s.

The verifier can confirm expected behavior by ensuring that the result element in the `In_Process_Failure` container corresponds directly with the plot shown in Figure RL10-4 below:

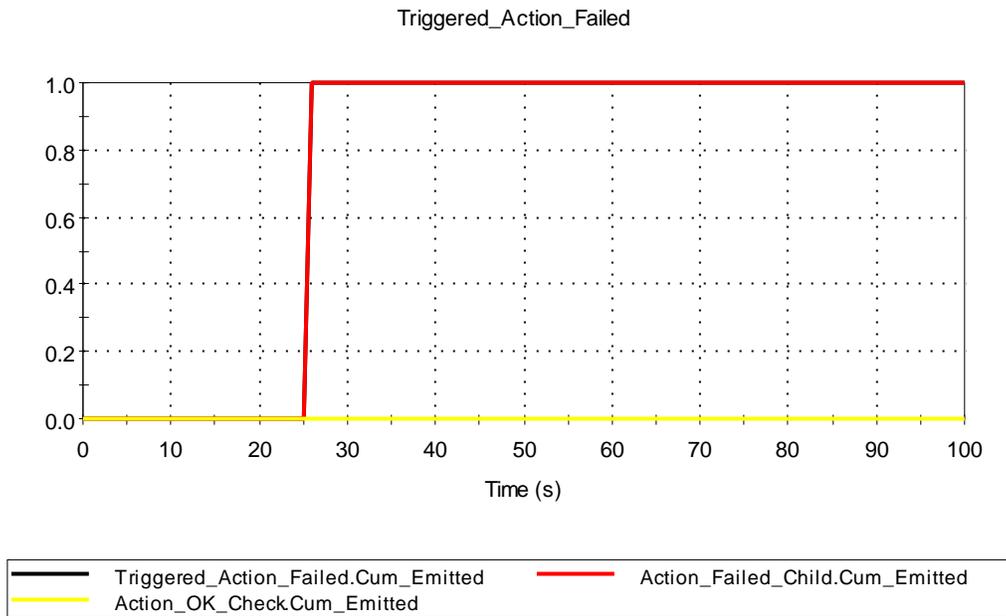


Figure RL10-4

The verifier should then enter the Action_Event system. Inside the system is a Triggered_Event, which uses the ~Action_Event local property. This is connected to a Random Choice element, which routes the output of the Triggered Event back to the parent Action element. The verifier simply needs to confirm that one event is emitted during all 250 realizations. This can be confirmed by verifying that the Result plot matches the plot below in Figure RL10-5.

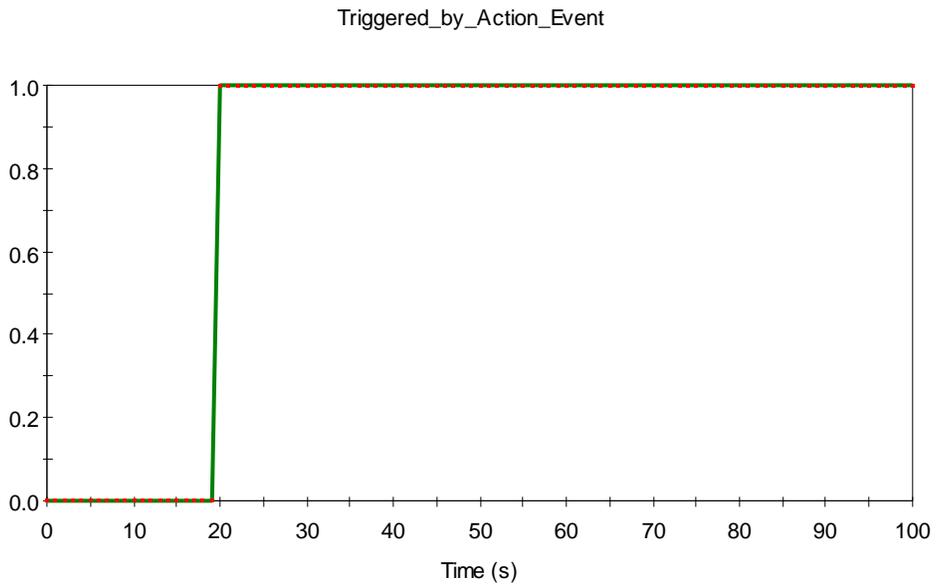


Figure RL10-5

RL_11_Static_Model

This test verifies the correct functioning of failure modes in a static reliability model.

The verifier should open the model called RL_11_StaticModel and run the model. For each failure mode confirm that the 90% confidence interval on the mean value of Operational and Inherent Availability includes the analytic solution (0.714 for all failure modes).

The expected mean Availabilities are calculated using the same formula as the static calculation uses:

$$(MTTF)/(MTTF+MTTR)$$

In this case, all failure modes have a mean time to failure of 50d and a mean repair time of 20d, resulting in a mean availability of 0.714.

RL_12_Reliability_Availability

This test verifies the correct calculation of reliability and availability statistics for reliability elements. The verifier should open the model called RL_12_Reliability_Availability and run the model.

In the model, two function elements below both fail according to a uniform distribution based on total time with a lower bound of 0s and an upper bound of 200s.

In both cases, the mean reliability of the component should have a mean of 0.5. The verifier should check that the values in the Summary Section, Performance Analysis Dialog and the Exposed outputs are all identical, and that they correspond with the expected value. In addition they should verify that the decline in reliability is approximately a straight line, decreasing from 1 to 0.5.

Because of the uniform failure mode, components that fail during the simulation have an expected availability of 50s. This means that half of the components fail at a mean time of 50s, and the other half operate for the full 100s. The expected average inherent availability of both components would be 0.75. However, since the Availability outputs are based on a moving average of availability over the proceeding two fixed timesteps, the Inherent Availability output will track the Reliability output and drop in an approximately linear fashion from 1 to 0.5.

The two function elements differ slightly in their Operational Availability results. The Function1_1 element is actually turned off at ETime = 50s. Therefore, the Operational Availability is actually equal to $0.5 * (\text{Availability in the first 50s}) + 0.5 * 0$. The availability during the first 50s is equal to 0.875 (reliability decreases in a straight line to 0.75 at 50s), so the Operational Availability should be equal to 0.4375. Again the verifier should ensure that the results summary displays a value that corresponds with the expected value. The Operational Availability output should show a straight line decline up until T=50s, at which point the instantaneous operational availability should drop over two timesteps to zero.

RL_13_Failure_Repair

This test verifies that the elements correctly calculate Failure Time and Repair Time statistics.

In the test file, a Function element that fails according to a Uniform (0-100) distribution and repaired with a Gamma distribution of (10, 2) is placed in the root level of the model and inside a second Function element with no failure modes, where it is an Internal Requirement (this is done to test that GoldSim correctly treats unmet Internal Requirements as failures). A similar test is repeated with an Action element that fails according to a Normal (50, 10) distribution and is repaired according to a Gamma distribution with parameters (1, 0.1).

Run the model and display the results failure and repair time distributions. Confirm that the mean and standard deviation of the Normal and Gamma distributions are correct, and that the Failure and Repair time charts for Function1, Function2, Action1 and Action2 match those shown below the elements in the graphics pane..

RL_14_Tree_States

This test verifies that GoldSim correctly reports the amount of time spent in each status. This model runs a parent, child and grandchild through statuses from -5 to 5.

The verifier should open RL_14_Tree_States.gsm and run the model. The values displayed in the causal analysis by time in state should correspond with figures RL14-1 to RL14-3 below (also reproduced in the test file) for both the Requirements_Parent_Function and the Fault_Parent_Function.

For the Parent Element:

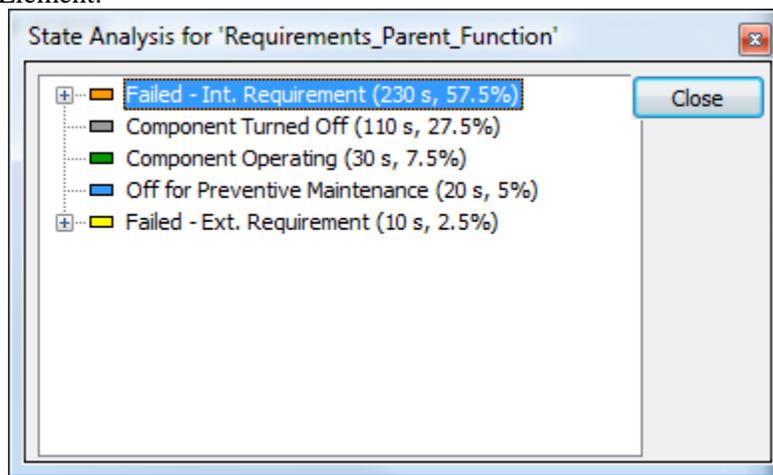


Figure RL14-1

For the Child Element:

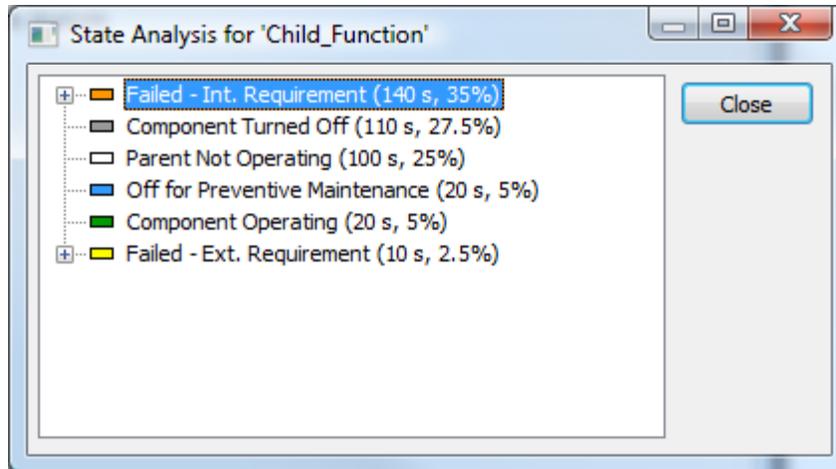


Figure RL14-2

For the Grandchild Element:

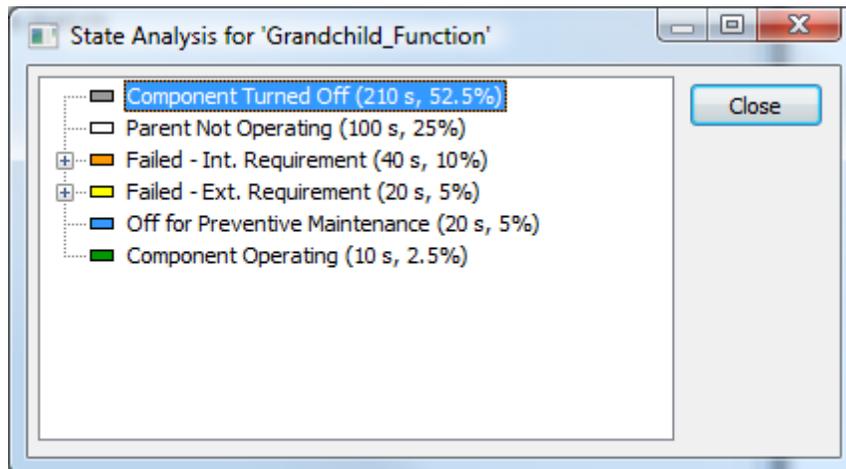


Figure RL14-3

RL_14b_Tree_States_All_Other_States

This test ensures that GoldSim can correctly handle a large number of states (>100 unique internal and external requirements trees).

The verifier should open RL_14b_Tree_States_All_Other_States.gsm and run the model. The causal analysis entries for Internal and External requirements should both display an entry labeled "All Other States".

RL_15_Root_Cause_Analysis

This test verifies the correct functioning of the RL module's root cause analysis features. The verifier should open the model called RL_15_Root_Cause_Analysis.gsm run it. Results for elements using fault - and requirements-trees should match the results pasted in the test file.

RL16_Event_Driven_System

This test verifies that GoldSim correctly simulates event driven systems (where results should be identical whether the simulation is run with 1 or 100000 timesteps).

To run the test, the verifier should run the model with 1, 10 and 1000 timesteps. The final value of Lost_Production should be identical in all three cases, and the 90% confidence interval on the final value should include the expected result. The expected availability would be $MTTF/(MTTF+MTTR) = 1000/1000.25 = 0.99975$. Thus one would expect 0.00025 of each pump's output over 25 years to be lost. A perfect pump would output $3330\text{bbl/day} * 365 \text{ days} * 25$ or 30,386,250 bbl. Thus the expected lost production from the three pumps would be $0.00025 * 3 * 30,386,250$ bbl or 22790 bbl over 25 years.

RL17_Failed_Output

This test verifies the correct functioning of the Failed output and ~Failed available property. Event triggered failure modes are triggered 10s apart and repaired after 5s.

The verifier should run the model and confirm that the Failed_Output plot matches Fig. RL17-1 below.

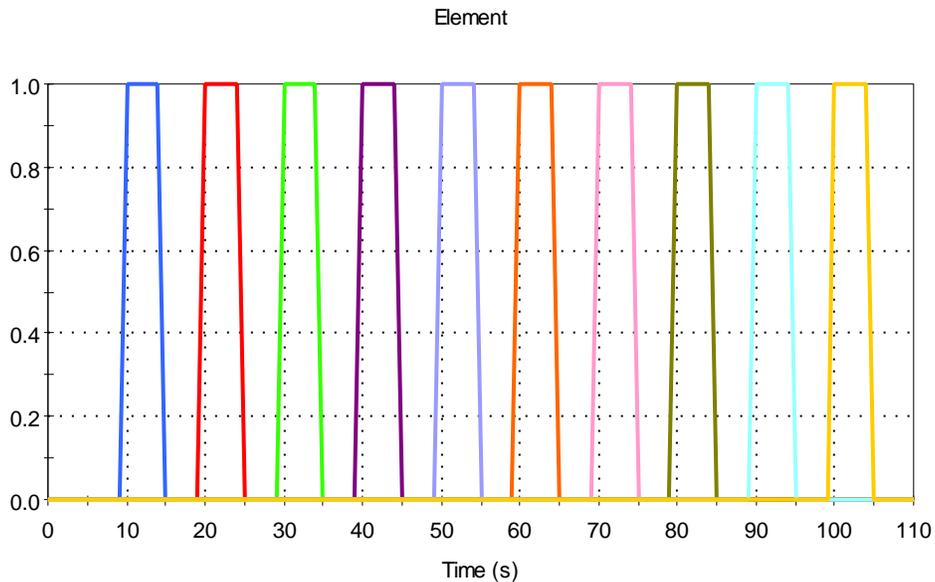


Figure RL17-1

The verifier should then confirm that the Failed_Local_Property plot matches Fig. RL17-2 below. Note that the local property will lag the output by one timestep (as elements within a Reliability system are updated prior to their parent's failure modes being checked).

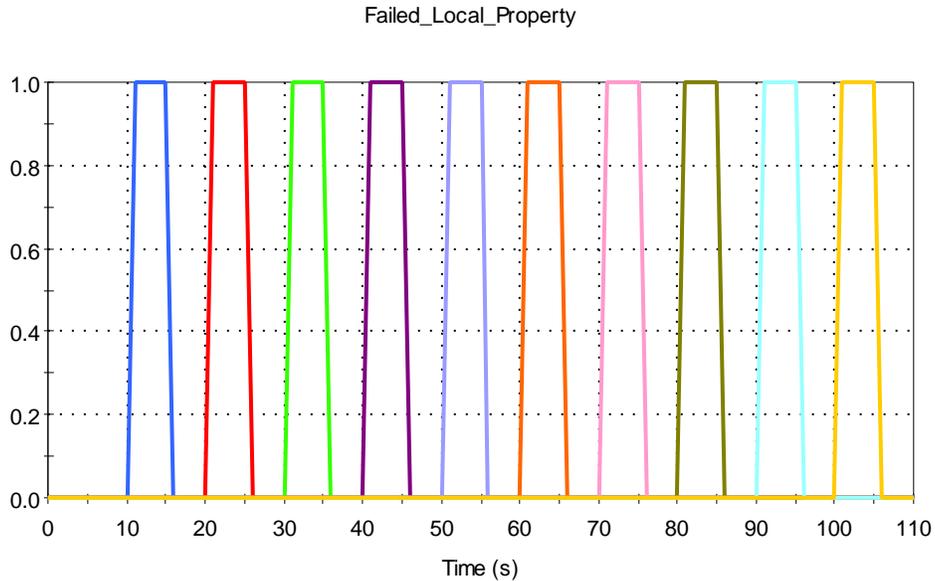


Figure RL17-2

RL18_RL_Export

This test checks that export of high-level reliability results to Excel works correctly.

The verifier should run the model and then open the RL18_Export_Check.xls spreadsheet. Values from the exported spreadsheet (RL18_Export.xls) should be pasted into the Paste Here worksheet and the verifier should confirm that the sheet displays the expected result by going to the Check worksheet. If the Check value is 0 the feature is working correctly.

RL19_FM_Import

This test verifies that the Failure Mode data import from spreadsheets works correctly.

First the tester should delete some of the failure modes for the pump, but not failure mode 5. Then the verifier should open the Pump element and manually import Failure Mode data using the Import Now button. They should then go to the Reliability tab of the Model|Options dialog and ensure that the automatic import option is selected for failure mode import. The model should then be run. The verifier should confirm that that root cause analysis results for the pump match the expected results in Figure RL_19 below. In addition, the tester should enter the Pump's failure modes dialog to confirm that failure mode 5, Cumulative test, has resource requirements that are not deleted during the failure mode import. Finally the tester should compare the reliability elements' failure modes to those of the spreadsheet to confirm the import worked correctly.

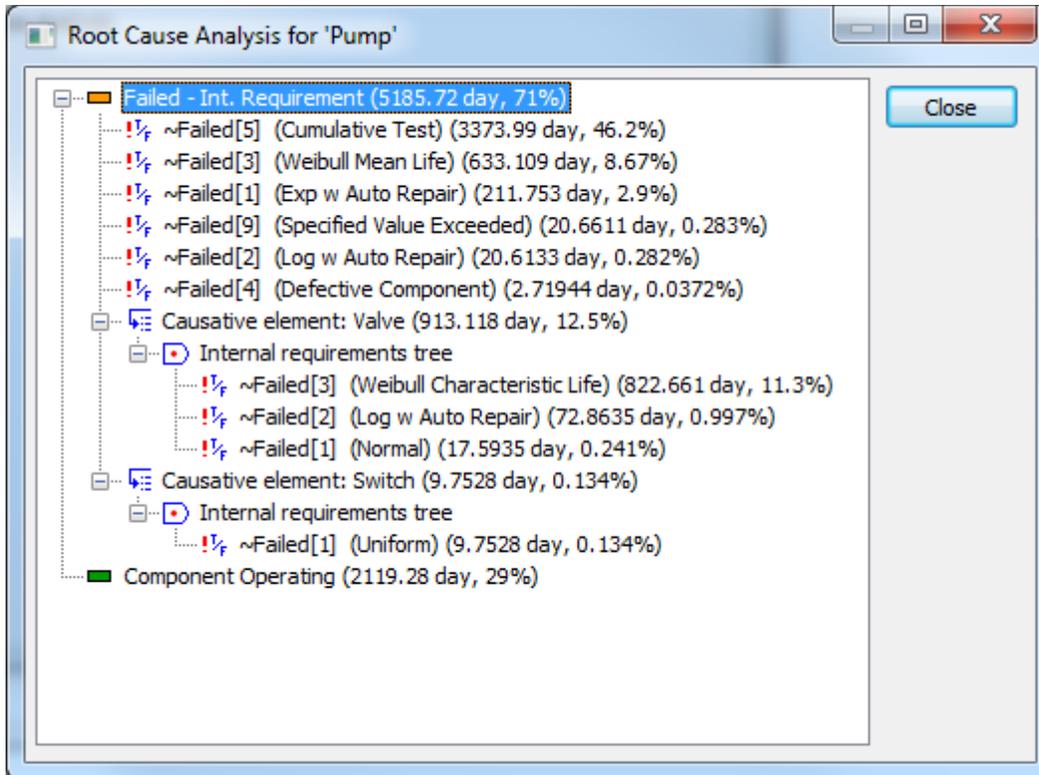


Figure RL19

RL20_Resources

This test verifies the proper functioning of Resources features in the Reliability elements.

In the test there are a number of stores, both global and local, and two Reliability elements (a Function and an Action element). Each uses an AutoOn trigger, but requires one or more "StartCartridges" to turn on - which are not delivered until $ETime \geq 10d$. Both components should begin operating at that time, and consume fuel from their local stores while they are operational. They will run out of their initial stockpile of fuel, then shutdown. After 40d, they begin to receive fuel at the same rate it is consumed, and restart. They then fail at the same time (65d). A maintenance worker is shared between the two elements, so one is repaired while the other waits. Both eventually return to service.

In addition to the status of the elements, the behavior of triggered Actions using resources is also tested. Each triggered action requires a unit of Catalyst. There is an initial stockpile of 5 units, and this is replenished at day 10. A regular Timed Event triggers the Action once per day. The Action fails 5 times (as there is catalyst available, but the unit is not on), then immediately issues 5 Actions when the store of Catalyst is replenished at day 10. One Action per day is then successful until day 20.

Run the model and compare the Results in the Status, Action and Replace_Status plots to RL20_1 through RL20_3 below. Note that in Figure RL20_1 the Action element's output is shifted by 1 day. Both exact agreement or a one timestep shift are acceptable.

Reliability Element Status

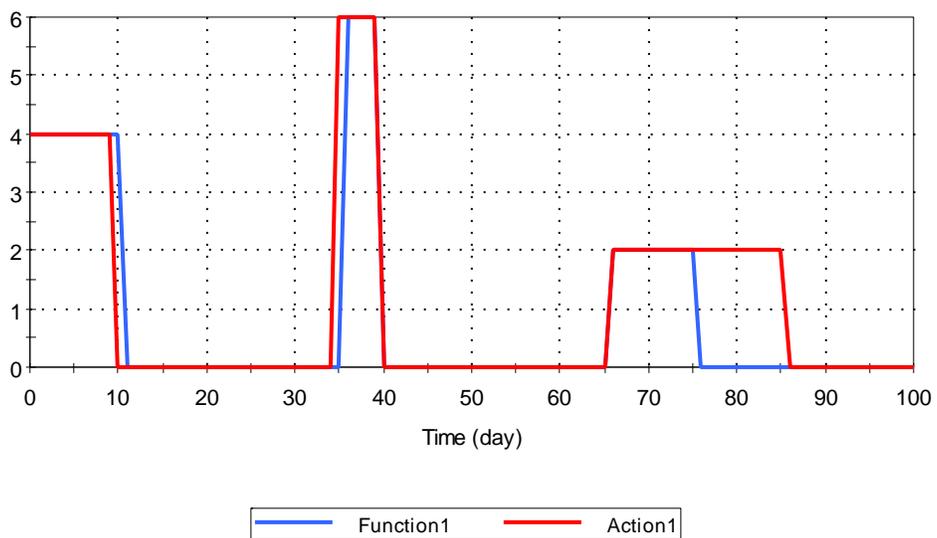


Figure RL20_1

Action Outputs

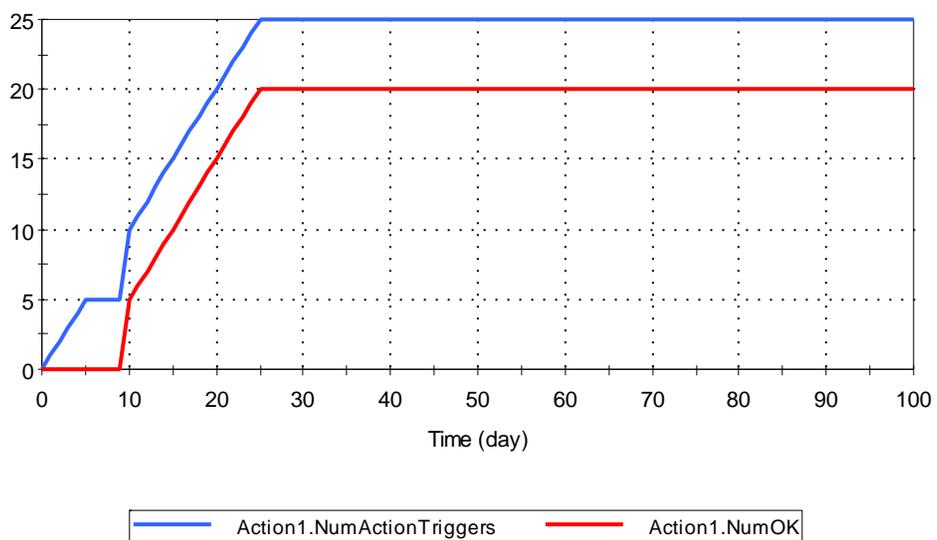


Figure RL20_2

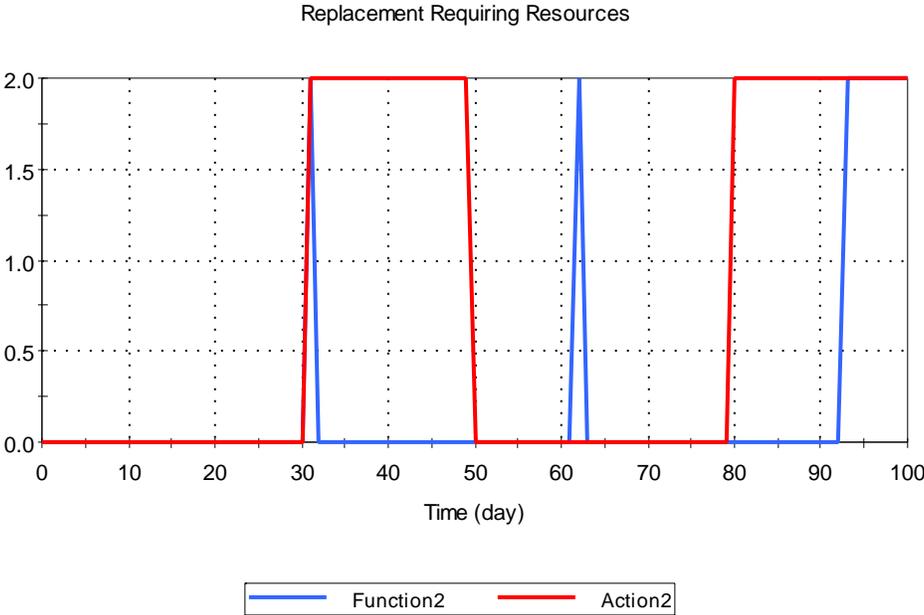


Figure RL20_3

7. OPTIMIZATION MODULE TESTS

Access the Optimization dialog by going to Run|Optimization. Test the Optimization dialogs to ensure that all buttons, drop-downs, and fields work as expected, in both the Define Optimization Settings and Run Optimization tabs.

OP_01_Maximum_Minimum

Open the test file “OP_01_Maximum_Minimum” and follow the instructions in the file. This file tests GoldSim’s ability to locate a minimum and a maximum within a specified range.

The tester should select the High precision level and optimize the model with the goal set to Maximize, and then with the goal set to Minimize. The tester should also confirm that selecting “Copy optimized values to element definitions” after closing the optimization dialog, and then running a deterministic simulation provides the same objective function value.

A successful test is indicated by locating a maximum at $X=0.22488$ with $F(X)=.788685$, and a minimum at $X=0.72488$ with $F(X)=-0.47836$. Test results should correspond with the actual results to four significant figures.

OP_02_Boolean_Integer_Conversion

Open the test file “OP_02_Boolean_Integer_Conversion” and follow the instructions in the file. This file tests GoldSim’s ability to use both integer and Boolean optimization variables, and also ensures the proper conversion between different units. This test also checks that optimized values are correctly propagated as local properties when the "Copy optimized values to element definitions " option is selected.

The tester should ensure that the start values for X, Y, and TF are set to their defaults (0, 0, and false respectively). They should then run the optimizer with Precision set to Low through five optimization cycles (it should first be verified that the “Randomize Optimization Sequence” option is checked), selecting “Copy optimized values to initial values of optimization variables” when closing the optimization dialog at the end of each optimization run. After the fifth cycle choose the “Copy optimized values to element definitions” option and then run a deterministic simulation to check that the objective function corresponds with its optimized value (thus verifying that the controlled elements have been assigned the optimized values). The tester should ensure that the results are acceptable, as described in the next paragraph, and then repeat the procedure (without copying optimized values) for Precision settings of Medium and High.

This problem has a strict optimum of $F=0.000762m$, with $X=1.2345$ ft/0.37628m, $Y=9$ and TF equal to true.

For the Low precision setting, an acceptable result after five optimization runs is indicated by $F<0.1$.

For the Medium precision setting, an acceptable result after five optimization runs is indicated by $F<0.01$.

For the High precision setting, an acceptable result after five optimization runs is indicated by $F<0.001$.

The optimized variables for the High precision level should also correspond closely with the optima listed above. The optimized value for X should correspond to 4 decimal places, and values for Y and TF should be equal to the optimal values.

OP_03_Conditions

Open the test file "OP_03_Conditions" and follow the instructions in the file. This test is designed to test the optimizer's ability to locate an overall maximum, as well as the "Require this condition to be true" feature in the optimizer.

The tester should first ensure the following initial settings:

Sphere	X-coordinate	Y-coordinate	Z-coordinate	Radius
1	X1 = 1	Y1 = 8	Z1 = 4	R1 = 2
2	X2 = -2	Y2 = -2	Z2 = -2	R2 = 7
3	X3 = 10	Y3 = 0	Z3 = 0	R3 = 4

In the simulation settings dialog "Repeat sampling sequences" should be unchecked, and the optimizer should be set to the High precision level.

- 1) Run the optimizer with the following settings for the reject region: Xreject=0, Yreject=1 and Rreject=3. The optimizer should report an optimum solution of 5.9999 or greater at a point within the square between [0.99, 7.99] and [1.01, 8.01]).
- 2) Run the optimizer with the following settings for the reject region: Xreject=1, Yreject=8 and Rreject=1 (this places a small reject region inside of sphere 1). The optimizer should report an optimum solution of 4.99 or greater, but this is not the true maximum. Up to 10 further optimization runs should be conducted to ensure that the optimizer reports a maximum value of 5.73 or greater at a point along the perimeter of the reject region.
- 3) Run the optimizer with the following settings for the reject region: Xreject=1, Yreject=8 and Rreject=2 (this eliminates sphere 1 from consideration). The optimizer should report an optimum solution of 4.99 or greater (at a point within the square between [-2.01, -2.01] and [-1.99, -1.99]).
- 4) Run the optimizer with the following settings for the reject region: Xreject=-1, Yreject=0 and Rreject=10 (this eliminates sphere 1 and 2 from consideration). The optimizer should report an optimum solution of 3.99 or greater (at a point within the square between [9.99, -0.0001] and [10, 0.01]).

OP_04_Maximum

This test ensures the correct functioning of the Maximum optimization option.

The test uses an Objective Function that is likely to require a high number of realizations before the optimizer will converge. The upper limit of the expression is 0.2 and the lower limit is -0.2.

The verifier should run the model with the Optimizer set to Maximize and the Precision set to High. The optimization should then be rerun with the precision set to Maximum. Both optimizations should converge to an optimum value close to the 0.2 limit for the equation (>0.199 is acceptable in both cases).

The test should then be repeated for High and Maximum precision settings with the Optimizer set to Minimize. Again, both optimizations should converge to an optimum value close to the -0.2 limit for the equation (<-0.199 is acceptable in both cases).

When running a Maximum precision optimization the verifier can terminate the optimization before it converges if more than 5000 realizations have been run and the Objective Function value is within the acceptable range.

OP_05_Submodel

This test embeds test OP_01_Maximum_Minimum within a SubModel element to ensure that submodel optimization performs as expected.

The user should run the model, and confirm that the SubModel executes at time 10 days, and returns a value close to 0.72488.

8. LICENSING TESTS

Supersedes licensing tests in GSO.

See the document entitled GoldSim_Licensing_Tests.doc. In SourceSafe, this document is located in \$/Verification/GoldSim.

9. FINANCIAL MODULE

See the document entitled FN Vplan.doc. In SourceSafe, this document is located in \$/Verification/GoldSim/Financial.

10. REFERENCES

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- Barten, W. (1996b). PICNIC-I test cases: Fracture Case, Paul Scherrer Institut
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APPENDIX I: TEST FILES

File Names	Description
CT_Cells1-01 – CT_Cells1-07	Cells: partitioning/Solubility
CT_Cells2-01 – CT_Cells2-10	Cells: advective links
CT_Cells3-01 – CT_Cells3-16	Cells: diffusive links
CT_Cells4-01 – CT_Cells4-05	Cells: decay
CT_Cells5-01 – CT_Cells5-03	Cells: time-varying
CT_Cells6-01 – CT_Cells6-02	Cells: cell nets
CT_ExtPath-01 – CT_ExtPath-03	External pathways
CT_Pipes-01 – CT_Pipes-09	Pipe pathways
CT_Net01 – CT_Net03	Network pathways
CT_Result-01 – CT_Result-07	Results
CT_SourceSampledFailure-01	Random source-term failures
CT_SourceTableFailure-01 – CT_SourceTableFailure-07	Source failure using table-defined failure distributions
CT_SourceBasic01 – CT_SourceBasic11	Basic source-term tests
CT_SourceBarriers01 – CT_SourceBarriers23	Source-term barrier tests
CT_SourceDecay-01	Source-term decay calculation
CT_SourceExposure-01 – CT_SourceExposure-04	Source term- exposure
CT_Species_Import	Spreadsheet import of species data (half-lives and decay rates)
CT_Species_Import_Export	Spreadsheet import and export of species data (half-lives and decay rates)
CT_Clone3	Tests cloning of all CT elements
CT_Conditionality1	Conditionality of environmental elements
CT_Timestep	Variable timestep for CT elements
CT_Recept-01	Receptor Element
TimeMonteCarlo-01 – TimeMonteCarlo-07	Time & Monte Carlo tests
GS0_Run_Controller	Tests the GoldSim Run Controller
GS00_User_Interface_Tests	Tests GoldSim user interface
GS00a_FilterGraphicsOptions	Tests filtering and custom influences
GS01_Spreadsheet	Spreadsheet
GS02_expressions	Expressions
GS03_array	Arrays
GS04_Stochastics ,GS04a_Stoc_Array, GS04b_Conditional_Tail_Expectation	Stochastic elements
GS05_Integrator1	Integrator elements
GS06-Integrator2	Integrator elements
GS07_selectors	Selector elements
GS08_look	Lookup-table elements
GS09a_dbas, GS09b_dbas, and GS09aFile_Element	Database connection
GS10_Clone1	Clone elements
GS11_Clone2	Clone elements
GS12_ext	External element

GS13_Sum	Sum element
GS14_Extrema	Extrema element
GS15_logical	And, Or, Not elements
GS16a_Event and Discrete Change Delays GS16b_Information and Material Delays	Delay elements
GS17_Timed_Events_and_Discrete_Changes	Timed events and Discrete Change elements
GS18_Random_Timed_Events	Timed Event element
GS19_Reservoir	Reservoir element
GS19a_Reservoir2	Reservoir element
GS20_Element_Activation	Activation, deactivation, and reactivation of containers and elements
GS21_Conditional_Containers	Container Conditionality tests
GS22_Datetime	Date/time based runs
GS23_Elapsedtime	Elapsed time runs
GS24_Timestep	Timestep phases
GS25a_Multiprocessor_Dynamic	Test multiprocessor solution for dynamic models
GS25b_Multiprocessor_Static	Test multiprocessor solution for static models
GS26_Event_Substep	Updating Event during timestep
GS27_Triggering	Triggering
GS28_Deterministic Options	Deterministic simulation settings
GS29_External2	Table-definition output for external elements
GS30_Table_Function	Tests table-call function
GS31_Param_Import_Samp	Importance sampling of parameters
GS32_Save_Results	Result Saving
GS33_Previous_Timestep_Value	Tests Previous-Timestep Operator (~)
GS34_Modify_Units_and_Sets	Ordinal sets and user-defined units
GS35_Dynamic_Export	Result Export
GS36_Static_Export	Result Export
GS37_Initial_Values_and_Previous-Value_Links	Initial values and feedback links
GS38_Changed_and_Occurs	Changed() and Occurs()
GS39_Decision_Milestone_Status	Decision, Milestone, and Status elements
GS40_Information_Time_Series	Information Time Series elements
GS40b_TimeSeriesExcelSupport	Excel support for time history elements
GS41_Material_Time_Series	Material Time Series elements
GS42_Date_Time_Series	Date/Time simulations for Time Series elements
GS43_Versioning	Versioning of model files
GS44_External_File_Locking	File locking of external files
GS45_Command-Line_Arguments	Command Line Arguments
GS46_Dashboard_and_Player 1 and 2, GS46a_Dynamic_Dashboard	Dashboard element and GoldSim Player
GS47_Masterclock_Outputs	Outputs of the Masterclock
GS48_Convolution and GS48b_Truncated_Convolution	Convolution elements

GS49_RandomChoice	Random choice element
GS50_LookupTables	Lookup table elements
GS51_Looping	Looping subsystems
GS52_InternalClocks	Submodels with internal clocks
GS53_Sensitivity	Sensitivity Analysis
GS54_Splitter	Splitter elements
GS55_Allocator	Allocator Elements
GS56_History_Generator	History Generator elements
GS57_Interrupt	Interrupt elements
GS58_Currencies	Currency dialog/conversion
GS59a through GS59i	Submodel Tests
GS60_TimeSeries	Time Series Elements
GS60b_TimeSeriesExcelSupport	Time Series Excel Links
OP_01_Maximum_Minimum	Ability to locate a maximum and minimum
OP_02_Boolean_Integer_Condition	Tests optimization of Boolean and integer variables, and respect of a user-defined condition
OP_03_Conditions	Tests user-defined conditions and restrictions on optimized values
OP_04_Maximum	Tests maximum optimization option
Result-01 to Result-14	Result display
RL_01_Failure_Modes	Tests all of the reliability element failure modes
RL_02_FMCV	Tests built in and user defined failure mode control variables
RL_03_Automatic_Repair_Distributions	Tests automatic repair distributions
RL_04_Outputs	Tests reliability element outputs
RL_05_Requirements	Tests requirements trees
RL_06_PMReplace	Tests PM modes
RL_07_Combined_Failure_Modes	Tests multiple failure modes
RL_08_Cloning	Tests cloning of RL elements
RL_09_Dynamic_Fields	Tests dynamic fields in RL elements
RL_10_Action_Delay	Tests the delay features of the Action RL element
RL_11_Static_Model	Tests the operation of RL elements in a static model
RL_12_Reliability_Availability	Tests reliability and availability statistics
RL_13_Failure_Repair	Tests time to failure and time to repair statistics
RL_14_Tree_States	Tests that RL element states are correctly identified and catalogued
RL_15_Root_Cause_Analysis	Tests root cause analysis functionality
RL_16_Event_Driven_System	Tests that results for event driven systems are calculated correctly.

APPENDIX II AUTOMATIC TEST FILES (Updated for GoldSim 10.10)

//Automatic Tests for GoldSim's Ctrl-F8 Test Procedure

//Normal parsing of numbers

9
9.
9.2
.9
0.9
9E3
9.E3
9.2E3
9E-3
9.E-3
9.2E-3
9.222E-15
1.23456789012345
1.2345678901234545

//Parse-errors in numbers

9876543210987654321.5
2.1098765432109876543
0.9876543210987654321
5E-10000
5E10000
A.
A.1
1.XA
.A
0.XA
9EA
AE3
9.87654321A9876543
9876543210987654321.0XA
9.876543210987654321XA9
98.76 54321

//Normal parsing of identifiers

GEE+2*GEE-GEE*3+SQRT(GEE^2) gee
GEE/2 gee
GEE gee
Gee gee

//Parse-errors in identifiers

GEE+2 gee
GEE-2 gee
GEE* gee
GEE/0 gee
GEE/ gee
Sqrt(gee) gee
SQRT-GEE gee
2^GEE gee
GEEE gee

```
Gee. gee

//Normal parsing of binary operators
5+2
5-2
5*2
5/2
5^2
5>2
5>=2
2<5
2<=5
5=5
5==5
5!=2
5<>2
5 + 2
(1==1) and (1==1) or (1==1)
(1==1) and (1==2)
(1==1) and (1==1) or (1==2)
(1=1) and (1=1) or (1=2)
5<2
5==2
5<>5

//Parse-errors in binary operators
5>>2
5?0
5=!2
5=>2

//Normal parsing of unary operators
NOT (1==1)
-5
-(-5)
-5^2
(-5)^2
!(1==1)
!(1==2)
NOT (1==1)
NOT NOT (1==1)
NOT (1==2)
--5
---5
-0

//Parse-errors in unary operators
!!5
-b
!B
5!
NOT^2
!^2
-^2
(!)5
(NOT (1==2))^2
- 5
```

```
//Normal parsing of func1()
SIN(1)
COS(1)
TAN(1)
COT(1)
SINH(0.5)
COSH(0.5)
TANH(0.5)
ASIN(0.75) deg
ACOS(0.75)
ATAN(0.75)
ATAN(5)
LN(0.5)
LOG(222)
ABS(5)
ABS(-2)
SIN(5{deg})
SIN(pi/2)
COS(3*(pi/4))
SINH(5)
COSH(5)
TANH(5)
Round(1.4999)
Round(-1.4999)
Trunc(1.4999)
Trunc(-1.4999)
Sqrt(10^2)
Floor(1.6)
Floor(-1.6)
Floor(3.999999999999)
Ceil(1.6)
Ceil(-1.6)
Ceil(4.000000000001)
gm2cm(.05)
cm2gm(.05)

//Errors in func1()
ASIN(5)
ACOS(5)
LN(-2)
LOG(-2)
SIN(2A)
COS(9876543210987654321.01)
SIN(5{ft})
Sqrt(-2)
Exp(ln(2)

//Normal parsing of fun2(,)
BESS(2,10)
BESS(10,10)
BESS(100,50)
BESS(-5,10)
BESS(15.1,2)
MIN(1,5)
MIN(BESS(2,10),BESS(10,10))
MAX(1,5)
MAX(BESS(2,10),BESS(10,10))
```

```
MOD(8,3)
MOD(-2,5)
MIN(2,2)
MAX(2,2)
min(1,5)
max(1,5)
mod(8,3)
0.5*erf(1.96/sqrt(2))
beta(1,2)
beta(3,4)
Ftop(.05,10)
Ptof(.05,10)
Atop(.05,10)
Atof(.05,10)
Ptoa(.05,10)
pc2cc(.05,10)
cc2pc(.05,10)
ari2cm(.05,.10)
ari2vol(.05,.10)
geo2vol(.05,.10)

//Errors in func2(,)
BESS(5,-10)
MIN(BESS(5,-10),BESS(2,10))
MAX(BESS(-5,10),BESS(2,10)
MOD(2,0)
BSS(2,10)
MN(1,2)
MX(2,3)
MAD(2,10)
MIN(2, )
MAX( ,3)
MIN(2,3)
MAX3,4
Beta(-1,2)

//Normal func3(,,)
if((1==1),2,3)
if((1==2),1,2)
if((1==1),5,3)
if      ((1==1),2,3)
if((1==1) and (1==1),3,4)
if((1==2) or (1==1),2,3)
if((1==2) and (1==1),2,3)
If((1==1),2,3)
IF((1==1),2,3)
If((1==1) then 2 else 3)

//Errors in func3(,,)
if{(1==1),2,3}
if((1==1),2)
if((1==1))
if((1==1), , )
if(1*,2,3)
if(A,2,3)
```

```

iff((1==1),2,3)
if1,2,3

//Normal parsing of units
2{m2} m2
2{m^2} m2
5{g/l} g/l
5{lbf-ft2} lbf-ft2
5{(m2/sec)/(ft-lbf)} (m2/sec)/(ft-lbf)
5{(g)/(l)} g/l
5{(g/l)} g/l
5{(lbf)-(ft2)} lbf-ft2
5{lbf-ft2} lbf-ft2
3{in}*5{lbf}
(6{ft})|in|
"3/11/98 23:30:00"- "3/11/98 10:00:00" day
"3/11/98" - "12/25/2001" day
-10C K
(-10C) K
-10F R
(-10F) R

//Parse-errors in units
2{(m)2} m2
2{m(2)} m2m2 m2
2m^2 m2
2{(m)^2} m2
2{m^(2)} m2
2{{m2}} m2
5{g//l} g/l
3{in}+5{lbf}
3{in}^5{lbf}
"3/11/98 25:30:00"- "3/11/98 10:00:00"
"3/11/98 - "12/25/2001"

//Normal precedence
(-2)^2/4*2+8-5>2 or (1==1) and (1==2)
(2*(-2)^3/4)^2-8
-(2*5)/5*4
(80-3*4*(2^3+2)/5>6/3)

```

File UnitsEcho0.txt:

GoldSim Version 9.29.975

```

1 {$} $ 1
1 {'} m 0.3048
1 {"} Missing closing "" for date operator
1 {°} rad 0.0174532925199433
1 {a} s 31557600
1 {ac} m2 4046.8564224
1 {acre} m2 4046.8564224
1 {af} m3 1233.48183754752
1 {afd} m3/s 0.0142764101568
1 {amp} amp 1
1 {pamp} amp 1e-012
1 {namp} amp 1e-009
1 {uamp} amp 1e-006
1 {mamp} amp 0.001
1 {kamp} amp 1000
1 {Mamp} amp 1000000
1 {Gamp} amp 1000000000
1 {Tamp} amp 1000000000000
1 {Ang} m 1e-010
1 {atm} kg/m-s2 101325
1 {bar} kg/m-s2 100000
1 {pbar} kg/m-s2 1e-007
1 {nbar} kg/m-s2 0.0001
1 {ubar} kg/m-s2 0.1
1 {mbar} kg/m-s2 100
1 {kbar} kg/m-s2 100000000
1 {Mbar} kg/m-s2 100000000000
1 {Gbar} kg/m-s2 100000000000000
1 {Tbar} kg/m-s2 1e+017
1 {bbl} m3 0.1589873
1 {bbl dry} m3 0.11563
1 {bbl liq} m3 0.11924
1 {bpd} m3/s 1.84013078703704e-006
1 {Bq} 1/s 1
1 {pBq} 1/s 1e-012
1 {nBq} 1/s 1e-009
1 {uBq} 1/s 1e-006
1 {mBq} 1/s 0.001
1 {kBq} 1/s 1000
1 {MBq} 1/s 1000000
1 {GBq} 1/s 1000000000
1 {TBq} 1/s 1000000000000
1 {BTU} kg-m2/s2 1055.056
1 {bushel} m3 0.03523907
1 {C} K 274.15
1 {cal} kg-m2/s2 4.1868
1 {pcal} kg-m2/s2 4.1868e-012
1 {ncal} kg-m2/s2 4.1868e-009
1 {ucal} kg-m2/s2 4.1868e-006
1 {mcal} kg-m2/s2 0.0041868
1 {kcal} kg-m2/s2 4186.8
1 {Mcal} kg-m2/s2 4186800
1 {Gcal} kg-m2/s2 4186800000
1 {Tcal} kg-m2/s2 4186800000000
1 {cc} m3 1e-006
1 {cd} cd 1
1 {pcd} cd 1e-012
1 {ncd} cd 1e-009
1 {ucd} cd 1e-006
1 {mcd} cd 0.001
1 {kcd} cd 1000

```

1 {Mcd}	cd	1000000
1 {Gcd}	cd	1000000000
1 {Tcd}	cd	1000000000000
1 {Cdeg}	K	1
1 {cfs}	m ³ /s	0.028316846592
1 {Ci}	1/s	37000000000
1 {cm}	m	0.01
1 {Co}	s-amp	1
1 {pCo}	s-amp	1e-012
1 {nCo}	s-amp	1e-009
1 {uCo}	s-amp	1e-006
1 {mCo}	s-amp	0.001
1 {kCo}	s-amp	1000
1 {MCo}	s-amp	1000000
1 {GCo}	s-amp	1000000000
1 {TCo}	s-amp	1000000000000
1 {cp}	kg/m-s	0.001
1 {cup}	m ³	0.00023658825
1 {cycle}	rad	6.28318530717959
1 {d}	s	86400
1 {Darcy}	m ²	9.86923266716013e-013
1 {day}	s	86400
1 {deg}	rad	0.0174532925199433
1 {dyne}	kg-m/s ²	1e-005
1 {eV}	kg-m ² /s ²	1.60217733e-019
1 {peV}	kg-m ² /s ²	1.60217733e-031
1 {neV}	kg-m ² /s ²	1.60217733e-028
1 {ueV}	kg-m ² /s ²	1.60217733e-025
1 {meV}	kg-m ² /s ²	1.60217733e-022
1 {keV}	kg-m ² /s ²	1.60217733e-016
1 {MeV}	kg-m ² /s ²	1.60217733e-013
1 {GeV}	kg-m ² /s ²	1.60217733e-010
1 {TeV}	kg-m ² /s ²	1.60217733e-007
1 {F}	K	255.9277777777778
1 {Fa}	s ⁴ -amp ² /kg-m ²	1
1 {fath}	m	1.8288
1 {Fdeg}	K	0.5555555555555556
1 {flng}	m	201.168
1 {floz}	m ³	2.957353125e-005
1 {fpm}	m/s	0.00508
1 {fps}	m/s	0.3048
1 {ft}	m	0.3048
1 {g}	kg	0.001
1 {pg}	kg	1e-015
1 {ng}	kg	1e-012
1 {ug}	kg	1e-009
1 {mg}	kg	1e-006
1 {kg}	kg	1
1 {Mg}	kg	1000
1 {Gg}	kg	1000000
1 {Tg}	kg	1000000000
1 {gal}	m ³	0.003785412
1 {gali}	m ³	0.00454609
1 {galus}	m ³	0.003785412
1 {gee}	m/s ²	9.80665
1 {gf}	kg-m/s ²	0.00980665
1 {gpm}	m ³ /s	6.30902e-005
1 {Gy}	m ² /s ²	1
1 {pGy}	m ² /s ²	1e-012
1 {nGy}	m ² /s ²	1e-009
1 {uGy}	m ² /s ²	1e-006
1 {mGy}	m ² /s ²	0.001
1 {kGy}	m ² /s ²	1000
1 {MGy}	m ² /s ²	1000000

1 {GGy}	m2/s2	1000000000
1 {TGy}	m2/s2	1000000000000
1 {ha}	m2	10000
1 {hp}	kg-m2/s3	745.699920901874
1 {hr}	s	3600
1 {Hz}	1/s	1
1 {pHz}	1/s	1e-012
1 {nHz}	1/s	1e-009
1 {uHz}	1/s	1e-006
1 {mHz}	1/s	0.001
1 {kHz}	1/s	1000
1 {MHz}	1/s	1000000
1 {GHz}	1/s	1000000000
1 {THz}	1/s	1000000000000
1 {in}	m	0.0254
1 {J}	kg-m2/s2	1
1 {pJ}	kg-m2/s2	1e-012
1 {nJ}	kg-m2/s2	1e-009
1 {uJ}	kg-m2/s2	1e-006
1 {mJ}	kg-m2/s2	0.001
1 {kJ}	kg-m2/s2	1000
1 {MJ}	kg-m2/s2	1000000
1 {GJ}	kg-m2/s2	1000000000
1 {TJ}	kg-m2/s2	1000000000000
1 {K}	K	1
1 {pK}	K	1e-012
1 {nK}	K	1e-009
1 {uK}	K	1e-006
1 {mK}	K	0.001
1 {kK}	K	1000
1 {MK}	K	1000000
1 {GK}	K	1000000000
1 {TK}	K	1000000000000
1 {kgf}	kg-m/s2	9.80665
1 {kip}	kg-m/s2	4448.22190946
1 {kp}	kg/m-s2	98066.5
1 {kph}	m/s	0.2777777777777778
1 {kt}	m/s	0.5144444444444444
1 {kwh}	kg-m2/s2	3600000
1 {l}	m3	0.001
1 {pl}	m3	1e-015
1 {nl}	m3	1e-012
1 {ul}	m3	1e-009
1 {ml}	m3	1e-006
1 {kl}	m3	1
1 {Ml}	m3	1000
1 {Gl}	m3	1000000
1 {Tl}	m3	1000000000
1 {lamb}	cd/m2	10000
1 {lbf}	kg-m/s2	4.44822190946
1 {lbm}	kg	0.4535924
1 {lm}	cd	0.0795774715459477
1 {lx}	cd/m2	1
1 {ly}	m	9.4607304725808e+015
1 {m}	m	1
1 {pm}	m	1e-012
1 {nm}	m	1e-009
1 {um}	m	1e-006
1 {mm}	m	0.001
1 {km}	m	1000
1 {Mm}	m	1000000
1 {Gm}	m	1000000000
1 {Tm}	m	1000000000000
1 {md}	m2	9.86923266716013e-016

1 {MGD}	m ³ /s	0.04381263888888889
1 {mgf}	kg-m/s ²	9.80665e-006
1 {mi}	m	1609.344
1 {mil}	m	2.54e-005
1 {min}	s	60
1 {minarc}	rad	0.000290888208665722
1 {mol}	mol	1
1 {pmol}	mol	1e-012
1 {nmol}	mol	1e-009
1 {umol}	mol	1e-006
1 {mmol}	mol	0.001
1 {kmol}	mol	1000
1 {Mmol}	mol	1000000
1 {Gmol}	mol	1000000000
1 {Tmol}	mol	1000000000000
1 {mon}	s	2629800
1 {mpg}	1/m ²	425143.683171079
1 {mph}	m/s	0.44704
1 {N}	kg-m/s ²	1
1 {pN}	kg-m/s ²	1e-012
1 {nN}	kg-m/s ²	1e-009
1 {uN}	kg-m/s ²	1e-006
1 {mN}	kg-m/s ²	0.001
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- 6. REQUEST TO INSTALL PRODUCTION WELL IN SECTION 29 (Envirocare, 2005)**

ENVIROCARE OF UTAH, LLC.

SAFE AND SECURE

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CD05-0171

April 11, 2005

Dane Finerfrock, Executive Secretary
State of Utah
Division of Water Quality
168 North 1950 West
P.O. Box 144850
Salt Lake City, Utah 84114-4850

Re: Request to install production well – submittal of revised modeling

Dear Mr. Finerfrock:

Envirocare of Utah, LLC (Envirocare) has a Groundwater Quality Discharge Permit UGW450005 (GWQDP) issued by the Division of Water Quality (DWQ) and administered by the Division of Radiation Control (DRC). Condition I.E.18 of the GWQDP requires that Envirocare receive approval prior to installing a pumping well. On September 8, 2004, Envirocare submitted for DWQ review and approval a groundwater model to demonstrate pumping effects on the shallow, unconfined aquifer. On December 17, 2004, DWQ's consultant, URS, provided comments on the model and on February 11, 2005, a conference call was held to discuss a path forward. The enclosed modeling report incorporates changes agreed upon during the February 11, 2005, conference call. Envirocare has also attached a Technical Memorandum specifically addressing the December 17, 2004, Interrogatories.

Also discussed during the conference call was the preparation of a "post-model audit plan". The purpose of this plan is to evaluate how the production well affects the shallow, unconfined aquifer beneath the site. The remainder of this letter provides the requested information.

The groundwater model demonstrates that the production wells will not impact groundwater flow in the shallow, unconfined aquifer. The results of the model indicate that a production well screened from 550 to 600 feet below ground surface (bgs), pumped at 200 gallons per minute, 24 hours per day, 4 months per year (122 days), would create approximately 0.5 feet of drawdown in the upper aquifer after 20 years. This drawdown will not affect the hydraulic gradient beneath the facility.

Condition I.H.2.c)2. of the GWQDP specifies hydraulic gradient limits for all disposal facilities at the Envirocare facility. Specifically, the limits are as follows:

ENVIROCARE

Disposal Cell	Horizontal Hydraulic Gradient Limit
Class A	1.00 E-3
LARW	9.67 E-4
Mixed Waste	9.67 E-4
11c.(2)	3.29 E-3

These limits were used in the previous modeling exercises to demonstrate compliance with the Groundwater Protection Levels. Envirocare is required [Conditions I.F.5.a), I.F.5.b), and I.H.2.a)] to measure and report groundwater elevations on a monthly basis and calculate fresh-water and salt-water gradients. It is important to note that based on the conservative fate and transport modeling (HELP, UNSAT-H, and PATHRAE), contaminants from the disposal cell won't reach the water table for many years. Any effects from the production wells will have attenuated before any transport can occur.

Even though the MOD-FLOW model demonstrates little to no impact on the shallow, unconfined aquifer, Envirocare commits that should production wells cause the average gradients beneath any of the disposal embankments to go above the specified horizontal hydraulic gradient. Envirocare will shut down the production wells until either:

- 1) the average hydraulic gradient returns to below the specified value, or
- 2) Envirocare remodels the disposal cell using the new average gradient value and demonstrates that the groundwater protection levels are met.

In addition, Envirocare commits to the installation of two observation wells in the immediate vicinity of the production well north of our current operations. Monitoring wells G-19A (screened from 18 to 28 feet bgs), GW-19B (screened from 79 to 99 feet bgs), and piezometer PZ-1 (screened from 19 to 29 feet bgs) will fulfill this requirement for the production well near the southwest corner pond. These wells will also be monitored on a monthly basis, which will provide information to evaluate if the production well is affecting the vertical gradient in the shallow, unconfined aquifer and deeper, confined aquifer.

Envirocare is located in a groundwater discharge area. Condition I.H.2.b)2. requires that the upper gradient be calculated on a monthly basis. The two new observation wells installed with northern production well can be added to this condition for reporting. Should the vertical gradient be reversed, Envirocare will immediately notify the DWQ and provide an evaluation of how this reversal will impact the long-term performance of the facility.

ENVIROCARE Summary

Envirocare currently uses approximately 20,000,000 gallons of salt water for dust control at our Clive facility. This water is trucked from a production well located north of Interstate-80. Envirocare requests that the DRC approve the installation and use of the two production wells to reduce truck traffic and costs associated with hauling water. Envirocare commits to monitor and report the effects of the production wells on the shallow, unconfined aquifer as part of the monthly monitoring program. Should the operation change the hydraulic gradient beneath the disposal sites to an un-analyzed condition, Envirocare commits to stopping production. Envirocare also commits to installing and monitoring one shallow and one intermediate depth well for the northern production well in order to evaluate the vertical gradient.

Envirocare is committed to protecting human health and the environment. Although there are no known receptors for the groundwater beneath the facility, Envirocare will continue to protect this groundwater as if there were an end use. The conservative nature of the modeling coupled with the poor groundwater quality beneath the facility means that there is little risk in allowing Envirocare to install the proposed production wells.

Should you have any questions regarding this letter or if you would like to discuss the content or substance of this letter, please feel free to contact me at (801) 532-1330.

Sincerely,



Daniel B. Shrum
Director of Safety and Compliance

Enclosures

Cc: Bob Baird, URS, w/ attachments

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

To: Dan Shrum, Envirocare of Utah, Inc.
From: Susan Wyman, P.E., P.G., Whetstone Associates, Inc. *SAW*
Date: March 15, 2005
Subject: Response to Interrogatories, Pumping Well Modeling

4101U

On behalf of UDEQ DRC, URS Corporation submitted comments on the numerical groundwater models created to assess the potential drawdown in the surficial aquifer from production well(s) at the Envirocare facility located at Clive, Utah. The Modflow modeling was performed by Whetstone Associates and presented in two technical memoranda dated April 9, 2003 and September 7, 2004. The interrogatory comments were received in December 2004, and a conference call was held between Envirocare, Envirocare's consultant (Whetstone Associates), and DRC's consultant (URS). This memorandum addresses the interrogatories presented in the December 2004 URS memo, as clarified in the February 2005 conference call.

Interrogatory #1A. Please provide discussion on regional groundwater flow and how the present local flow model dovetails into it.

Background. Some discussion and quantification of regional flow is necessary because of the artificial boundaries (upgradient and downgradient) used in the model. Also note that the development of a quantitative regional model is sometimes useful to help set such boundaries.

Interrogatory #1B. Please provide a discussion and graphic of the conceptual model with an emphasis on hydrostratigraphic units and natural boundary conditions (or lack thereof). Aquifer parameters and model layers should be identified/characterized within this context. If newer data have augmented or modified earlier interpretation then this should be discussed. If not, relate the current conceptual model (and MODFLOW implementation) to the previous conceptual model.

Background. There is no discussion of the conceptual model. Instead, the narrative (partially) documents a MODFLOW implementation. In addition, the present conceptual model—implicit in the 'Model Domain' discussion—appears to be inconsistent with the information provided in earlier reports, e.g., Pentacore 2000 and Bingham 1996. Earlier reports and modeling consider four (4) units—the upper most being unsaturated.

The statement that "model layers represent geologic material encountered during drilling at the site (p.3)..." is about as close as the memorandum gets to a discussion of the conceptual flow model for the site.

The present model (conceptual aspects) and its parameterization should specifically incorporate the four geohydrological units identified in these earlier reports. (Note, however, the unsaturated zone is not of interest here.)

Response. A description of the regional hydrologic system has been added to the revised report, along with brief discussion of the four hydrostratigraphic units described in previous hydrogeology reports about the site (Bingham [1991, 1992], Pentacore [2000]). As described in the revised report, the regional aquifer comprises the Great Salt Lake Desert sub-basin of the West Desert Basin, a closed basin that drains to the Great Salt Lake. The MODFLOW model represents 4% (234 square miles) of the 6,250 square miles of the Great Salt Lake Desert sub-basin.

The hydrostratigraphic units mapped at the Envirocare site represent the shallow subsurface in a localized area of the model domain. Four units have been identified. The upper unit (Unit 4) is unsaturated. Unit 3 averages 15 ft in thickness and is only partially saturated. Unit 2 averages 15 ft and is typically saturated. The thickness of Unit 1 has not been determined, because few of the wells installed on site are drilled to depths greater than 55 ft. The four hydrostratigraphic units together represent the upper 30 - 50 ft of the aquifer and are incorporated into Layer 1 of the 1,000-ft thick model.

More than 5 deep monitoring wells and piezometers have been installed to depths of 100 – 250 ft. The hydraulic properties of model layers 2-11 and 13-20 were based on information from these borings.

Table 1. Thickness of Upper Hydrostratigraphic Units

HSU	Minimum Thickness (ft)	Maximum Thickness (ft)	Average thickness (ft)	Saturation
Unit 4	6 to 16.5	16.5	10	Unsaturated
Unit 3	7 to 25	25	15	Partially saturated
Unit 2	2.5 to 25	25	15	Saturated
Unit 1	>10	ND	ND	Saturated

Notes: ND = not determined

Interrogatory #2A. Please...explain why changes in bedrock elevation do not need to be incorporated into the present model—be that by means of direct incorporation of some variability of the depth in the model, e.g., through the use inactive Fcells in some of the lower layers, or more simply via sensitivity analyses.

Background. It is clear in earlier reports that the depth to bedrock is variable, e.g., in the 1996 Bingham report: "Because of the lack of detailed subsurface data concerning the bedrock, the exact depth to and relationships of various bedrock units are unknown, however, the presence of nearby outcrops and the regional block-faulted basins suggest that the valley-fill deposits are relatively thin within the area of the site. ..."

Given reasonable estimates for the range of depths to bedrock over the modeled area and in the vicinity of the site, resulting variation in transmissivity may impact the drawdown.

Other possible impacts—bedrock outcrops represent interior no flow areas and also may result in some recharge at interior locations, e.g., one mile to the west and two miles to from the vicinity of Lone Mountain to the south and east.

Response. Changes in bedrock were not incorporated into the April 2003 and September 2004 modeling submissions because:

- Bedrock has not been encountered in any drill holes at the site, as the modeling reports described. The modeling reports provided data for the Cox Construction well and the Broken Arrow well, which were drilled to depths of 350 ft and 620 ft, respectively. (Note that since the Broken Arrow well was drilled in 1996, the same year that the Bingham report was published, the data from this well may not have been included in the Bingham report. The model is based on the more current information, which indicates that the depth to bedrock in the vicinity of the site exceeds 620 ft.)
- In a report on basin-and-range aquifers, the USGS (Robson and Banta, 1995) reported that “the thickness of the basin fill is not well known in some basins, but ranges from about 1,000 to 5,000 feet in many basins, and may exceed 10,000 in a few deep basins in Utah and south-central Arizona.”
- The Utah Division of Water Resources reports that in the Great Salt Lake Desert region, groundwater in bedrock is hydrologically connected the alluvial basins (DWR, 2001). The Utah State Water Plan for the West Desert Basin states that:

“Many of the fault block mountains are underlain by carbonate rocks which provide groundwater flow paths between basins. Therefore much of the southern Great Salt Lake Desert is hydrologically connected in what Gates (1987) calls the ‘Great Salt Lake Desert flow system.’ This system ultimately discharges to Fish Springs Flat, the margins of the Bonneville Salt Flats and the Great Salt Lake.”

- The USGS (Robson and Banta, 1995) also reports that groundwater in the basin-and-range aquifers may flow between the basins by passing through the carbonate rocks in the bedrock ranges:

“Carbonate rocks predominate in a 20,000- to 30,000-foot thick sequence of Paleozoic and Lower Mesozoic rocks in an extensive area of western Utah ... and southern and eastern Nevada.... The location of solution-altered zones of enhanced permeability within these carbonate rocks is poorly known. However, some data indicate that ground water might flow between basins through permeable carbonate rocks in the mountains of west-central Utah, and water might flow from recharge areas in the mountains to local basins through permeable carbonate rocks bordering the northeastern part of the aquifer system.”

For these reasons, changes in bedrock elevation were not incorporated into the base case model. Sensitivity analyses have been added to the revised report to evaluate the effects of an impermeable bedrock high (sensitivity analysis PW-BH) and a shallower (600 ft) depth to bedrock (sensitivity analysis PW-6F).

Interrogatory #2B. Provide more work on the constant head upgradient and downgradient boundary conditions. Why were no sensitivity analyses on the constant heads performed? Also provide alternative model formulations and calculations employing constant flux boundary conditions.

Background. When non-natural hydrological boundary conditions are employed, it is common to both examine constant head and constant flux boundaries conditions, and to perform sensitivities analyses. Similar results across the board demonstrate decoupling of transient effects from the boundaries under question.

Response. It is true that the boundary conditions in the model do not coincide with the physical boundaries of the regional aquifer. The regional aquifer is bounded by the Great Salt Lake to the north, the Cedar Mountains to the east, and by mountain ranges in the state of Nevada to the west. It is impractical to include such a large area in the groundwater model, a fact that is recognized by Anderson and Woessner (1992) and Rumbaugh (2002). Anderson and Woessner state that:

“It may not be possible or convenient to design a grid that includes the physical boundaries of the system if the focus of interest is far removed from the boundaries.”

Rumbaugh states:

“It is desirable to include only natural hydrologic boundaries as boundary conditions in the model. Most numerical models, however, employ a grid that must end somewhere. Thus, it is often unavoidable to specify artificial boundaries at the edges of the model. When these grid boundaries are sufficiently remote from the area of interest, the artificial conditions on the grid boundary do not significantly impact the predictive capabilities of the model.”

The smaller model domain was carved out from the regional system, and hydraulic boundaries, rather than physical boundaries, were applied to the smaller model domain. In this common approach to modeling, “hydraulic boundaries may be defined from a water table map of the area to be modeled,” (Anderson and Woessner, 1992) and no-flow boundaries are located along flow lines with constant head boundaries along equipotential lines. The important consideration is that the simulation must be structured so that pumping from the well will not affect heads or fluxes near the hydraulic boundaries.

Sensitivity analyses have been added to the revised modeling report, investigating lower and higher hydraulic gradients, by setting higher and lower constant heads in cells along the downgradient model boundary. However, since gradient was perhaps the most important component of the model (from which impacts to gradient were determined), the base case model is more applicable for evaluating impacts due to pumping. It should be noted that neither the high nor low-gradient sensitivity analyses indicated unacceptable changes in hydraulic gradient below the individual embankments or below the site as a whole.

Constant flux boundaries (a.k.a. specified flow boundaries) are typically used for physical boundaries such as underflow through a river channel. Fluxes must be generally well defined. In the present model, the source of flow data from which to specify fluxes at every boundary node would have to be derived from the model itself, which was set up using constant heads. Reading the cell-by-cell flows and applying the flows to the boundary cells would be indistinguishable from the constant head boundary solution. Also, Anderson and Woessner (1992) state that, “Although hydrogeologically defensible, exclusive use of flux boundaries generally should be avoided for the following mathematical reason. The governing equation is written in terms of derivatives, or differences in head, so that the solution will be nonunique if the boundary conditions are also

specified as derivatives. Steady-state problems require at least one boundary node with a specified head in order to give the model a reference elevation from which to calculate heads.” Because constant flux boundaries would be non-unique, they were not used in the model.

Interrogatory #3. Provide the rationale for use of a large, full 3D model as opposed to a quasi-3D model.

Background. It is recognized that the use of a true 3D model is not incorrect. However, the full 20 layer 3D model is unwieldy, both from the perspective of input preparation and review of output. If a much more manageable quasi-3D model provides similar results, it would be an easier tool to use in sensitivity analyses (discussed below). Also, the sophistication of a 3D model here may convey an unwarranted sense of accuracy to the untrained observer. What are the reasons for the larger 20 layer 3D model? Please provide the appropriate discussion.

Typically the use of three dimensions in a model reflects either known spatial complexity in the aquifer properties and/or boundary conditions. Or, a finer-grained discretization might be required for purely numerical reasons. However, the distribution of aquifer properties in the current model—a single high conductivity 50-foot layer (12) embedded in a lower conductivity material (11 layers above and 8 layers below)—exhibits less ‘real’ site-specific complexity than even the four unit configuration used in earlier reports. The current model is essentially a big box having homogeneous aquifer properties with the exception of layer 12.

The bottom line is that the present model appears to be quasi-generic, hydrologically simpler than earlier models, numerically more complex, and not well-related to the accepted hydrostratigraphy. Envirocare should either (1) clearly justify the use of this modeling approach using ‘new’ findings and updated hydrostratigraphic knowledge, or (2) develop and apply a new, numerically simpler, more geohydrologically ‘realistic’ model.

Response. The system was modeled using a three-dimensional model grid to answer the question of spatial changes in hydraulic gradient. Anderson and Woessner (1992) state that “Profile or full three-dimensional models are used to simulate unconfined aquifers when vertical head gradients are important.” This is the case at the Envirocare site, where the proposed wells would pump from a depth of 550 – 600 feet and the issue of critical concern is the effect on heads and gradients at the water table. Hydrogeologic data from the site have shown that the aquifer is vertically stratified (as would be expected in lacustrine deposits) and the three-dimensional model was required to determine the changes in vertical hydraulic gradient and horizontal hydraulic gradient across the site. Twenty 50-ft thick layers were used to minimize the effects of numerical averaging of heads in the vertical direction. By defining 20 layers, the vertical head gradients could be calculated between any of 20 elevations.

The hydraulic properties of Layer 1 and Layer 12 differ from each other and from those in Layers 2-11 and 13 – 20. It was not our intent to imply that each model layer has different hydraulic properties or that the model represents a very complicated system. The 20 layers serve to provide a more useful three-dimensional view of model results.

Interrogatory #4. Provide a complete description of model input organized around the MODFLOW packages used in the model.

Background. The current presentation is a narrative which provides model configuration along with many but not all of the aquifer parameters. Verifying model input as described in the report is awkward at best. Because the MODFLOW model is the focus of this effort, a complete and transparent description of input parameters is needed. Presenting the input organized around the MODFLOW packages results in a complete description of the input and a direct linkage to the conceptual model.

Also, some inputs to MODFLOW are calculated—specifically the VCONT (leakage) array—and have been omitted in the current document. The calculation is straightforward, using other input aquifer/model parameters—cell/layer vertical hydraulic conductivities and layer thicknesses. Detailing VCONT calculations will document consistency between the conductivities, layer thicknesses and leakages.

Response. A section has been added to the report documenting each of the Modflow packages used in the model, including the calculation of the VCONT array. In summary, leakance between model layers (VCONT) was calculated using the following equation:

$$VCONT = \frac{1}{\left[\frac{0.5T_o}{Kv_o} \right] + \left[\frac{0.5T_u}{Kv_u} \right]}$$

Where:

- T_o is the thickness (ft) of the overlying layer.
- Kv_o is the vertical hydraulic conductivity (ft/d) of the overlying layer.
- T_u is the thickness (ft) of the underlying layer.
- Kv_u is the vertical hydraulic conductivity (ft/d) of the underlying layer.

The vertical hydraulic conductivity values that were used to calculate VCONT are summarized in Table 2.

Table 2. Calculation of MODFLOW VCONT Array

Layer	Geologic Unit	Thickness	K_h (ft/d)	K_h (cm/sec)	K_v (ft/d)	V_{cont}
1	Silts, silty clays, sandy silts	varies	1.73	6.1E-04	0.173	varies
2	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
3	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
4	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
5	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
6	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
7	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
8	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
9	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
10	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
11	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	6.88E-03
12	Gravel	50	283	1.0E-01	28.3	6.88E-03
13	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
14	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
15	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
16	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
17	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
18	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
19	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
20	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	N/A

Interrogatory #5. Provide a section on the calibration of the model.

Background. Model calibration has not been addressed in the memorandum. The acceptance of model predictions is predicated on calibration of the model. The role of and proposed implementation of a post-model audit should also be addressed. Develop an appendix reviewing the present working inventory of wells, their applicability vis-à-vis location, screening, etc., to the post-model audit activities, and identifying additional monitoring which may be required to fill in gaps in the present well configuration. A preliminary monitoring protocol—location, depth, frequency—and decision tree should also be a part of this effort.

Response. A section has been added to the report, discussing model calibration. In summary:

Calibration of a flow model refers to a demonstration that the model is capable of producing field-measured heads and flows which are known as calibration targets. Calibration is an inverse problem, which involves finding a set of hydraulic parameters, boundary conditions, and stresses that produce simulated heads and fluxes that match the field-measured values within a specified range of error. The model was run as a forward simulation, rather than an inverse calibration. An inverse calibration would require both field measured head and flux values, because head values

alone produce non-unique model solutions. Since the 243-square mile model is “carved out” of the larger regional aquifer, field measurements of fluxes across the model domain are not available. In the forward problem, system parameters such as hydraulic conductivity, specific storage, and hydrologic stresses such as recharge rate are specified and the model calculates heads. Although Anderson and Woessner (1992) report that “*most* field problems require solving an inverse problem,” in this case the forward problem is believed to be appropriate.

A Post-Model Audit has been proposed by Envirocare, as a separate document from the modeling report. Because the model is intended as a screening tool for decision-making, the Post-Model Audit focuses on actual field measurements of head and gradient, comparing those field values to the allowable hydraulic gradients specified in the GWQDP.

Interrogatory #6. Provide a section on the sensitivity analyses.

Background. There are by necessity a number of qualitative uncertainties, e.g., the conceptual model, location of boundary conditions, etc., and quantitative uncertainties, e.g., aquifer properties, spatial variability, etc. incorporated into the present model. Sensitivity analyses are needed to bound the predictions of the model, and to identify those uncertainties that significantly impact predictions. In particular, please assess the effects of variations in hydraulic properties, recharge, hydrostratigraphy, and boundary conditions. In regard to the last item: significant variation in the depth of the transmissive zone, i.e., the depth of the no-flow bottom of the model as a function of location, and a comparison of constant head and flux boundary conditions should be examined.

The variation of the depth is of interest because the site is one mile square and yet bedrock surfaces one mile west of the site. There may be an as-yet undetermined decrease in depth to bedrock (assumed to be a no-flow boundary?) underneath western portions of the site and almost certainly within a mile of the site. This will impact flow at the site. (Indeed one earlier model implements a model-extent limiting, no-flow boundary along the perimeter of that daylighting bedrock.) Finally, as noted above, constant head and flux boundary conditions are often compared when non-natural boundary conditions are needed.

Response. A section on sensitivity analysis has been added to the report. Several sensitivity analyses were performed to investigate the effects of differing aquifer thicknesses and boundary conditions. The file names and conditions are summarized in Table 3. The following sensitivity analyses were run:

- PW-6F. Sensitivity analyses evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model.
- PW-ST. Sensitivity analyses evaluated higher storage coefficients. Values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model.
- PW-LG. Sensitivity analyses using a lower hydraulic gradient. Gradient in the sensitivity analysis (4.95×10^{-4}) was 89% of the value used in the base case model (5.57×10^{-4}).
- PW-HG. Sensitivity analyses using a higher hydraulic gradient. Gradient in the sensitivity analysis (6.06×10^{-4}) was 109% of the value used in the base case model (5.57×10^{-4}).

- PW-HG. Sensitivity analyses evaluated a bedrock high, which was assumed to be impermeable and was modeled as no-flow cells. Although the conceptual hydrologic model of the regional aquifer indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock does not transmit water.

Table 3. Sensitivity Analyses

CASE	Model Run (File Name)	Model Thickness	Boundary Conditions	Gradient	Specific Storage
Base Case	Model20	1000 ft	Constant Head (4275 -> 4230)	5.57E-04	1.98E-4, 5.3E-5, 2.66E-5
Bedrock Ridge	PW-BH	Variable: 1000 ft with bedrock high	Constant Head (4275 -> 4230)	5.57E-04	1.98E-4, 5.3E-5, 2.66E-5
Shallow Bedrock	PW-6F	600 ft	Constant Head (4275 -> 4230)	5.57E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Storage	PW-ST	1000 ft	Constant Head (4275 -> 4230)	5.57E-04	6.0E-3, 1.6E-3, 8.1E-4
Lower Gradient	PW-LG	1000 ft	Constant Head (4275 -> 4235)	4.95E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Gradient	PW-HG	1000 ft	Constant Head (4275 -> 4226)	6.06E-04	1.98E-4, 5.3E-5, 2.66E-5

Interrogatory #7. Provide a complete description—discussion and input—of the steady state calculations (no well) used to generate the starting heads using in the well calculations.

Background. This steady-state calculation is the basis for all following calculations. It is the 'present case' describing the system prior to pumping and can be used for model calibration.

Also, MODFLOW models with pumping are realized as relatively simple extensions to the steady-state model via the addition of the well package and time-dependence. Finally, the steady-state model is the implementation that most directly and clearly relates to the conceptual flow model.

Response. The original submissions and the revised report contained a discussion of the calculation of steady-state heads. In summary, the groundwater flow model was first run without pumping to arrive at the steady-state solution, using the PCG2 solver and the 16-digit precision code. The heads from the steady-state model were saved in the binary file PW16ssdp.hds and used as starting heads for the transient simulation.

The report descriptions of model domain, model grid, aquifer hydraulic properties, constant heads, recharge, etc apply to the steady state model. The additional components that apply to the transient model include aquifer storage, pumping rates, and stress periods.

Interrogatory #8. Please address salinity effects in a separate section in the report.

Background. Because the salinity of the groundwater, some density effects are expected to be important. Discuss where and how these effects might be anticipated, how they impact model predictions, and how or if they are accommodated in the model.

The reports indicate that no attempt was made to reproduce vertical gradients—and this may be entirely reasonable due to limitations of MODFLOW. However, vertical gradients are important in performance assessment and so some discussion on the limitations of the present modeling approach in this regard would be helpful. What other approach might be needed in this context? What recommendations result from the evaluations?

Salinity of the water in this system and its implications on density driven flow and the role of vertical gradients in performance assessments are important topics. Envirocare should address these matters separately in evaluating its proposal to develop production wells at the Clive site?

Response. The section of the report discussing freshwater heads has been expanded. Envirocare routinely measures actual (saltwater) head and calculates the freshwater equivalent head for each monitoring well. Both saltwater and freshwater heads are reported monthly. Saltwater and freshwater equivalent gradients are also calculated and reported, including horizontal ground water flow direction and velocity and vertical hydraulic gradients at well pairs.

At the Envirocare facility, the differences between the elevation of the unadjusted saline water phreatic surface elevation and the calculated fresh water equivalent head elevation at the midpoints of the saturated filter packs are relatively minor, averaging 0.15 feet. Similarly, the ground water flow directions and gradients as seen on the ground water elevation contour maps are essentially identical (Pentacore, 2004).

The MODFLOW model was developed based on freshwater equivalent heads and hydraulic gradients calculated and reported by Envirocare. The use of freshwater heads and gradients ensures the numerically correct implementation of the model, since the flow equations solved by MODFLOW inherently incorporate a standard density of water.

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EVALUATION OF POTENTIAL
DRAWDOWN AND GRADIENT
CHANGES RESULTING FROM
PUMPING TWO DEEP WELLS
AT THE ENVIROCARE FACILITY

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1. INTRODUCTION

Envirocare of Utah proposes to install two production wells to provide groundwater for operational use at the Clive, Utah low-level radioactive waste disposal facility. Envirocare's Ground Water Quality Discharge permit (GWQDP) # UGW450005 requires that Envirocare receive approval from the Division of Water Quality (DWQ) prior to installing any pumping wells at the site. At issue is whether pumping from the proposed deep wells would affect the hydraulic gradients in the shallow aquifer, and potentially change the assumptions used in previous fate and transport models on which the existing facility permits are predicated.

To support decision-making, a three-dimensional finite difference groundwater flow model was developed to evaluate the potential drawdown and gradient changes that could be associated with pumping from two water supply production wells. The analysis was performed using the United States Geological Survey (USGS) MODFLOW software (McDonald and Harbaugh, 1988) and the Groundwater Vistas 3.0 pre/post-processor (Rumbaugh, 2002). The purpose of this report is to describe the conceptual model, the numerical model input parameters, model assumptions, and results.

1.1 Location and Site Description

The Envirocare facility is located in Section 32, T1S, R11W near Clive, Utah approximately 80 miles west of Salt Lake City. Envirocare began waste disposal at the facility in 1988, and currently operates four disposal embankments: the Mixed Waste, LARW, 11e.(2), and Class A embankments. The Mixed Waste embankment is currently being expanded to the north, the LARW embankment is nearing final cover and completion, the Class A embankment is being expanded west and north, and the 11e.(2) embankment is being expanded to the west. In the northeast corner of Section 32, the U.S. Department of Energy (DOE) disposed of the Vitro Uranium Mill tailings; this area is owned and monitored by the DOE.

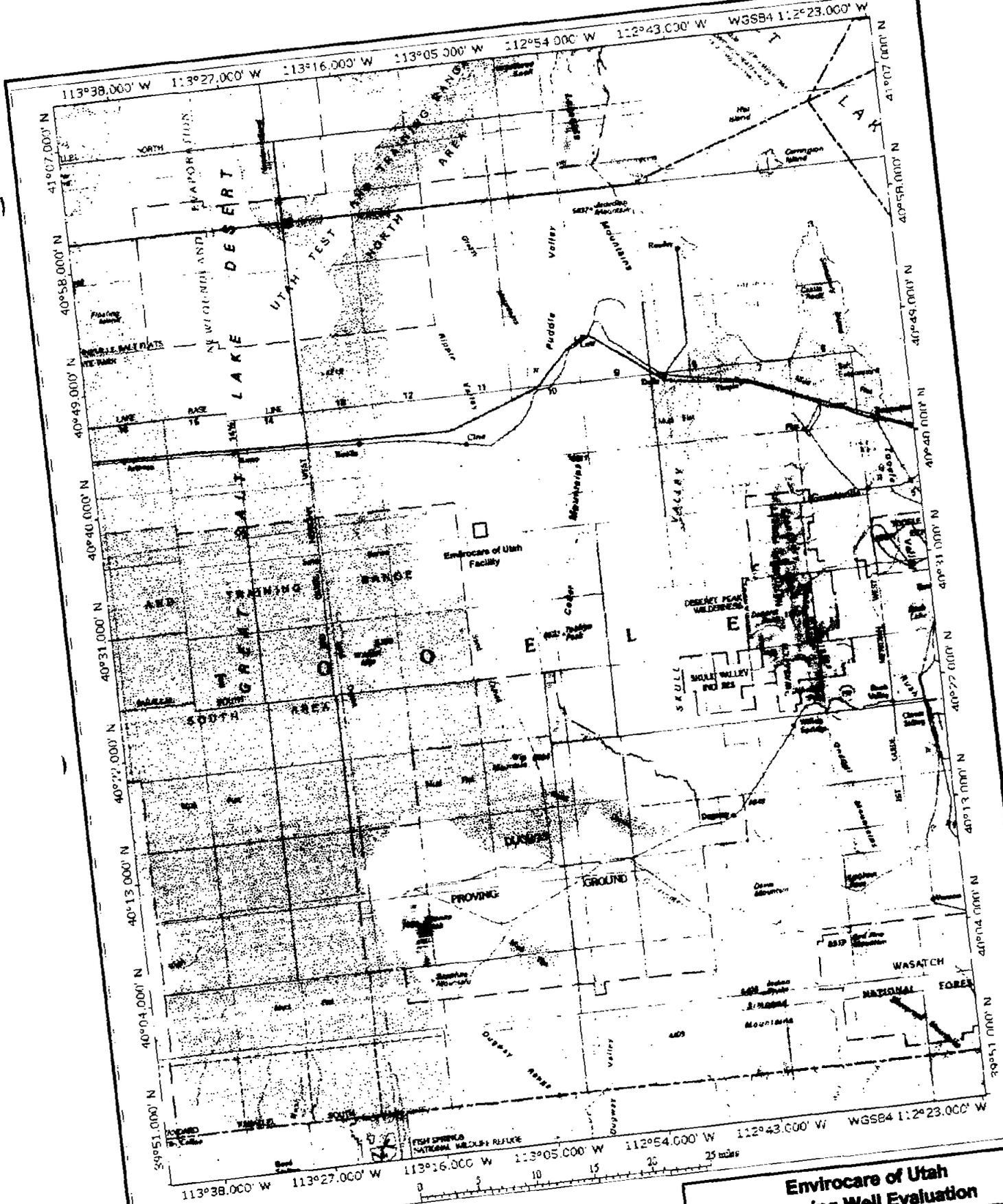
The facility, including DOE's Vitro tailings disposal cell, is one square mile in size and encompasses all of Section 32 (Figure 1). The facility is located at an average elevation of approximately 4,270 feet above mean seal level (amsl). The natural topography slopes slightly toward the southwest with approximately 10 feet of relief over one mile. The area is semi-arid, with an average precipitation of approximately 7.8 inches per year and average pan evaporation of 49.5 inches per year (MSI, 2003).

1.2 Previous Modeling

Two previous technical memoranda documented numerical groundwater flow modeling of a single production well (Whetstone, 2003) and two production wells (Whetstone, 2004) at the Envirocare site. These memoranda were reviewed by URS Corporation on behalf of UDEQ DRC. URS Corporation submitted interrogatory comments in December 2004, and a conference call was held between Envirocare, Envirocare's consultant (Whetstone Associates), and DRC's consultant (URS) in February 2005. The interrogatory comments and the conference call conveyed DRC's desire for additional model documentation and sensitivity analyses.

The current report expands the technical memoranda to:

- Clarify the purpose and scope of the modeling exercise
- Describe the regional hydrologic system,
- Provide more information about the conceptual model
- Document additional model input parameters, including leakance (VCONT)
- Provide additional interpretation of model results
- Include sensitivity analyses on aquifer thickness, gradient, and boundary conditions



**Envirocare of Utah
Pumping Well Evaluation**

**FIGURE 1
SITE LOCATION MAP**

Whetstone <small>Environmental Services</small>	Date: 3/14/05
	Project/File: 4101U
	Drawn/Checked By: SW/SE

The modeling results presented as the "Base Case" model are identical to those presented in the September 7, 2004 submission. The MODFLOW files (model20.nam, model20.bas, model20.bcf, model20.wel, model20.rch, model20.oc, model20.pcg, and pw16ssdp.hds) have not been modified, although additional data extraction targets were set up in the Groundwater Vistas pre/post-processor to assist in interpreting the results.

1.3 Model Purpose and Scope

The purpose of the modeling exercise is to determine whether pumping from two production wells would affect the hydraulic gradient beneath the facility. Condition I.H.2.c)2. of the GWQDP specifies hydraulic gradient limits for all disposal facilities at the Envirocare site (Table 1). These limits were used in the previous PATHRAE fate and transport modeling exercises to demonstrate compliance with the Groundwater Protection Levels.

Table 1. Horizontal Hydraulic Gradient Limits Specified in the GWQDP

Disposal Cell	Horizontal Hydraulic Gradient Limit
Class A	1.00 E-3
LARW	9.67 E-4
Mixed Waste	9.67 E-4
11e.(2)	3.29 E-3

The MODFLOW model is designed to be a feasibility-level screening analysis to support decision-making by Envirocare and DRC. Envirocare desires to determine whether any unacceptable changes in hydraulic gradients beneath the site may occur, before investing capital in the construction of two deep water supply wells. Similarly, DRC requires an evaluation of the effects of pumping on the site hydraulic gradient before the production wells can be approved. The model is intended to provide a "best estimate" of expected drawdown and gradient changes resulting from pumping. Although the model, like any groundwater model, possesses inherent uncertainties, the level of uncertainty is considered acceptable for the purpose of decision-making.

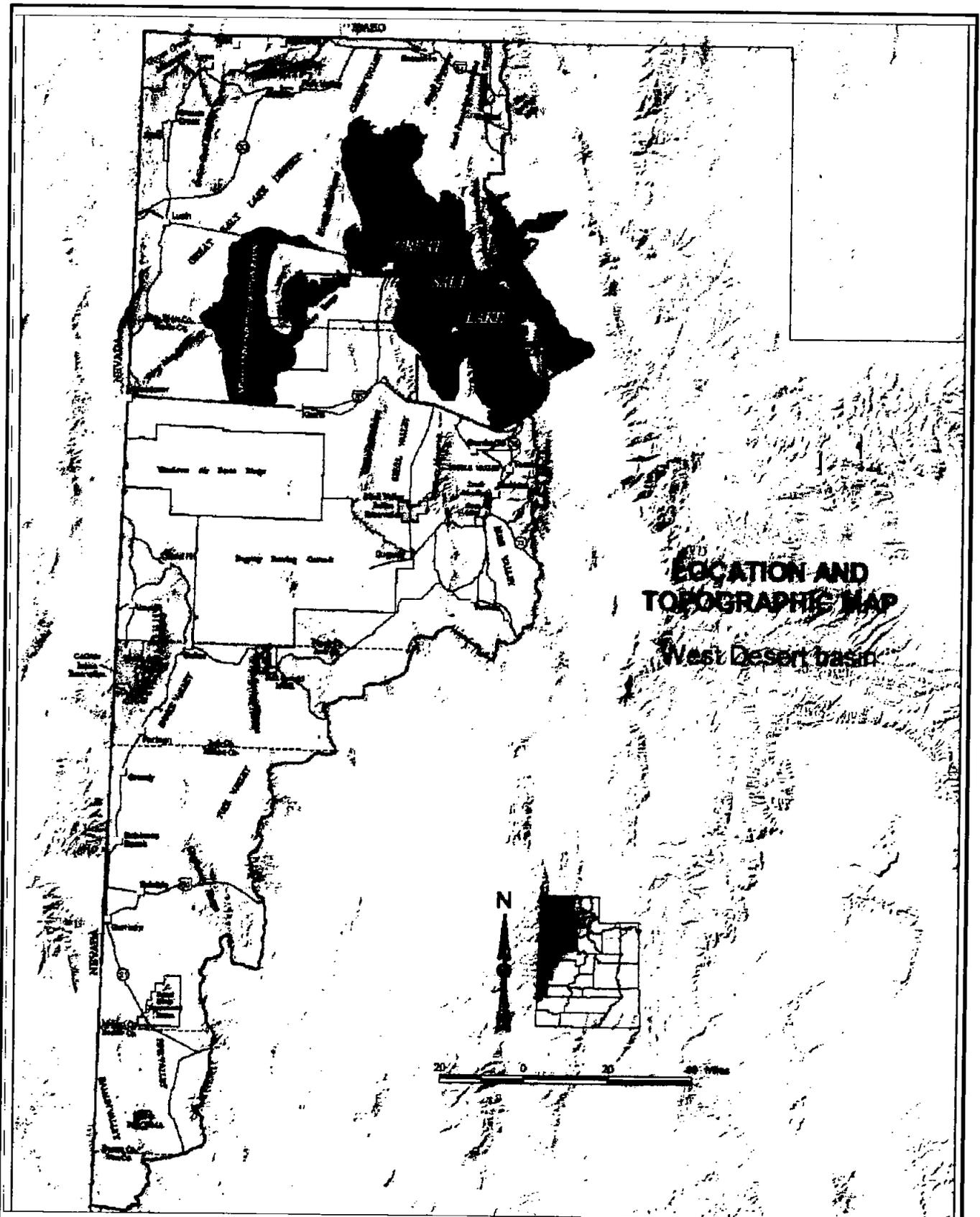
Uncertainties in the modeling will be addressed by a Post-Model Audit (PMA) plan, in which Envirocare proposes to monitor and report water levels and hydraulic gradients. Envirocare is currently required to measure and report groundwater elevations on a monthly basis and calculate fresh-water and salt-water gradients. Additional monitoring locations for horizontal and vertical hydraulic gradients would be implemented as part of the PMA, and contingencies or mitigation strategies would be developed. Tying the pumping permit to real-world conditions will help to address the issue of model uncertainty.

2. CONCEPTUAL MODEL

2.1 Geologic Setting

2.1.1 Regional Geologic Setting

The Envirocare facility is located in the West Desert Basin, a region that has no external drainage and is characterized by small fault-block mountains and intervening alluvial valleys (DWR, 2001). The regional topography is shown in Figure 2.



SOURCE: Division of Water Resources (DWR), 2001. Utah State Water Plan, West Desert Basin, April 2001

**Envirocare of Utah
Pumping Well Evaluation**

**FIGURE 2
TOPOGRAPHIC MAP AND LOCATION
WEST DESERT BASIN**

Date: 3/14/05



Project/File: 4101U

Drawn/Checked By: SW / SE

EXPLANATION



P3 - Beach and beach-adjacent fine and shallow subaerial (Miocene and Pliocene)
 P4 - Calicheous sandstone, quartzite, limestone, and dolomite (Lower Permian and Upper Pennsylvanian)
 Q4 - Quaternary alluvial deposits including lacustrine deposits, alluvium, and alluvium



NORTH



Scale (Miles)

SOURCE: Moore, William J., and Sorenson, Martin L., 1979. Geologic Map of the Tropic 1° by 2° Quadrangle, Utah, U.S. Geological Survey, Miscellaneous Investigations Series, Map I-1132



**Envirocare of Utah
Pumping Well Evaluation**

**FIGURE 3
REGIONAL GEOLOGIC MAP**

Scale: 1" = 5 miles	Date: 4/19/80
Project No.: 4107U	File:
Drawn By: BW	Checked By: SE



) The West Desert Basin is part of the Basin and Range geologic province. The Basin and Range province is characterized by north-south trending mountain ranges with alluvium-filled intermontane valleys. The mountains are mainly Paleozoic-age sedimentary and metamorphic rock, but can also be comprised of volcanic rocks. The intermountain troughs are primarily filled with unconsolidated alluvial, lacustrine, fluvial, and evaporite deposits; but pyroclastics, aeolian sediments, and basalt flows also occur (Bingham Environmental, 1996; Dames & Moore, 1982, 1987; Stephens, 1974). Sediments near the mountains are predominately of colluvial and alluvial origin, and are generally coarser than the lacustrine deposits found in the center of the valleys. A regional geologic map, excerpted from the USGS Tooele 1° by 2° geologic map (Moore and Sorenson, 1979) is presented in Figure 3.

The Envirocare facility is located on Quaternary-age lacustrine lake bed deposits associated with the former Lake Bonneville. Beneath the facility, the sediments consist of interbedded silt, sand, and clay with occasional gravel lenses. The depth of the valley fill beneath the facility is at least 700 feet, although its total depth is unknown (Envirocare, 2004). The deepest borehole at the facility (well SC-1) was drilled to a depth of 250 feet below ground surface (bgs) without encountering bedrock. An exploratory borehole for a potential water-supply well in Section 29 (north of the Envirocare site) was drilled to 700 feet bgs and did not encounter bedrock.

The Grayback Hills begin approximately four miles north of the facility and are composed mainly of basalt flows and pyroclastics. The Cedar Mountains are found about 10 miles to the east-southeast and consist primarily of limestone, dolomite, and shale (Stephens, 1974).

2.2 Hydrogeologic Setting

2.2.1 Regional Hydrogeologic Setting

) The hydrology and hydrogeology of the West Desert Basin is described in detail in the Utah State Water Plan, West Desert Basin (DWR, 2001). The report describes the West Desert Basin, a region that has no external drainage and is characterized by small fault-block mountains and intervening alluvial valleys. The West Desert Basin is divided into four sub-basins for the purpose of water planning: Box Elder County, Great Salt Lake Desert, Tooele/Rush Valley and the Great Salt Lake (Figure 4). The Envirocare facility is located in the Great Salt Lake Desert sub-basin.

The Great Salt Lake Desert sub-basin includes the area west of the Great Salt Lake, south of the Box Elder County line, west of the Stansbury Mountains and the Sevier Lake Basin, and north of the Escalante Valley (Cedar-Beaver Basin). The southern end of the sub-basin contains mountains rising above 10,000 feet in elevation that generate ephemeral streams and small perennial streams which provide recharge locally to Pilot Valley, Wah Wah Valley, Pine Valley, Tule (White) Valley, and Snake Valley. The northern eastern portion of the sub-basin drains directly to the Great Salt Lake.

The mountain blocks are composed mostly of rocks of Paleozoic and Precambrian age. These hard, brittle rocks are permeable when fractured, and can provide groundwater aquifers (DWR, 2001). The Paleozoic formations include several limestone and dolomite units, which constitute an important regional aquifer system (DWR, 2001). The centers of the valleys and basins are typically underlain with lacustrine silt and clay, which have low permeability, and contain water with high dissolved solids. The alluvial slopes fringing the mountain blocks are composed of more permeable sand and gravel, and form important local aquifers.

Although local aquifers may exist at the flanks of the bedrock mountains, the bedrock and valley fill deposits in the Great Salt Lake Desert act as a single hydrogeologic system on a regional scale. DWR (2001) states that:

) "Many of the fault block mountains are underlain by carbonate rocks which provide groundwater flow paths between basins. Therefore much of the southern Great Salt Lake

) Desert is hydrologically connected in what Gates (1987) calls the "Great Salt Lake Desert flow system." This system ultimately discharges to Fish Springs Flat, the margins of the Bonneville Salt Flats and the Great Salt Lake."

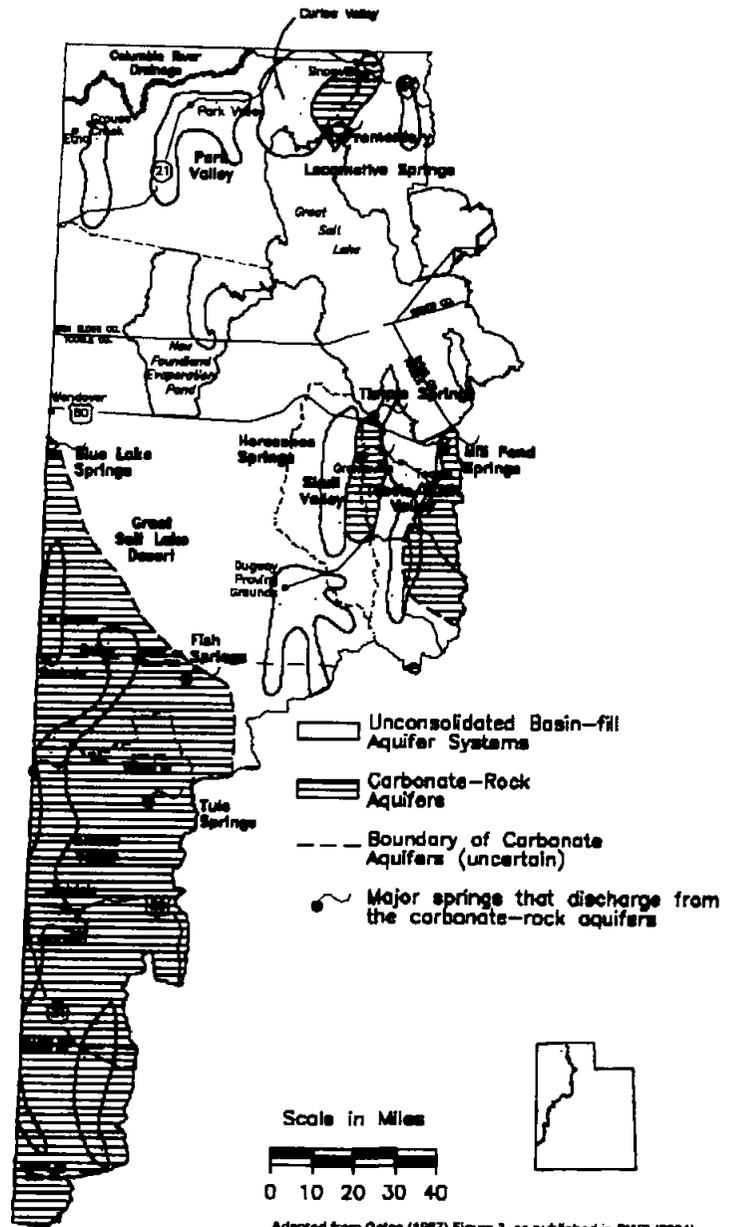
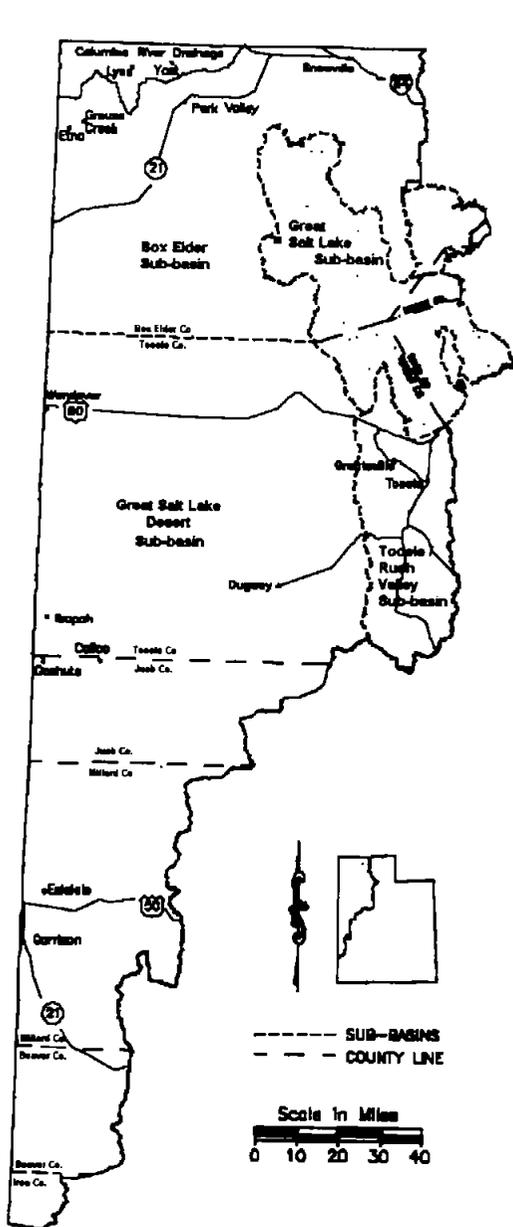
The USGS (Robson and Banta, 1995) also reports that groundwater in the basin-and-range aquifers may flow between the basins by passing through the carbonate rocks in the bedrock ranges:

"Carbonate rocks predominate in a 20,000- to 30,000-foot thick sequence of Paleozoic and Lower Mesozoic rocks in an extensive area of western Utah ... and southern and eastern Nevada.... The location of solution-altered zones of enhanced permeability within these carbonate rocks is poorly known. However, some data indicate that ground water might flow between basins through permeable carbonate rocks in the mountains of west-central Utah, and water might flow from recharge areas in the mountains to local basins through permeable carbonate rocks bordering the northeastern part of the aquifer system."

In the 5,000 square mile area that includes the Envirocare facility, the fault block mountains and valley fill were mapped as a single undifferentiated unit (Figure 5). Gates (1987) and DWR (2001) identified several coarse alluvial aquifers and carbonate aquifers in the West Desert Basin. However, the broad region of the Great Salt Lake Desert was not identified as a principle aquifer.

The thickness of the Lake Bonneville sediments in the Great Salt Lake Desert has not been thoroughly mapped. In a report on basin-and-range aquifers, the USGS (Robson and Banta, 1995) reported that "the thickness of the basin fill is not well known in some basins but ranges from about 1,000 to 5,000 feet in many basins and may exceed 10,000 in a few deep basins in Utah and south-central Arizona."

) Groundwater exploration occurred in the Great Salt Lake Desert as early as 1902, when the Southern Pacific Railroad drilled test wells to depths of 1,000 feet in search of fresh water for its steam locomotives. Although the test wells proved unproductive, they provide valuable information about subsurface strata and groundwater to depths of 1,000 feet in the central part of the basin (Schreiber, 1954). In their reconnaissance of the southern Great Salt Lake Desert, south of Interstate 80, Gates and Kruer (1981) state that large amounts of groundwater occur, but much of it is of poor quality, and much of it is in fine-grained deposits that will not yield more than a few gallons per minute.



Adapted from Gates (1987) Figure 3, as published in DWR (2001)

Figure 4. Sub-Basins of the West Desert Basin

Figure 5. Principal Aquifers of the West Desert Basin

Although the West Desert Basin has no streams that flow perennially to the Great Salt Lake, the general trend of both surface water and groundwater is toward the basin's lowest point, the Great Salt Lake.

2.2.2 Site Hydrogeologic Setting

Much information is available on the shallow aquifer at the Envirocare site. Approximately 100 monitoring wells and piezometers have been completed to depths of 55 feet or less at the site. In contrast, relatively few borings have been drilled to greater depths at the site. Those borings include 5 deep monitoring wells and piezometers that have been installed to depths between 100 and 250 feet.

Four hydrostratigraphic units have been identified at the site. The upper three units have a combined average total thickness of 40 feet (Table 2). The unconfined water-bearing zone occurring in Unit 3 (and the upper part of Unit 2) has been designated as the "shallow aquifer". The lower unit (Unit 1) is of unknown thickness and is referred to as the "deep aquifer" which is locally confined.

Table 2. Thickness of Upper Hydrostratigraphic Units

HSU	Minimum Thickness (ft)	Maximum Thickness (ft)	Average Thickness (ft)	Lithology	Saturation
Unit 4	6 to 16.5	16.5	10	Silt and clay	Unsaturated
Unit 3	7 to 25	25	15	Silty sand with interbedded silt and clay layers	Partially saturated
Unit 2	2.5 to 25	25	15	Silty clay with interbedded silts and sand lenses	Saturated
Unit 1	>10	ND	ND	Silty sand interbedded with clay and silt layers	Saturated

Notes: ND = not determined

Drilling logs and well drillers reports (Appendix A) indicate that the aquifer may be more permeable at depth. Geologic logs from deep test holes and production wells in the area including the following wells:

1. A 9 7/8-inch boring that was drilled to a depth of 620 feet for Broken Arrow, Inc., in Section 29 (directly north of the Envirocare facility.) The well was drilled from January 9 – 18, 1996 and the hole was abandoned on January 31 of that year. Gravel and cobble zones were identified from 483 – 487 ft, 497-495 ft, and 505-545 ft. A mixture of gravel and clay was logged from 182 – 483 ft. The lower gravel layer was 40 feet thick (505-545 ft) and was surrounded by clay above and below. The boring was drilled to 620 feet and did not encounter bedrock.
2. A water supply well that was drilled to a depth of 350 ft in Section 18, T1S, R11W (about 5 miles north of the Envirocare facility.) The hole was completed as an industrial well for Cox Construction Co in 1969, and encountered clay, clayey gravel, and sandstone at depth, according to the driller's log. The well yielded 600 gpm with a drawdown of 120 ft after 10 hours, from a screened interval of 185 – 350 ft.

3. NUMERICAL MODEL SET UP

3.1 Model Code

The model was developed using the USGS MODFLOW code (McDonald and Harbaugh, 1988) and the Groundwater Vistas pre/post-processor (Rumbaugh, 2002). The MODFLOW input files (Table 3) were created in Groundwater Vistas and run from an external, stand-alone, double-precision (16-digit) version of MODFLOW (modflowdp.exe). The double-precision executable was compiled from the standard, public-domain MODFLOW96 source code which was downloaded from the USGS website (<http://water.usgs.gov/nrp/gwsoftware/modflow.html>). The numerical accuracy of the double precision code was necessary to simulate the extremely low gradient across the site.

Table 3. MODFLOW Modules and Files

Name file	NAM	MODEL20.nam
Basic package	BAS 1	MODEL20.bas
Block-centered flow package	BCF 11	MODEL20.bcf
Well file	WEL 12	MODEL20.wel
Recharge file	RCH 18	MODEL20.rch
Output control file	OC 22	MODEL20.oc
Solver	PCG 19	MODEL20.pcg
Starting heads	DATA(BINARY) 10	PW16ssdp.hds

3.2 Model Domain and Grid

3.2.1 Model Domain

The regional aquifer is bounded by the Great Salt Lake to the north, the Cedar Mountains to the east, and by mountain ranges in the state of Nevada to the west. It is impractical to include such a large area in the groundwater model, a fact that is recognized by Anderson and Woessner (1992) and Rumbaugh (2002). Anderson and Woessner state that:

“It may not be possible or convenient to design a grid that includes the physical boundaries of the system if the focus of interest is far removed from the boundaries.”

Rumbaugh states:

“It is desirable to include only natural hydrologic boundaries as boundary conditions in the model. Most numerical models, however, employ a grid that must end somewhere. Thus, it is often unavoidable to specify artificial boundaries at the edges of the model. When these grid boundaries are sufficiently remote from the area of interest, the artificial conditions on the grid boundary do not significantly impact the predictive capabilities of the model.”

Although the Great Salt Lake Desert sub-basin occupies 4 million acres (6,250 square miles), less than 4% of this area is covered by the model. The model domain encompasses a rectangle of 15 miles by 15 miles, or about 234 square miles (Figure 6). This sizable domain was selected to avoid the effects of transient stresses (i.e., pumping) unrealistically encountering model boundaries.

3.2.2 Model Grid

The model uses a telescoping grid with 102 cells in the x-direction and 102 cells in the y-direction. The horizontal grid spacing ranges from a minimum of 100 feet near the proposed pumping wells to a maximum of 12,000 feet near the model boundaries. The model domain is 1,000 feet thick, and is divided into 20 layers of uniform (50-ft) thickness (Table 4). The model contains 208,080 active cells.

The system was modeled using a three-dimensional model grid to answer the question of spatial changes in hydraulic gradient. Anderson and Woessner (1992) state that “Profile or full three-dimensional models are used to simulate unconfined aquifers when vertical head gradients are important.” This is the case at the Envirocare site, where the proposed wells would pump from a depth of 550 – 600 feet and the issue of critical concern is the effect on heads and gradients at the water table. Hydrogeologic data from the site have shown that the aquifer is vertically stratified (as would be expected in lacustrine deposits) and the three-dimensional model was required to determine the changes in vertical hydraulic gradient and horizontal hydraulic gradient across the site. Twenty 50-ft thick layers were used to minimize the effects of numerical averaging of heads in the vertical direction.

EXPLANATION



Constant Head Boundary Cells

Model Grid

Model Grid too dense to display



**Envirocare of Utah
Pumping Well Evaluation**

**FIGURE 6
GROUNDWATER MODEL DOMAIN**

Transit County, Utah

Drawn: 08/07/04

Scale: 1" = 12,000 ft ET

Wireframe

Hydrogeology & Environmental Sciences, Inc.

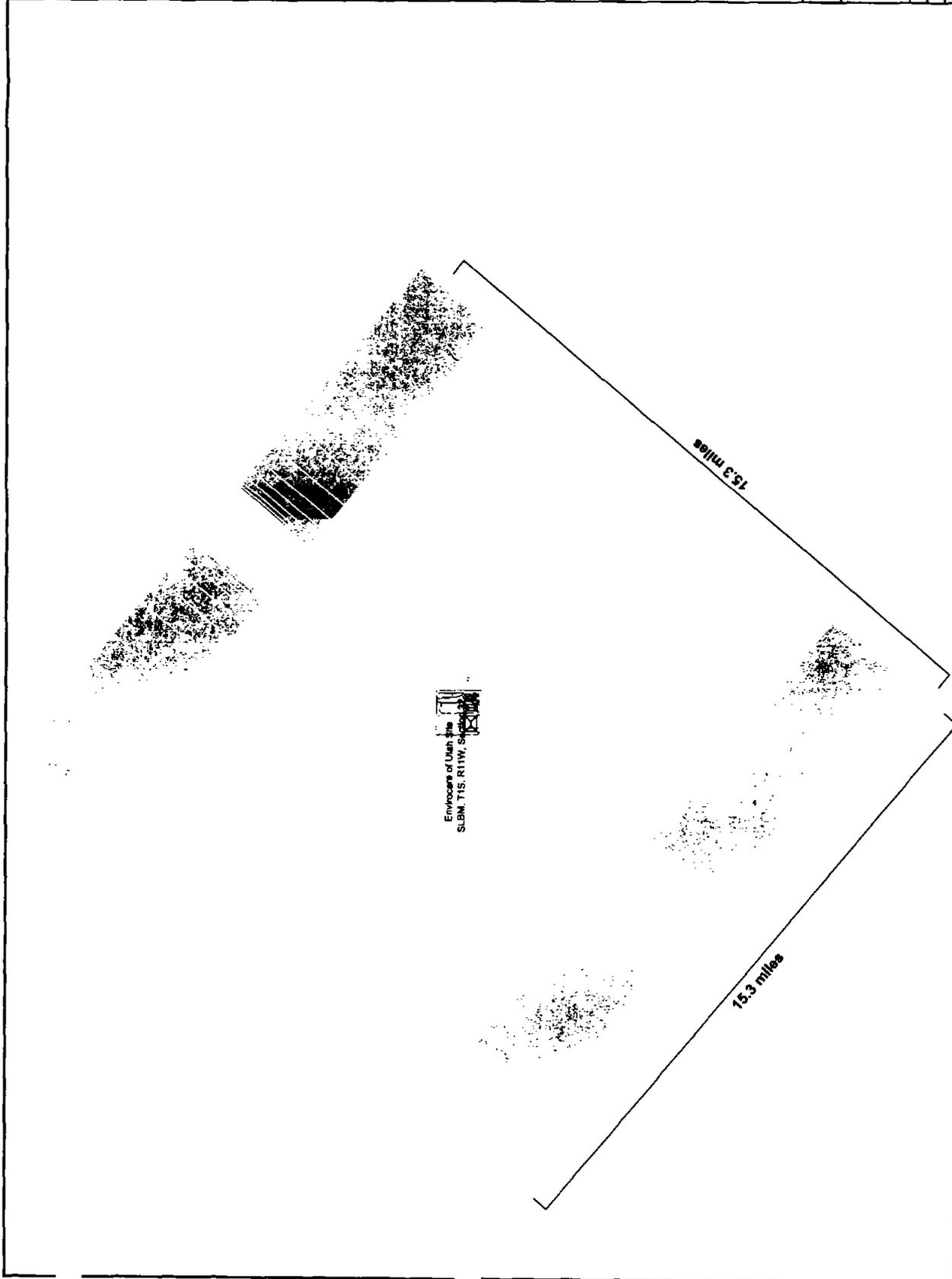


Table 4. Model Layers

Layer	Depth to top (ft)	Depth to bottom (ft)	Top Elevation (ft amsl)	Bottom Elevation (ft amsl)	Geologic Material
1	0	50	4275	4225	Silts, silty clays, sandy silts
2	50	100	4225	4175	Silts, silty clays, sandy silts
3	100	150	4175	4125	Silts, silty clays, sandy silts
4	150	200	4125	4075	Silts, silty clays, sandy silts
5	200	250	4075	4025	Silts, silty clays, sandy silts
6	250	300	4025	3975	Silts, silty clays, sandy silts
7	300	350	3975	3925	Silts, silty clays, sandy silts
8	350	400	3925	3875	Silts, silty clays, sandy silts
9	400	450	3875	3825	Silts, silty clays, sandy silts
10	450	500	3825	3775	Silts, silty clays, sandy silts
11	500	550	3775	3725	Silts, silty clays, sandy silts
12	550	600	3725	3675	Gravel
13	600	650	3675	3625	Silts, silty clays, sandy silts
14	650	700	3625	3575	Silts, silty clays, sandy silts
15	700	750	3575	3525	Silts, silty clays, sandy silts
16	750	800	3525	3475	Silts, silty clays, sandy silts
17	800	850	3475	3425	Silts, silty clays, sandy silts
18	850	900	3425	3375	Silts, silty clays, sandy silts
19	900	950	3375	3325	Silts, silty clays, sandy silts
20	950	1000	3325	3275	Silts, silty clays, sandy silts

NOTES: amsl = above mean sea level

A sensitivity analysis (Section 5.3) was also performed to evaluate a 600-ft thick aquifer, which is 60% of the thickness used in the base case model.

3.3 Hydraulic Gradient

The model boundaries in all layers were set to constant heads of 4,375 feet at the upgradient boundary (model north) and 4,230 feet at the downgradient boundary (model south). The constant head cells establish a very small uniform gradient of 0.000654 ft/ft¹ (6.54×10^{-4}) in the steady-state model (Table 5).

Table 5. Constant Head Boundaries and Steady-State Uniform Gradient

Upgradient Constant Head (model north)	4,275	ft
Downgradient Constant Head (model south)	4,230	ft
Distance (from center of boundary nodes) ¹	68,822	ft
Uniform Gradient	0.000654	

Sensitivity analyses were performed using lower and higher hydraulic gradients, as described in Section 5.3.

¹ The uniform hydraulic gradient of 6.54×10^{-4} cm/sec was reported as 5.57×10^{-4} cm/sec in previous modeling reports, based on a model distance of 80,822 ft. Because MODFLOW assigns the constant head to the center of the boundary nodes (which are 12,000 ft wide), the actual distance between constant heads is 68,822 ft and the resulting gradient is 17% greater. This gradient calculation occurs external to the model, and no changes to the Base Case model were made from the previous submission.

3.3.1 Freshwater Equivalent Heads

Envirocare routinely measures actual (saltwater) head and calculates the freshwater equivalent head for all monitoring wells. Both saltwater and freshwater heads are reported monthly. Saltwater and freshwater equivalent gradients are also calculated and reported, including horizontal ground water flow direction and velocity and vertical hydraulic gradients at well pairs.

At the Envirocare facility, the differences between the elevation of the unadjusted saline water phreatic surface elevation and the calculated fresh water equivalent head elevation at the midpoints of the saturated filter packs are relatively minor, averaging 0.15 feet. Similarly, the ground water flow directions and gradients as seen on the ground water elevation contour maps are essentially identical (Envirocare, 2004).

The MODFLOW model was developed based on freshwater equivalent heads and hydraulic gradients calculated and reported by Envirocare. The use of freshwater heads and gradients ensures the numerically correct implementation of the model, since the flow equations solved by MODFLOW inherently incorporate a standard density of water.

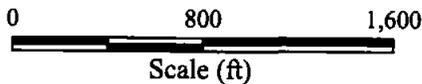
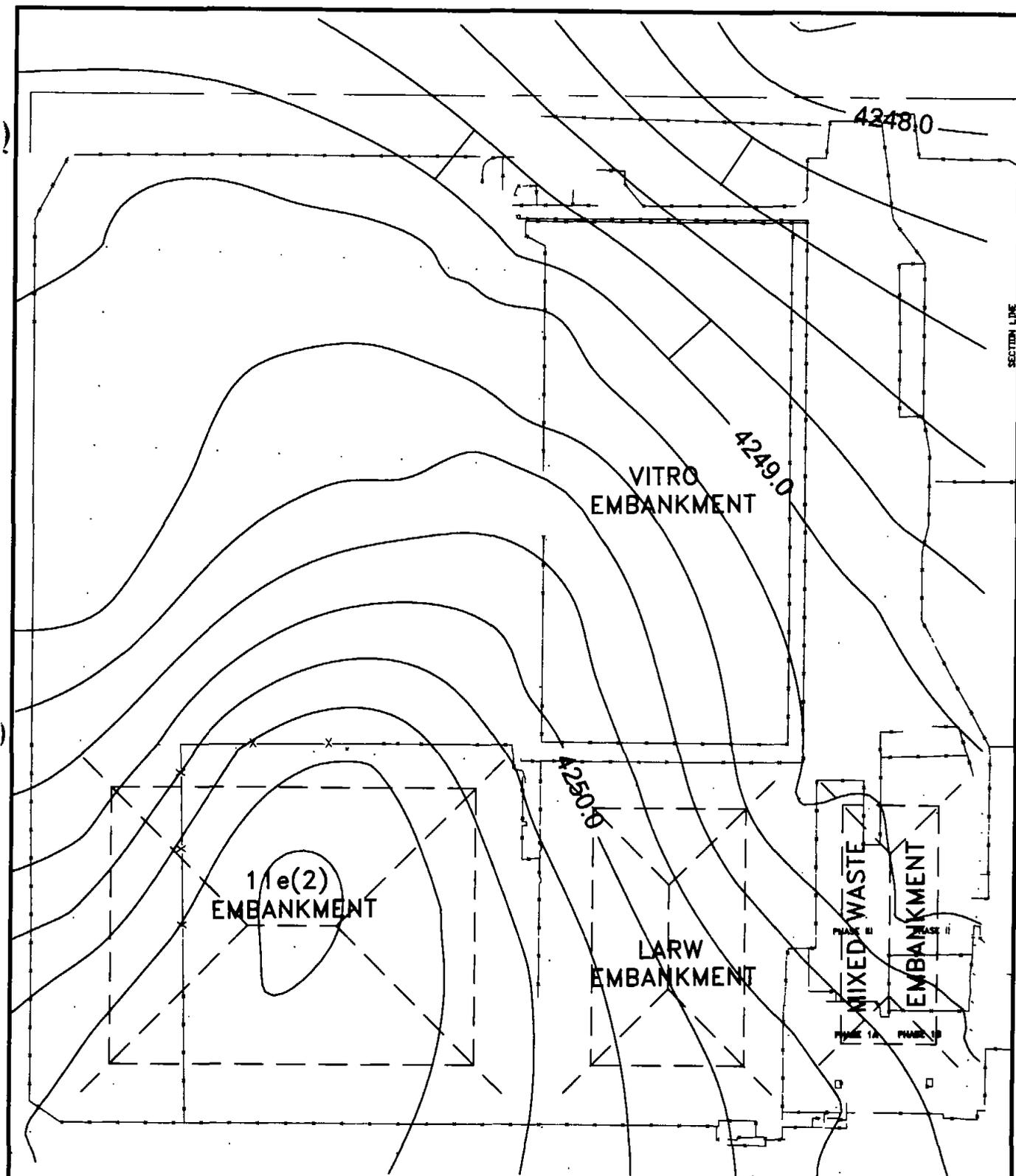
3.3.2 Hydraulic Gradient

The hydraulic gradient used in the model (6.54×10^{-4}) approximates the actual site-specific hydraulic gradient, and is 24% higher than the average gradient measured at the site in all unconfined wells during January 2003 (Table 6). Variable, rather than uniform, gradients exist across the site, due primarily to human-influenced perturbations resulting in changes in infiltration and evaporation from shallow groundwater (Figure 7). Hydraulic gradients have declined in recent years in some areas of the site. Pentacore (2000) reported that the average hydraulic gradient across the site was 0.001 (1×10^{-3}), which is half an order of magnitude higher than the more recent measurements.

Table 6. Hydraulic Gradients at the Envirocare Site, January 2003

Area	Water Type	Maximum	Minimum	Average
All unconfined wells	Fresh	2.27E-03	9.39E-06	4.96E-04
	Salt	2.60E-03	5.82E-06	4.87E-04
LARW	Fresh	8.10E-04	1.10E-04	5.73E-04
	Salt	9.09E-04	4.67E-05	5.91E-04
Class A	Fresh	1.13E-03	1.06E-04	6.41E-04
	Salt	1.06E-03	1.51E-04	6.18E-04
11e.(2)	Fresh	1.11E-03	3.48E-05	4.57E-04
	Salt	1.04E-03	5.82E-06	4.59E-04
Mixed Waste	Fresh	2.27E-03	8.15E-05	5.04E-04
	Salt	2.60E-03	1.77E-05	5.41E-04
Deep	Fresh	3.31E-04	8.45E-05	2.29E-04
	Salt	2.99E-04	4.49E-05	1.74E-04
B & C	Fresh	1.06E-03	1.54E-05	3.33E-04
	Salt	8.55E-04	9.13E-05	3.44E-04

Early hydrogeologic reports for the Envirocare site identified very slight upward vertical gradients based on freshwater elevations and downward or mixed, vertical gradients based on saltwater heads. However, the most recent hydrogeologic report (Envirocare, 2004) identified no significant vertical gradients. Envirocare (2004) evaluated vertical hydraulic gradients by analyzing head differences between monitoring wells completed in the "shallow" (Unit 2) and "deep" (Unit 1) aquifers at the site. Envirocare identified slight downward vertical gradients near well pair GW-19A/GW-19B, located in the southwest corner of the facility, and slight upward gradients near wells I-3-30/I-3-100, north of the Mixed Waste Landfill. Because



Envirocare of Utah Pumping Well Evaluation	
<i>FIGURE 7 Water Level Contours in the Shallow Aquifer January, 2003</i>	
Tooele County, Utah	
Date: 03.14.03	
Scale: 1" = 800 FEET	

vertical gradient elsewhere beneath the facility were of very low magnitude, the report concluded that "vertical flow is not significant either upward or downward". The steady-state model produced almost negligible vertical gradients (0.00000132 downward), which is considered consistent with overall site conditions.

The sides of the domain (model east and model west) are no-flow boundaries. The groundwater flow direction in the shallow aquifer at the site is approximately N40°E. The grid (and results) were rotated and oriented in the prevailing flow direction, corresponding to site conditions.

3.4 Hydraulic Properties

3.4.1 Hydraulic Conductivity

The hydraulic conductivities applied to model layers represent geologic material encountered during drilling at the site. Large quantities of site-specific data have been collected from monitoring wells installed to less than 55 ft depth in the shallow aquifer. In addition, more than 5 deep monitoring wells and piezometers have been installed to depths of 100 – 250 feet.

Hydraulic conductivity values are derived from boring logs and slug tests conducted at the site. The horizontal hydraulic conductivity of the silts, silty clays, and sandy silts is based on slug tests performed in 69 wells on site. The geometric mean hydraulic conductivity of the 69 tests is 6.09×10^{-4} cm/sec (1.726 ft/day), as shown in Table 7. The vertical hydraulic conductivity of these materials is assumed to be ten times lower than the horizontal hydraulic conductivity, or 6.09×10^{-5} cm/sec (0.1726 ft/day). For comparison, Pentacore (2000) assumed a vertical hydraulic conductivity, K_v , of 0.00283 ft/day (1×10^{-6} cm/sec). The use of this lower vertical hydraulic conductivity in the model would have produced less drawdown in the upper aquifer.

The hydraulic conductivity of the gravel zone was conservatively assigned to the lowest end of the range for gravel (0.1 – 100 cm/sec) given by Freeze and Cherry (1979, table 2.2). A specific capacity analysis of the Cox Construction well (located about five miles north of Section 32 and screened from 185 – 350 feet in clay, gravel, and sand) produced a hydraulic conductivity of 0.1 cm/sec based on an unconfined specific storage of 0.1 and 0.2 cm/sec based on a confined specific storage of 0.00001. The gravel layer in the model corresponds to the gravel layer in the Broken Arrow abandoned hole, directly north of Section 32, which was logged as a clean gravel and would therefore be expected to have a higher hydraulic conductivity than the Cox Construction well. The use of a higher K for the gravel layer in the model would produce less drawdown at the well and a more widespread cone of depression.

Table 7. Hydraulic Conductivity Values

Lithology	Parameter	Value (cm/sec)	Value (ft/day)	Data Source
Silts, silty clays, sandy silts	K_h	6.09E-04	1.7263	Average of 69 slug tests
	K_v	6.09E-05	0.1726	Assume $K_h = 10K_v$
Gravel layer	K_h	1.00E-01	283	lower range in Freeze & Cherry
	K_v	1.00E-02	28.3	Assume $K_h = 10K_v$

Notes: K_h = horizontal hydraulic conductivity
 K_v = vertical hydraulic conductivity

3.4.2 Specific Storage and Specific Yield

The specific yield and specific storage values used in the model are shown in Table 8. Specific storage was calculated using the formula derived by Jacob (1940):

$$S_s = \rho_w g \cdot (n\beta_w + \beta_p)$$

where: S_s = specific storage (1/ft)
 ρ_w = density of water (lb/ft³)
 n = porosity (unitless)
 g = acceleration due to gravity (ft/sec²)
 β_w = compressibility of water (ft²/lb)
 β_p = compressibility of pores (ft²/lb)

In this equation, the density of water (ρ_w), acceleration due to gravity (g), and compressibility of water (β_w) were assumed to be known constants of 62.4 lb/ft³, 32.2 ft/sec², and 2.30x10⁻⁸ ft²/lb, respectively. The porosity of the shallow site materials (0.29) was derived from laboratory testing, while the porosity was assumed to decrease by 30% to 0.20 for underlying dense silty sands. The effective porosity of gravel (0.13) was derived as a weighted average of gravel and silty clay, from a table of default values. Vertical compressibility values for the various aquifer materials were selected from a table developed by Domenico and Mifflin (1965), reprinted in Domenico and Schwartz (1990).

Table 8. Specific Yield and Specific Storage Values

Material	Units	Silty sand	Dense silty sand	Dense sandy gravel
S_y	unitless	0.15	0.12	0.07
ρ_w	(lb/ft ³)	62.4	62.4	62.4
g	ft/sec ²	32.2	32.2	32.2
n	unitless	0.29	0.20	0.13
β_w	ft ² /lb	2.30E-08	2.30E-08	2.30E-08
β_p	ft ² /lb	3.00E-06	8.00E-07	4.00E-07
Calculated S_s	/ft	6.04E-03	1.62E-03	8.10E-04
Modeled S	unitless	1.98E-04	5.3E-05	2.66E-04
Applied to		Layer 1	Layers 2-11, 13-20	Layer 12

The storage coefficients (S) used in the base case model were lower than those calculated by multiplying S_s (in Table 8) times layer thickness, which caused the model to conservatively over-estimate drawdown. A sensitivity analysis was performed by increasing S values to those calculated in Table 8.

3.4.3 Leakance

Leakance between model layers (VCONT) was calculated using the following equation:

$$VCONT = \frac{1}{\left[\frac{0.5T_o}{Kv_o} \right] + \left[\frac{0.5T_u}{Kv_u} \right]}$$

Where:

- T_o is the thickness (ft) of the overlying layer.
 Kv_o is the vertical hydraulic conductivity (ft/d) of the overlying layer.
 T_u is the thickness (ft) of the underlying layer.
 Kv_u is the vertical hydraulic conductivity (ft/d) of the underlying layer.

The vertical hydraulic conductivity values that were used to calculate VCONT are summarized in Table 9.

Table 9. Calculation of MODFLOW VCONT Array

Layer	Geologic Unit	Thickness	K_h (ft/d)	K_h (cm/sec)	K_v (ft/d)	V_{cont}
1	Silts, silty clays, sandy silts	varies	1.73	6.1E-04	0.173	Varies
2	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
3	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
4	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
5	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
6	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
7	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
8	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
9	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
10	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
11	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	6.88E-03
12	Gravel	50	283	1.0E-01	28.3	6.88E-03
13	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
14	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
15	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
16	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
17	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
18	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
19	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	3.46E-03
20	Silts, silty clays, sandy silts	50	1.73	6.1E-04	0.173	N/A

3.5 Recharge

Recharge was applied to Layer 1 of the model at a rate of 2.283×10^{-6} ft/day (0.01 inches/yr). Lower recharge would result in higher drawdown of the aquifer. Higher recharge would result in less drawdown.

4. STEADY-STATE FLOW MODELING

4.1 Steady-State Model Runs

The groundwater flow model was first run without pumping to arrive at the steady-state solution. A double-precision (16-digit) version of the MODFLOW96 code (modflowdp.exe) was run external to the Groundwater Vistas pre/post-processor. The numerical accuracy of the double precision code was necessary to simulate the extremely low gradient across the site. The model utilized the pre-conditioned conjugate gradient (PCG2) solver.

The steady-state model (PW16ss) produced a flow field having a uniform hydraulic gradient of 6.54×10^{-4} . The heads in model Layer 1 are shown in Figure 8. Steady-state heads in Layers 2 – 20 were identical to Layer 1 in the steady-state simulation. The heads from the steady-state model were saved in the binary file PW16ssdp.hds. Steady-state heads were also generated for each sensitivity analysis, as discussed in Section 5.3.

4.2 Calibration

Calibration of a flow model refers to a demonstration that the model is capable of producing field-measured heads and flows which are known as calibration targets. Calibration is an inverse problem, which involves finding a set of hydraulic parameters, boundary conditions, and stresses that produce simulated heads and fluxes that match the field-measured values within a specified range of error. The model was run as a forward simulation, rather than an inverse calibration. An inverse calibration would require both field measured head and flux values, because head values alone produce non-unique model solutions. Since the 243-square mile model is “carved out” of the larger regional aquifer, field measurements of fluxes across the model domain are not available. In the forward problem, system parameters such as hydraulic conductivity, specific storage, and hydrologic stresses such as recharge rate are specified and the model calculates heads. Although Anderson and Woessner (1992) report that “most field problems require solving an inverse problem,” in this case the forward problem is believed to be appropriate.

5. TRANSIENT FLOW MODELING

The heads from the steady-state simulation (PW16ss.hds) were used as starting heads for the transient simulation, which was also run using double precision. The transient model included the wells and stress periods described below.

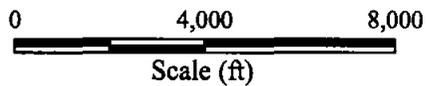
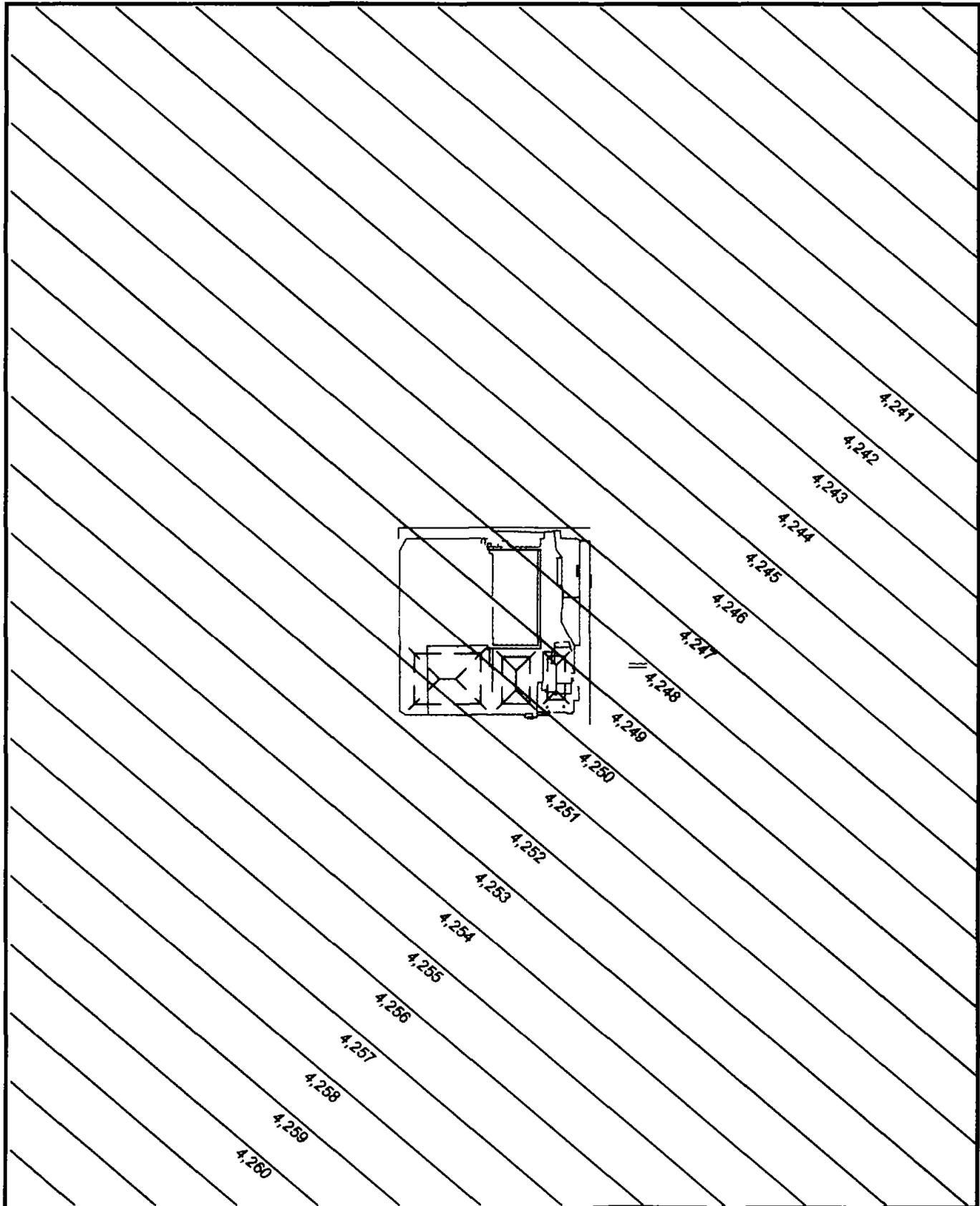
5.1 Pumping Well Set Up

The model simulated pumping from two proposed production wells. The first pumping well is modeled as pumping from the southwest corner of the site, near existing monitoring wells GW-19A, GW-19B, and PZ-1. The second pumping well is modeled located in Section 29, east of the existing pond (Figure 9). In this report, the wells are referred to as the Southwest Pond Well and the Section 29 Well, respectively. The site coordinates and model grid coordinates are provided in Table 10.

Table 10. Pumping Well Coordinates

WELL	SITE NORTHING	SITE EASTING	MODEL ROW	MODEL COLUMN	MODEL LAYER
Section 29 Well	15,870	14,137	87	53	12
Southwest Pond Well	9,868	10,032	17	45	12

The wells simulated as being pumped from a 50-ft thick gravel layer, which corresponds to the gravel layer identified in the Broken Arrow abandoned test well. The pumping wells are in model Layer 12, and simulate pumping from 550 to 600 ft below ground surface (3,725 to 3,775 ft elevation).



**Envirocare of Utah
Pumping Well Evaluation**

FIGURE 8
*Water Level Contours in Model Layer 1
Steady State (Pre-pumping)*

Tooele County, Utah

Date: 09.07.04

Scale: 1" = 4,000 FEET





Figure 9. Aerial Photographs Showing Location of (a) Proposed Section 29 Well and (b) Proposed Southwest Pond Well

The model simulates a pumping rate of 200 gallons per minute (gpm) from each well for 4 months of the year (June 1 to September 30). The wells are modeled as pumping for 122 days at a rate of 38,503 ft³/day per well, or 77,006 ft³/day total. The wells are turned off from October 1 to May 31 (243 days). This equates to an average annual withdrawal of 107.8 acre-ft per well, or a total of 215.7 acre-ft per year (Table 11).

Table 11. Pumping Rate Used in Transient Simulation

	Flow Rate (gpm)	Flow Rate (ft ³ /day)	Months Pumped	Days Pumped	Annual Volume Pumped (acre-ft/yr)	Average Annual Pumping Rate (gallons/year)
Per Well	200	38,503	4	122	107.8	35,136,000
Total	400	77,006	4	122	215.7	70,272,000

5.2 Stress Period Set Up

The transient simulation was run for 52 stress periods, 40 of which simulated 20 years of pumping and 12 of which simulated 20 years of water level recovery. Pumping rates and time discretization for stress periods 1 – 40 are shown in Table 12. Time discretization for stress periods 41 – 52, which simulate water level recovery without pumping, is summarized in Table 13.

Table 12. Pumping Rate per Transient Stress Period

Stress Period Number	Stress Period Length (Days)	Cumulative Time (Years)	Pumping Rate Per Well (ft ³ /day)	Pumping Rate Per Well (gpm)	Pumping Rate Total (ft ³ /day)	Pumping Rate Total (gpm)
1	150	0.41	0	0	0	0
2	122	0.75	38,503	200	77,005	400
3	243	1.41	0	0	0	0
4	122	1.75	38,503	200	77,005	400
5	243	2.41	0	0	0	0
6	122	2.75	38,503	200	77,005	400
7	243	3.41	0	0	0	0
8	122	3.75	38,503	200	77,005	400
9	243	4.41	0	0	0	0
10	122	4.75	38,503	200	77,005	400
11	243	5.41	0	0	0	0
12	122	5.75	38,503	200	77,005	400
13	243	6.41	0	0	0	0
14	122	6.75	38,503	200	77,005	400
15	243	7.41	0	0	0	0
16	122	7.75	38,503	200	77,005	400
17	243	8.41	0	0	0	0
18	122	8.75	38,503	200	77,005	400
19	243	9.41	0	0	0	0
20	122	9.75	38,503	200	77,005	400
21	243	10.41	0	0	0	0
22	122	10.75	38,503	200	77,005	400
23	243	11.41	0	0	0	0
24	122	11.75	38,503	200	77,005	400
25	243	12.41	0	0	0	0
26	122	12.75	38,503	200	77,005	400
27	243	13.41	0	0	0	0
28	122	13.75	38,503	200	77,005	400
29	243	14.41	0	0	0	0
30	122	14.75	38,503	200	77,005	400
31	243	15.41	0	0	0	0
32	122	15.75	38,503	200	77,005	400
33	243	16.41	0	0	0	0
34	122	16.75	38,503	200	77,005	400
35	243	17.41	0	0	0	0
36	122	17.75	38,503	200	77,005	400
37	243	18.41	0	0	0	0
38	122	18.75	38,503	200	77,005	400
39	243	19.41	0	0	0	0
40	122	19.75	38,503	200	77,005	400

Table 13. Transient Stress Periods for Water Level Recovery

Stress Period Number	Stress Period Length (Days)	Cumulative Time (Days)	Cumulative Time (Years)
41	8	7215	19.767
42	32	7247	19.855
43	128	7375	20.205
44	256	7631	20.907
45	365	7996	21.907
46	365	8361	22.907
47	730	9091	24.907
48	730	9821	26.907
49	730	10551	28.907
50	1095	11646	31.907
51	1460	13106	35.907
52	1825	14931	40.907

5.3 Sensitivity Analysis

Several sensitivity analyses were performed to investigate the effects of variations in aquifer thicknesses and boundary conditions. The file names and conditions are summarized in Table 14. The following sensitivity analyses were run:

- PW-6F. Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model.
- PW-ST. Sensitivity analysis PW-ST evaluated higher storage coefficients. Values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model.
- PW-LG. Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis (5.81×10^{-4}) was 89% of the value used in the base case model (6.54×10^{-4}).
- PW-HG. Sensitivity analyses PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis (7.82×10^{-4}) was 109% of the value used in the base case model (6.54×10^{-4}).
- PW-BH. Sensitivity analysis PW-BH evaluated a bedrock high, which was assumed to have a permeability ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (Section 2.2.1) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water (Table 15.)

Table 14. Sensitivity Analyses

CASE	Model Run (File Name)	Model Thickness	Boundary Conditions	Gradient	Specific Storage
Base Case	Model20	1000 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Thinner Aquifer	PW-6F	600 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Storage	PW-ST	1000 ft	Constant Head (4275 -> 4230)	6.54E-04	6.0E-3, 1.6E-3, 8.1E-4
Lower Gradient	PW-LG	1000 ft	Constant Head (4275 -> 4235)	5.81E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Gradient	PW-HG	1000 ft	Constant Head (4275 -> 4226)	7.12E-04	1.98E-4, 5.3E-5, 2.66E-5
Bedrock Ridge	PW-BH	Variable: 1000 ft with bedrock high	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5

Table 15. Hydraulic Conductivity Values for Sensitivity Analysis of Low-Permeability Bedrock High

Lithology	Parameter	Value (cm/sec)	Value (ft/day)	Data Source
Silts, silty clays, sandy silts	K_h	6.09E-04	1.7263	Average of 69 slug tests
	K_v	6.09E-05	0.1726	Assume $K_h = 10K_v$
Gravel layer	K_h	1.00E-01	283	lower range in Freeze & Cherry
	K_v	1.00E-02	28.3	Assume $K_h = 10K_v$
PPsc Bedrock	K_h	6.09E-05	0.1726	Assumed 1 o.o.m. lower than QI
	K_v	6.09E-06	0.01726	Assume $K_h = 10K_v$

Notes: K_h = horizontal hydraulic conductivity

K_v = vertical hydraulic conductivity

PPsc = Pennsylvanian / Permian Calcareous sandstone, quartzite, limestone, and dolomite. (Lower Permian and Upper Pennsylvanian). Also includes Basalt and basaltic andesite flows and shallow intrusives (Miocene and Pliocene).

QI = Quaternary lacustrine deposits

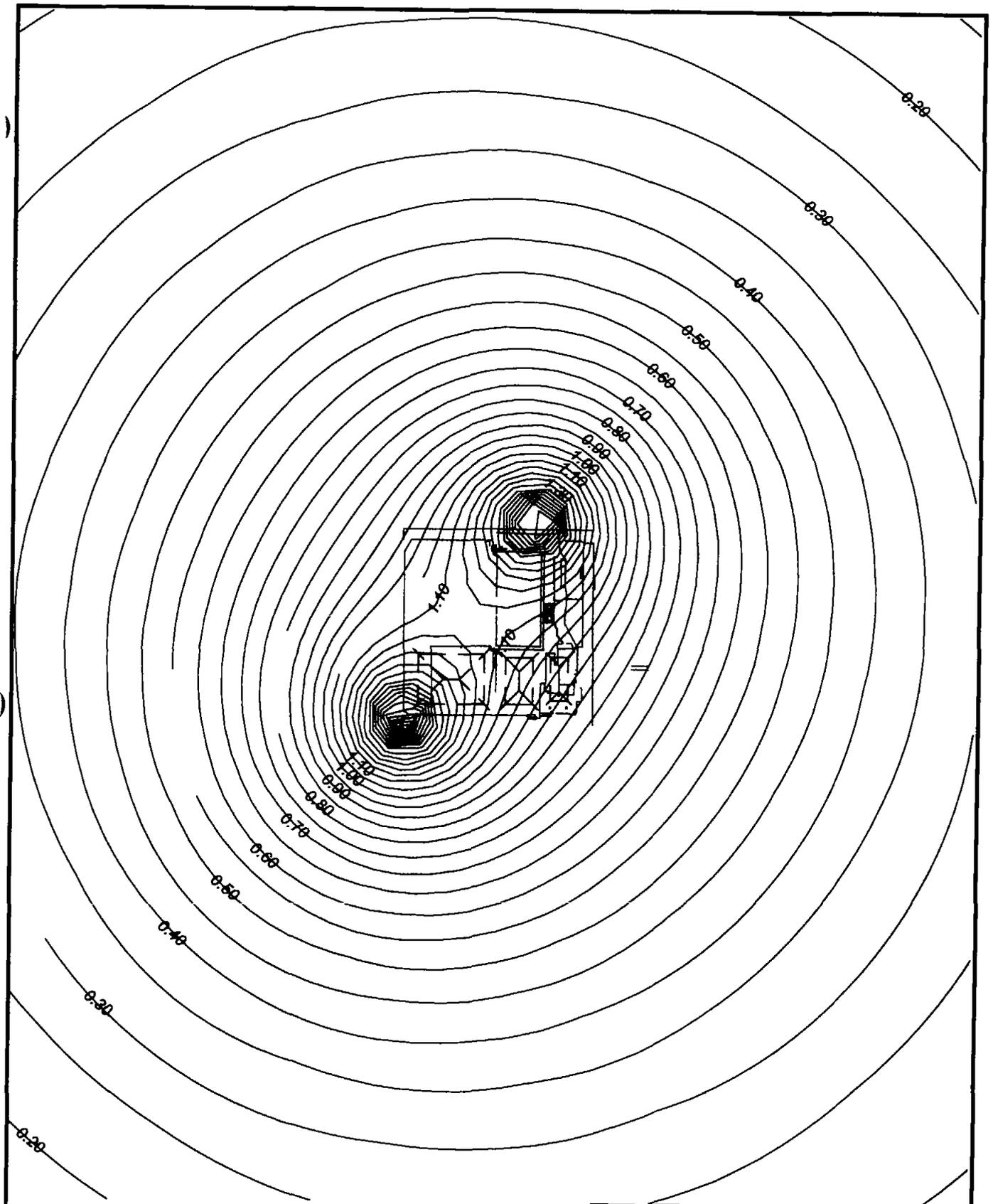
o.o.m. = order of magnitude

6. MODELING RESULTS

6.1 Base Case Model Results

6.1.1 Heads and Drawdown

The drawdown resulting from pumping at a rate of 200 gpm each from two wells for 4 months of each year for 20 years is shown in Table 16. These drawdown values are from the 100-ft wide model cells at the pumping wells (Row 87, Column 53, Layer 12 and Row 17, Column 45, Layer 12), directly above the pumping well (Layers 1 and 5), and directly below the pumping well (Layer 20). The drawdown is greatest at the pumping well in Layer 12 of the model, where a maximum drawdown of 3.034 ft is predicted at the Southwest Pond Well, and 3.029 ft is predicted at the Section 29 Well at the end of 20 years pumping (Figure 10).



NORTH



Scale (ft)

**Envirocare of Utah
Pumping Well Evaluation**

FIGURE 10
*Drawdown Contours in Model Layer 12
After 20 Years Pumping*

Tooele County, Utah

Date: 09.07.04

Scale: 1" = 4,000 FEET



Table 16. MODFLOW Model Results: Drawdown at the Pumping Wells During 20 Years of Pumping

Stress Period	Time (days)	Time (yrs)	Drawdown above SW Pumping Well in Layer 1	Drawdown above SW Pumping Well in Layer 5	Drawdown at SW Pumping Well in Layer 12	Drawdown below SW Pumping Well in Layer 20	Drawdown above Sec 29 Pumping Well in Layer 1	Drawdown above Sec 29 Pumping Well in Layer 5	Drawdown at Sec 29 Pumping Well in Layer 12	Drawdown below Sec 29 Pumping Well in Layer 20
R1	150	0.41	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R2	272	0.75	0.223	0.551	2.704	1.014	0.223	0.551	2.699	1.014
R3	515	1.41	0.155	0.117	0.065	0.065	0.156	0.118	0.065	0.065
R4	637	1.75	0.352	0.650	2.761	1.069	0.353	0.650	2.755	1.069
R5	880	2.41	0.252	0.194	0.112	0.112	0.253	0.195	0.112	0.112
R6	1002	2.75	0.436	0.717	2.804	1.112	0.437	0.718	2.799	1.112
R7	1245	3.41	0.318	0.249	0.150	0.149	0.319	0.249	0.150	0.149
R8	1367	3.75	0.494	0.767	2.839	1.147	0.495	0.767	2.834	1.147
R9	1610	4.41	0.365	0.290	0.180	0.179	0.366	0.290	0.180	0.179
R10	1732	4.75	0.537	0.804	2.867	1.175	0.539	0.805	2.862	1.175
R11	1975	5.41	0.402	0.322	0.205	0.204	0.403	0.323	0.205	0.204
R12	2097	5.75	0.571	0.834	2.891	1.198	0.572	0.835	2.886	1.198
R13	2340	6.41	0.431	0.348	0.226	0.225	0.432	0.349	0.226	0.225
R14	2462	6.75	0.598	0.858	2.911	1.218	0.599	0.859	2.906	1.218
R15	2705	7.41	0.454	0.369	0.244	0.243	0.456	0.370	0.245	0.243
R16	2827	7.75	0.620	0.878	2.928	1.235	0.622	0.879	2.923	1.236
R17	3070	8.41	0.474	0.388	0.260	0.259	0.476	0.389	0.260	0.259
R18	3192	8.75	0.639	0.896	2.943	1.250	0.640	0.897	2.938	1.251
R19	3435	9.41	0.491	0.403	0.274	0.272	0.493	0.404	0.274	0.273
R20	3557	9.75	0.655	0.911	2.956	1.264	0.657	0.912	2.951	1.264
R21	3800	10.41	0.506	0.417	0.286	0.285	0.507	0.418	0.287	0.285
R22	3922	10.75	0.669	0.924	2.968	1.275	0.671	0.925	2.963	1.275
R23	4165	11.41	0.519	0.429	0.297	0.295	0.520	0.430	0.297	0.296
R24	4287	11.75	0.681	0.936	2.979	1.286	0.683	0.937	2.974	1.286
R25	4530	12.41	0.530	0.440	0.307	0.305	0.532	0.441	0.307	0.306
R26	4652	12.75	0.692	0.946	2.988	1.295	0.694	0.947	2.983	1.295
R27	4895	13.41	0.541	0.450	0.316	0.314	0.542	0.451	0.316	0.314
R28	5017	13.75	0.702	0.956	2.997	1.304	0.704	0.957	2.992	1.304
R29	5260	14.41	0.550	0.459	0.324	0.322	0.551	0.460	0.324	0.322
R30	5382	14.75	0.711	0.964	3.004	1.311	0.713	0.965	2.999	1.312
R31	5625	15.41	0.558	0.467	0.331	0.329	0.560	0.468	0.331	0.330
R32	5747	15.75	0.719	0.972	3.011	1.318	0.721	0.973	3.006	1.319
R33	5990	16.41	0.565	0.474	0.338	0.336	0.567	0.475	0.338	0.336
R34	6112	16.75	0.726	0.979	3.018	1.325	0.728	0.980	3.013	1.325
R35	6355	17.41	0.572	0.480	0.344	0.342	0.574	0.481	0.344	0.342
R36	6477	17.75	0.733	0.985	3.024	1.331	0.735	0.986	3.019	1.331
R37	6720	18.41	0.579	0.486	0.349	0.347	0.580	0.487	0.350	0.348
R38	6842	18.75	0.739	0.991	3.029	1.336	0.741	0.992	3.024	1.336
R39	7085	19.41	0.584	0.492	0.354	0.353	0.586	0.493	0.355	0.353
R40	7207	19.75	0.744	0.996	3.034	1.341	0.746	0.997	3.029	1.341

Drawdown in the shallow aquifer (Model Layer 1) reaches a maximum of 0.75 ft at the end of 20 years. Drawdown in Layer 1, directly above the pumping wells, varies between about 0.59 ft and 0.75 ft during the final years of pumping as the well is cycled on and off (Figure 11.) Contours of the maximum drawdown in Layer 1 (in Year 20, at the end of pumping) are shown in Figure 12. The water levels in Layer 1 decline slightly over time, as shown in Figure 13.

These water level declines result in a very slight perturbation in the groundwater flow field (Figure 14) as the contours are deflected around the pumping wells.

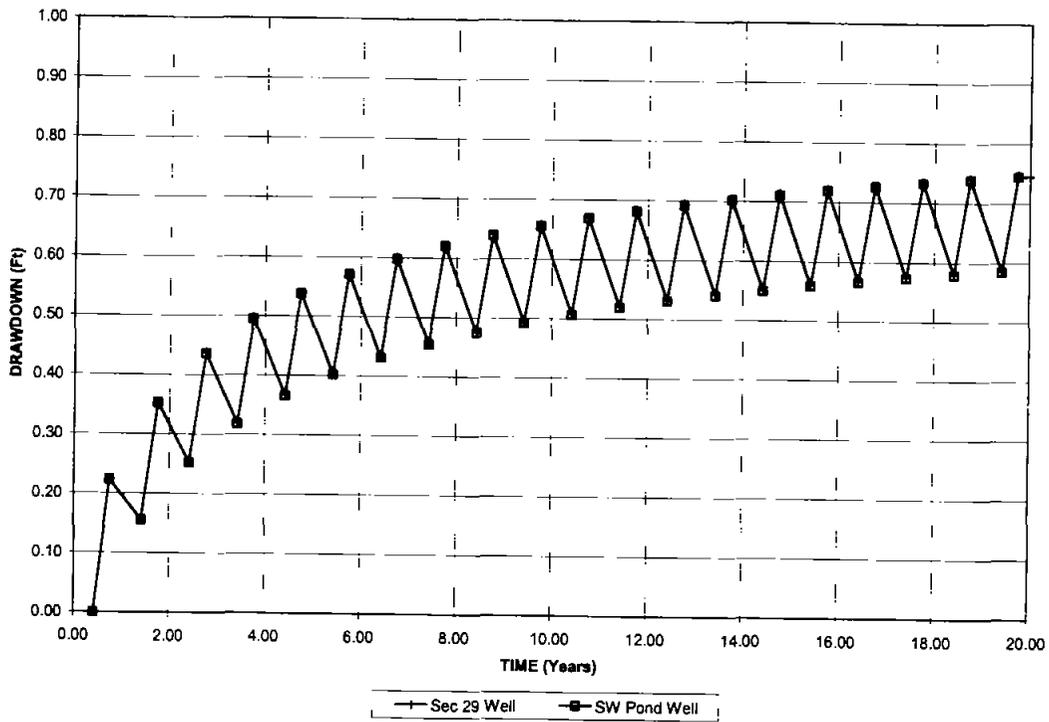
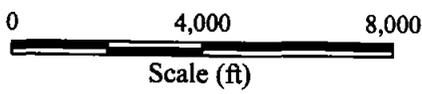
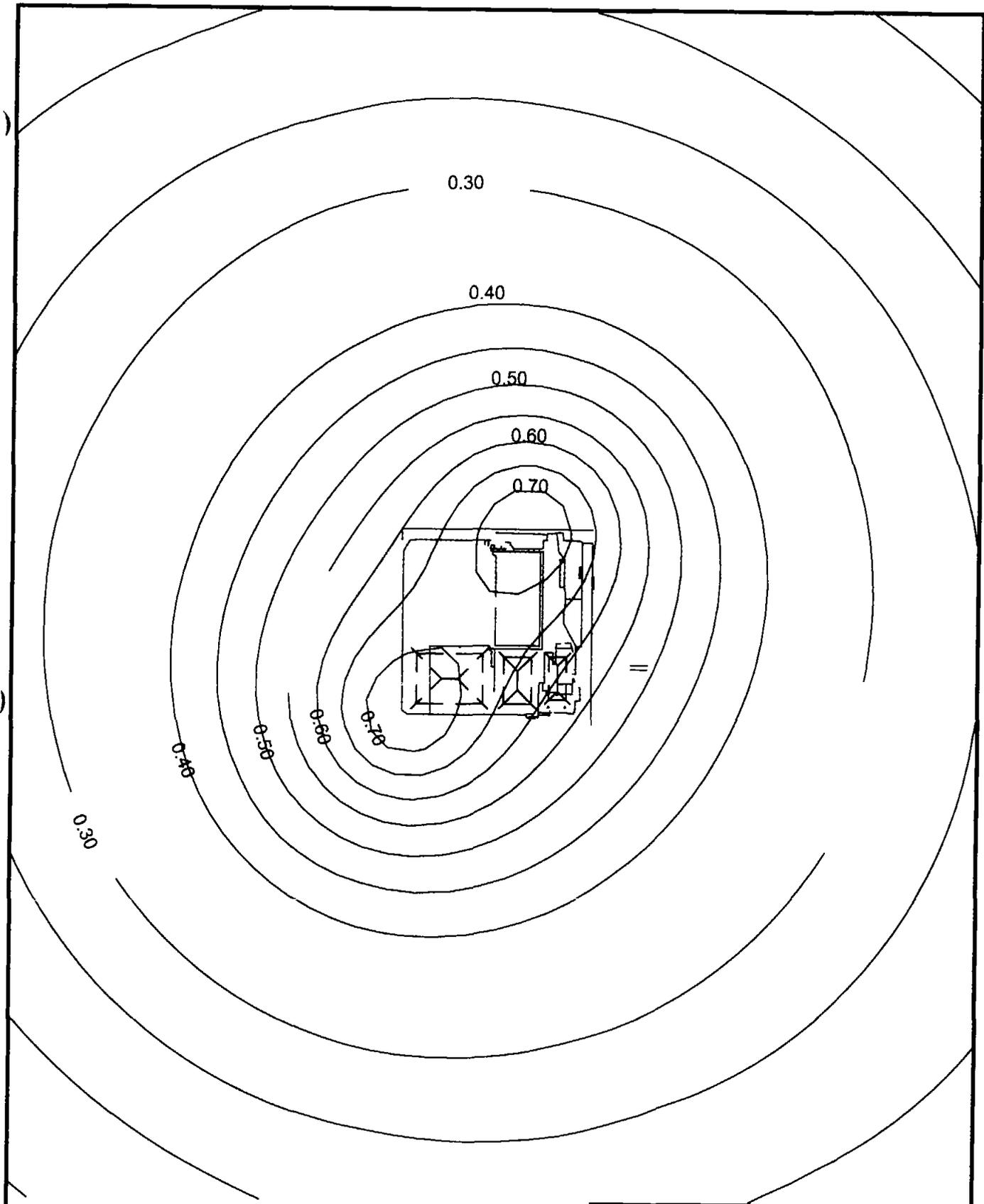


Figure 11. MODFLOW Model Results: Drawdown vs. Time in the Shallow Aquifer (Model Layer 1)



Envirocare of Utah Pumping Well Evaluation	
<i>FIGURE 12 Drawdown Contours in Model Layer 1 After 20 Years Pumping</i>	
Tooele County, Utah	
Date: 09.07.04	
Scale: 1" = 4,000 FEET	

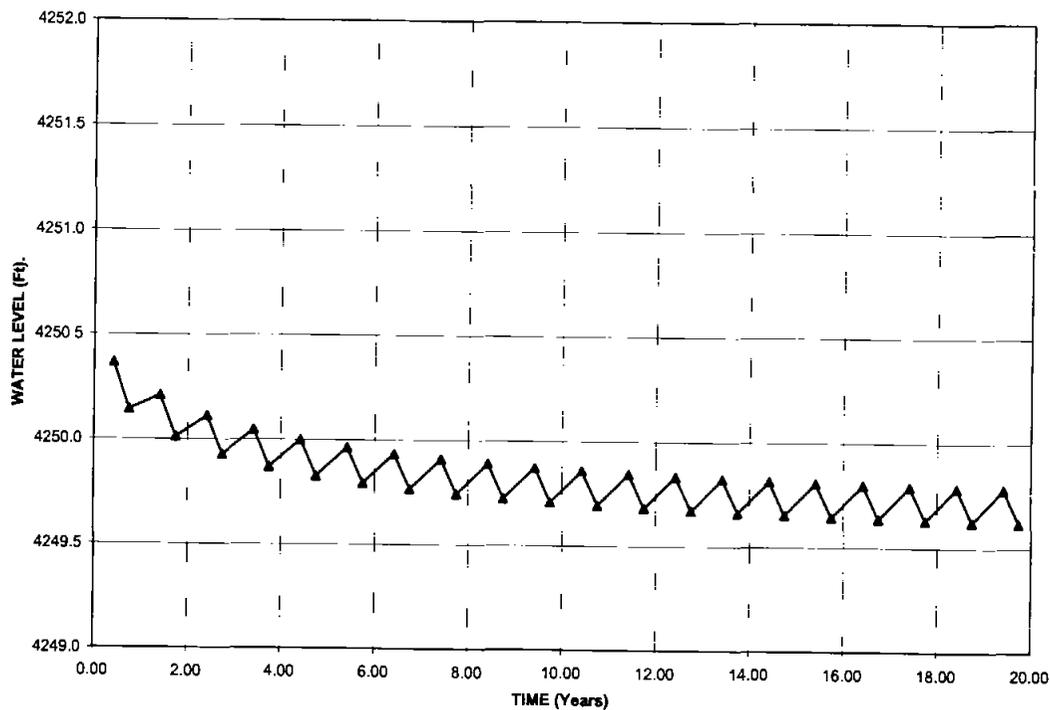


Figure 13. Model Results: Water Level vs. Time in the Shallow Aquifer (Model Layer 1)

6.1.2 Horizontal Hydraulic Gradients

Hydraulic gradients in the shallow aquifer *decrease* across the site in response to pumping from the two modeled production wells. Gradients beneath the embankments (Figure 15) are lowest during pumping and return to pre-pumping conditions within 3 years after the cessation of pumping (Figure 16). The gradients are lowest across the 11e.(2) cell, which is closest to the proposed Southwest Pond pumping well (Table 17, Figure 15). Although the gradient decreases in response to pumping, it is never reversed. The hydraulic gradient increases slightly upgradient of the Southwest Pond pumping well. The effect of these small changes in hydraulic gradient in the shallow aquifer would be to slow the potential rate of migration of constituents in groundwater downgradient of the site. The existing fate and transport modeling performed for waste disposal cells at the site would be even more conservative, and would over-predict constituent migration rates in the shallow aquifer.

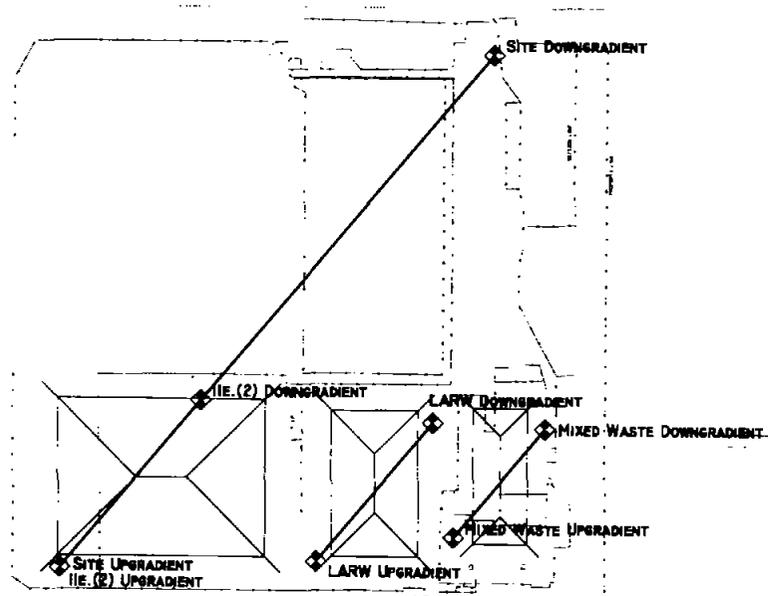


Figure 15. Locations for Horizontal Gradient Calculations

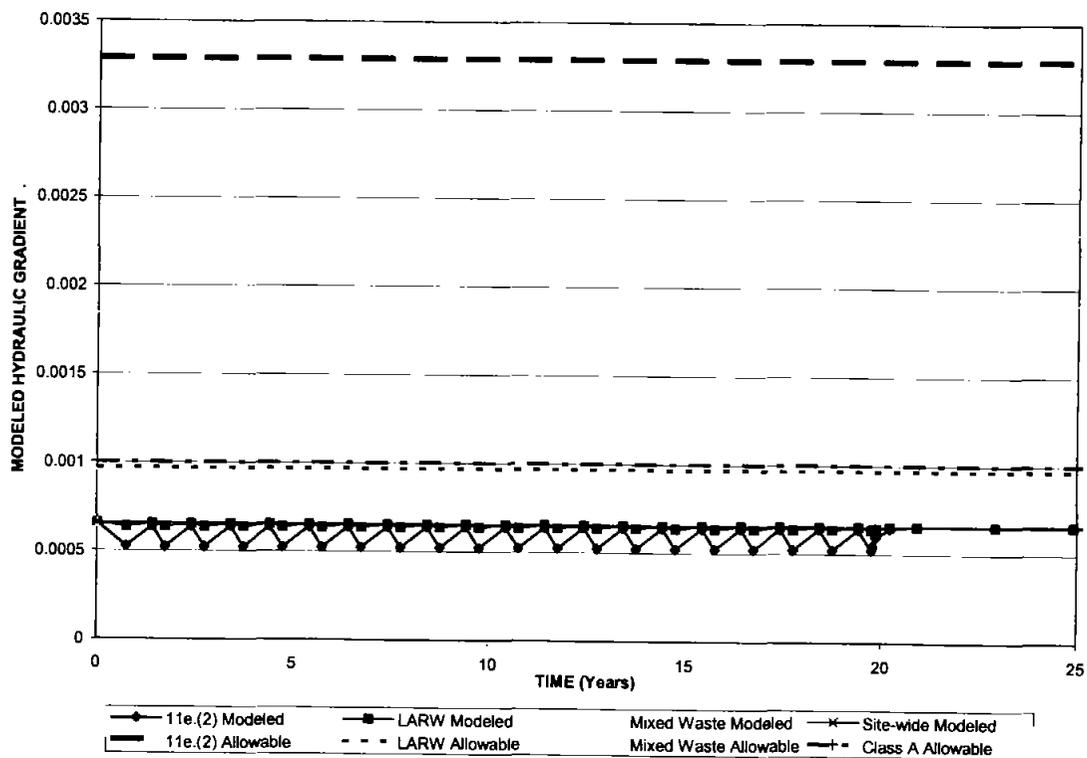


Figure 16. Changes in Site Hydraulic Gradients Over Time

Table 17. MODFLOW Model Results: Changes in Horizontal Hydraulic Gradients Over Time, Site-Wide and Across the 11e.(2), LARW, and Mixed Waste Embankments

Time (Days)	Time (Years)	11e.(2) Upgradient Head	11e.(2) Downgradient Head	Gradient Across 11e.(2)	Percent Change	LARW Upgradient Head	LARW Downgradient Head	Gradient Across LARW	Percent Change
0	0	4254.56	4253.02	0.000654	100.0%	4253.51	4252.40	0.000654	100.0%
272	0.7	4254.34	4252.85	0.000634	97.0%	4253.35	4252.25	0.000648	99.2%
515	1.4	4254.40	4252.88	0.000645	98.7%	4253.39	4252.28	0.000651	99.5%
637	1.7	4254.21	4252.73	0.000629	96.2%	4253.25	4252.15	0.000646	98.8%
880	2.4	4254.30	4252.79	0.000643	98.4%	4253.30	4252.20	0.000649	99.3%
1002	2.7	4254.12	4252.65	0.000628	96.1%	4253.17	4252.07	0.000645	98.7%
1245	3.4	4254.24	4252.72	0.000643	98.4%	4253.24	4252.14	0.000649	99.3%
1367	3.7	4254.06	4252.59	0.000628	96.1%	4253.11	4252.02	0.000645	98.7%
1610	4.4	4254.19	4252.68	0.000643	98.5%	4253.19	4252.09	0.000649	99.3%
1732	4.7	4254.02	4252.54	0.000629	96.2%	4253.07	4251.97	0.000645	98.7%
1975	5.4	4254.15	4252.64	0.000644	98.5%	4253.16	4252.05	0.000649	99.3%
2097	5.7	4253.98	4252.51	0.000629	96.2%	4253.04	4251.94	0.000645	98.7%
2340	6.4	4254.12	4252.61	0.000644	98.5%	4253.13	4252.02	0.000649	99.3%
2462	6.7	4253.96	4252.48	0.000629	96.3%	4253.01	4251.91	0.000645	98.7%
2705	7.4	4254.10	4252.58	0.000644	98.6%	4253.10	4252.00	0.000649	99.3%
2827	7.7	4253.94	4252.46	0.000629	96.3%	4252.99	4251.89	0.000645	98.7%
3070	8.4	4254.08	4252.56	0.000644	98.6%	4253.08	4251.98	0.000649	99.3%
3192	8.7	4253.92	4252.44	0.000629	96.3%	4252.97	4251.87	0.000645	98.7%
3435	9.4	4254.06	4252.55	0.000644	98.6%	4253.06	4251.96	0.000649	99.3%
3557	9.7	4253.90	4252.42	0.000629	96.3%	4252.95	4251.86	0.000645	98.7%
3800	10.4	4254.05	4252.53	0.000645	98.6%	4253.05	4251.95	0.000649	99.3%
3922	10.7	4253.89	4252.41	0.000630	96.3%	4252.94	4251.84	0.000645	98.7%
4165	11.4	4254.03	4252.52	0.000645	98.6%	4253.04	4251.93	0.000649	99.3%
4287	11.7	4253.87	4252.39	0.000630	96.3%	4252.93	4251.83	0.000645	98.7%
4530	12.4	4254.02	4252.51	0.000645	98.7%	4253.03	4251.92	0.000649	99.3%
4652	12.7	4253.86	4252.38	0.000630	96.4%	4252.91	4251.82	0.000645	98.7%
4895	13.4	4254.01	4252.50	0.000645	98.7%	4253.02	4251.91	0.000649	99.3%
5017	13.7	4253.85	4252.37	0.000630	96.4%	4252.90	4251.81	0.000645	98.7%
5260	14.4	4254.00	4252.49	0.000645	98.7%	4253.01	4251.90	0.000649	99.3%
5382	14.7	4253.84	4252.36	0.000630	96.4%	4252.90	4251.80	0.000645	98.7%
5625	15.4	4253.99	4252.48	0.000645	98.7%	4253.00	4251.89	0.000649	99.3%
5747	15.7	4253.84	4252.36	0.000630	96.4%	4252.89	4251.79	0.000645	98.7%
5990	16.4	4253.99	4252.47	0.000645	98.7%	4252.99	4251.89	0.000649	99.3%
6112	16.7	4253.83	4252.35	0.000630	96.4%	4252.88	4251.78	0.000645	98.7%
6355	17.4	4253.98	4252.46	0.000645	98.7%	4252.98	4251.88	0.000649	99.3%
6477	17.7	4253.82	4252.34	0.000630	96.4%	4252.87	4251.78	0.000645	98.7%
6720	18.4	4253.97	4252.46	0.000645	98.7%	4252.98	4251.87	0.000649	99.3%
6842	18.7	4253.82	4252.34	0.000630	96.4%	4252.87	4251.77	0.000645	98.7%
7085	19.4	4253.97	4252.45	0.000645	98.7%	4252.97	4251.87	0.000649	99.3%
7207	19.7	4253.81	4252.33	0.000630	96.4%	4252.86	4251.76	0.000645	98.7%
7215	19.8	4253.82	4252.33	0.000631	96.5%	4252.86	4251.77	0.000645	98.7%
7247	19.9	4253.84	4252.35	0.000635	97.1%	4252.88	4251.78	0.000646	98.9%
7375	20.2	4253.93	4252.42	0.000644	98.5%	4252.94	4251.84	0.000649	99.2%
7631	20.9	4254.05	4252.52	0.000651	99.6%	4253.03	4251.92	0.000651	99.6%
8361	22.9	4254.23	4252.69	0.000655	100.3%	4253.19	4252.08	0.000654	100.0%
9091	24.9	4254.32	4252.78	0.000655	100.2%	4253.27	4252.16	0.000654	100.0%
14931	40.9	4254.50	4252.96	0.000654	100.0%	4253.45	4252.34	0.000654	100.0%

Time (Days)	Time (Years)	M. Waste Upgradient Head	M. Waste Downgradient Head	Gradient Across M. Waste	Percent Change	Site Upgradient Head	Site Downgradient Head	Gradient Across Site	Percent Change
0	0.0	4252.86	4251.97	0.000654	100.0%	4254.56	4250.44	0.000654	100.0%
272	0.7	4252.72	4251.84	0.000652	99.7%	4254.34	4250.23	0.000652	99.7%
515	1.4	4252.75	4251.87	0.000652	99.8%	4254.40	4250.29	0.000653	99.8%
637	1.7	4252.63	4251.75	0.000650	99.5%	4254.21	4250.10	0.000651	99.6%
880	2.4	4252.67	4251.79	0.000652	99.6%	4254.30	4250.19	0.000652	99.8%
1002	2.7	4252.56	4251.68	0.000650	99.4%	4254.12	4250.02	0.000651	99.5%
1245	3.4	4252.61	4251.73	0.000651	99.6%	4254.24	4250.13	0.000652	99.7%
1367	3.7	4252.50	4251.63	0.000649	99.3%	4254.06	4249.96	0.000651	99.5%
1610	4.4	4252.57	4251.69	0.000651	99.5%	4254.19	4250.08	0.000652	99.7%
1732	4.7	4252.46	4251.59	0.000649	99.3%	4254.02	4249.92	0.000651	99.5%
1975	5.4	4252.53	4251.65	0.000651	99.5%	4254.15	4250.04	0.000652	99.7%
2097	5.7	4252.43	4251.55	0.000649	99.3%	4253.98	4249.89	0.000651	99.5%
2340	6.4	4252.50	4251.62	0.000651	99.5%	4254.12	4250.01	0.000652	99.7%
2462	6.7	4252.40	4251.53	0.000649	99.2%	4253.96	4249.86	0.000651	99.5%
2705	7.4	4252.48	4251.60	0.000651	99.5%	4254.10	4249.99	0.000652	99.7%
2827	7.7	4252.38	4251.50	0.000649	99.2%	4253.94	4249.84	0.000651	99.5%

3070	8.4	4252.46	4251.58	0.000650	99.5%	4254.08	4249.97	0.000652	99.7%
3192	8.7	4252.36	4251.48	0.000649	99.2%	4253.92	4249.82	0.000650	99.5%
3435	9.4	4252.44	4251.56	0.000650	99.5%	4254.06	4249.95	0.000652	99.7%
3557	9.7	4252.34	4251.47	0.000649	99.2%	4253.90	4249.80	0.000650	99.5%
3800	10.4	4252.43	4251.55	0.000650	99.5%	4254.05	4249.94	0.000652	99.7%
3922	10.7	4252.33	4251.45	0.000649	99.2%	4253.89	4249.79	0.000650	99.5%
4165	11.4	4252.41	4251.54	0.000650	99.5%	4254.03	4249.93	0.000652	99.7%
4287	11.7	4252.32	4251.44	0.000649	99.2%	4253.87	4249.78	0.000650	99.5%
4530	12.4	4252.40	4251.52	0.000650	99.5%	4254.02	4249.91	0.000652	99.7%
4652	12.7	4252.31	4251.43	0.000649	99.2%	4253.86	4249.76	0.000650	99.5%
4895	13.4	4252.39	4251.51	0.000650	99.5%	4254.01	4249.90	0.000652	99.7%
5017	13.7	4252.30	4251.42	0.000649	99.2%	4253.85	4249.75	0.000650	99.5%
5260	14.4	4252.38	4251.50	0.000650	99.5%	4254.00	4249.89	0.000652	99.7%
5382	14.7	4252.29	4251.41	0.000649	99.2%	4253.84	4249.75	0.000650	99.5%
5625	15.4	4252.37	4251.50	0.000650	99.5%	4253.99	4249.89	0.000652	99.7%
5747	15.7	4252.28	4251.40	0.000649	99.2%	4253.84	4249.74	0.000650	99.5%
5990	16.4	4252.37	4251.49	0.000650	99.5%	4253.99	4249.88	0.000652	99.7%
6112	16.7	4252.27	4251.40	0.000649	99.2%	4253.83	4249.73	0.000650	99.5%
6355	17.4	4252.36	4251.48	0.000650	99.5%	4253.98	4249.87	0.000652	99.7%
6477	17.7	4252.27	4251.39	0.000649	99.2%	4253.82	4249.72	0.000650	99.5%
6720	18.4	4252.35	4251.47	0.000650	99.5%	4253.97	4249.87	0.000652	99.7%
6842	18.7	4252.26	4251.38	0.000649	99.2%	4253.82	4249.72	0.000650	99.5%
7085	19.4	4252.35	4251.47	0.000650	99.5%	4253.97	4249.86	0.000652	99.7%
7207	19.7	4252.25	4251.38	0.000649	99.2%	4253.81	4249.71	0.000650	99.5%
7215	19.8	4252.26	4251.38	0.000649	99.2%	4253.82	4249.72	0.000651	99.5%
7247	19.9	4252.27	4251.39	0.000649	99.3%	4253.84	4249.74	0.000651	99.5%
7375	20.2	4252.32	4251.44	0.000650	99.4%	4253.93	4249.83	0.000652	99.7%
7631	20.9	4252.40	4251.52	0.000651	99.6%	4254.05	4249.94	0.000653	99.8%
8361	22.9	4252.54	4251.66	0.000653	99.9%	4254.23	4250.12	0.000653	99.9%
9091	24.9	4252.62	4251.74	0.000653	99.9%	4254.32	4250.20	0.000654	100.0%
14931	40.9	4252.80	4251.92	0.000654	100.0%	4254.50	4250.38	0.000654	100.0%

6.1.3 Vertical Hydraulic Gradients

Vertical migration of constituents from the shallow aquifer into the pumping well is not expected to occur during the 20 years of pumping. The transport velocity from the shallow to deep aquifer can be calculated as follows:

$$v = \frac{K_v \cdot i_v}{n_e} = \frac{(0.1726 \text{ ft/day})(2.29 \text{ ft}/500 \text{ ft})}{0.29} = 0.0027 \text{ ft/day} = 0.99 \text{ ft/yr}$$

where: v = transport velocity in the vertical direction (ft/yr)
 K_v = vertical hydraulic conductivity (ft/day)
 i_v = vertical hydraulic gradient (ft/ft)
 n_e = effective porosity (unitless)

Conservatively assuming that the maximum vertical gradient, which occurs in Year 20, applies throughout the 20 years of pumping, a constituent in the shallow aquifer directly above the pumping well would be transported less than 20 feet vertically during the 20 years of pumping. Vertical transport distances would be less, at locations further removed from the pumping well.

6.2 Water Level Recovery

Modeling results indicate that water levels in the shallow aquifer would recover 50% within 2 ½ years and 75% within 7 ¼ years of shutting off the pump (Figure 17). When the pump has been shut off for approximately the same length of time that it operated (20 years), the modeled water levels in the shallow aquifer have recovered to within 0.06 ft of the original static water level.

) Water level recovery at depth occurs more quickly (Figure 18) due to the higher hydraulic conductivity in the gravel layer. Water levels in the gravel zone recover 89% in the first year and 90% in two years. Within five years, water levels have recovered to within 0.2 ft of the original static water level.

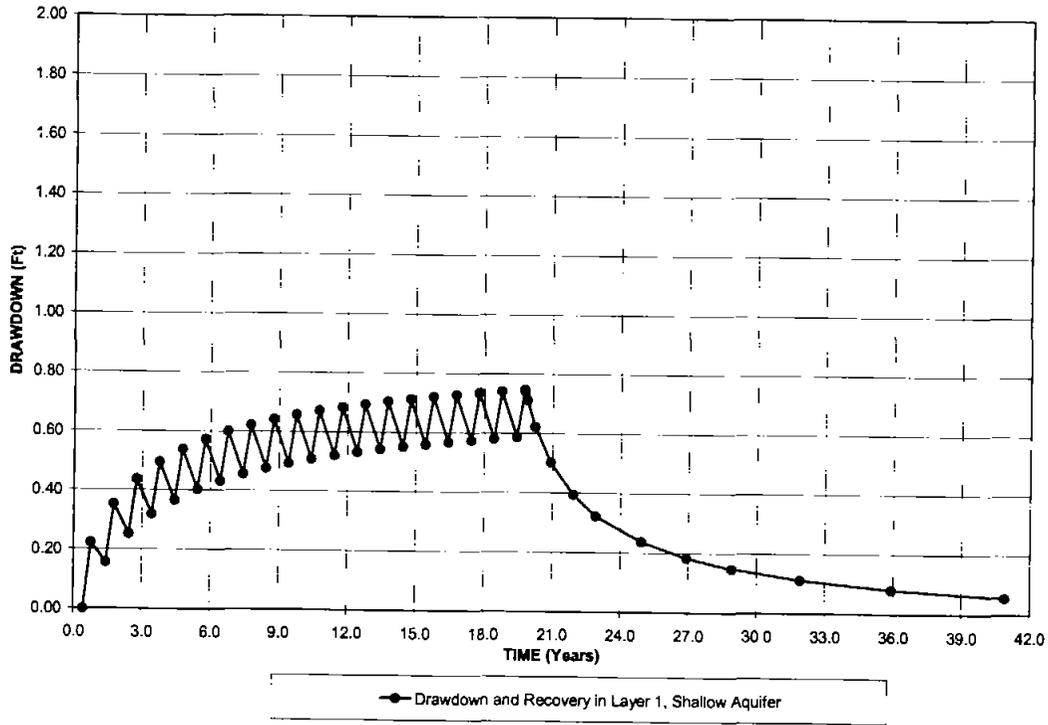


Figure 17. Model Results: Water Level Recovery in the Shallow Aquifer (Model Layer 1)

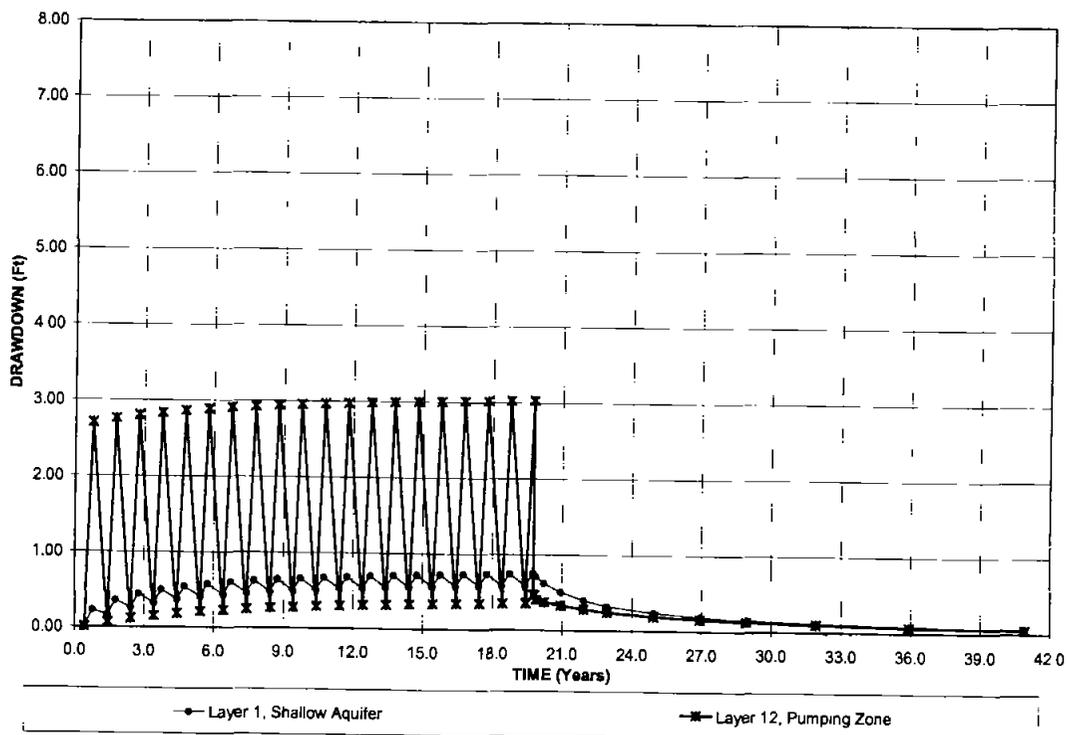


Figure 18. Model Results: Water Level Recovery in the Pumping Well Zone (Model Layer 12)

6.3 Sensitivity Analysis Results

Several sensitivity analyses were performed to investigate the effects of variations in aquifer thicknesses and boundary conditions. The results of the sensitivity analyses are provided in Appendix B. None of the sensitivity analyses resulted in higher gradients during pumping than those modeled in the steady-state simulation.

The maximum drawdown at both pumping wells was extracted from the model output files. Table 18 summarizes the maximum drawdown in Layer 1 (directly above the pumping well) and Layer 12 (in the pumping zone) for all model cases. The maximum drawdown occurred at the end of pumping (Model Year 20), and ranged from 0.75 to 1.2 feet at the water table directly above the pumping well² and from 3.0 – 3.6 feet in the pumping zone (Model Layer 12.)

² Model grid spacing is 100-ft in this area, and the drawdown calculated by MODFLOW represents the average drawdown in the 10,000 square-ft cell.

Table 18. Summary of Maximum Drawdown (in feet) for All Sensitivity Analyses Modeled

Well	Zone	Base Case	Thinner Aquifer Sensitivity Analysis	Higher Storativity Sensitivity Analysis	Lower Hydraulic Gradient Sensitivity Analysis	Higher Hydraulic Gradient Sensitivity Analysis	Low-K Bedrock Ridge Sensitivity Analysis
		Model20	PW-6F	PW-ST	PW-LG	PW-HG	PW-BH
Section 29 Well	Water Table (Layer 1)	0.746	0.774	0.707	0.745	0.747	1.100
Section 29 Well	Pumping Zone (Layer 12)	3.037	3.100	2.907	3.036	3.037	3.436
Southwest Pond Well	Water Table (Layer 1)	0.745	0.772	0.705	0.744	0.745	1.198
Southwest Pond Well	Pumping Zone (Layer 12)	3.051	3.114	2.921	3.051	3.051	3.581

Table 19. Summary of Model-Calculated Hydraulic Gradients (% of Starting Gradient)

Model Run (File Name)	Minimum Gradient Across 11e.(2) Cell	Minimum Gradient Across LARW Cell	Minimum Gradient Across Mixed Waste Cell	Minimum Gradient Across Site
Model20	96.10%	98.66%	99.22%	99.48%
PW-6F	95.99%	98.61%	99.19%	99.46%
PW-ST	96.17%	98.70%	99.25%	99.50%
PW-LG	95.63%	98.50%	99.13%	99.41%
PW-HG	96.40%	98.77%	99.29%	99.52%
PW-BH	85.29%	92.01%	93.59%	93.55%

Model Run (File Name)	Maximum Gradient Across 11e.(2) Cell	Maximum Gradient Across LARW Cell	Maximum Gradient Across Mixed Waste Cell	Maximum Gradient Across Site
Model20	100.27%	100.04%	100.00%	100.00%
PW-6F	100.29%	100.04%	100.00%	100.00%
PW-ST	100.29%	100.04%	100.00%	100.00%
PW-LG	100.31%	100.04%	100.00%	100.00%
PW-HG	100.25%	100.03%	100.00%	100.00%
PW-BH	98.39%	98.33%	100.00%	100.00%

The sensitivity analysis results are discussed individually in Section 6.3.1 through 6.3.5.

6.3.1 Sensitivity Analysis PW-6F Results

Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model. The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly greater than in the base case (Model20) simulation.

Drawdown at the water table and in the pumping zone is shown in Table 18. The maximum drawdown at the water table in Year 20 of the PW-6F sensitivity analysis was 0.774 ft, which is 3.75% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.114 ft, which is 3.28% greater than in the Base Case

6.3.2 Sensitivity Analysis PW-ST Results

Sensitivity analysis PW-ST evaluated higher storage coefficients. Storage values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model. The hydraulic gradients decrease during pumping and the gradient reductions are comparable to those in the Base Case. The hydraulic gradients across the site and across the individual disposal cells in the PW-ST sensitivity analysis are shown in Appendix B.

Maximum drawdown at the water table and in the pumping zone is summarized in Table 18. The maximum drawdown at the water table in Year 20 of the PW-ST sensitivity analysis was 0.707 ft, which is 5.2% less than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 2.92 ft, which is 4.5% less than in the Base Case.

6.3.3 Sensitivity Analysis PW-LG Results

Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis (5.81×10^{-4}) was 89% of the value used in the base case model (6.54×10^{-4}). The flow field simulated by the PW-LG sensitivity analysis model is nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping, and the changes in hydraulic gradients are slightly greater than in the Base Case model results. Drawdown at the water table and in the pumping zone is shown in Table 18. The maximum drawdown at the water table in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly less than) the Base Case model results.

6.3.4 Sensitivity Analysis PW-HG Results

Sensitivity analysis PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis (7.12×10^{-4}) was 109% of the value used in the base case model (6.54×10^{-4}). The flow field simulated by the PW-HG sensitivity analysis model is nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly less than in the base case (Model20) simulation. Maximum drawdown at the water table and in the pumping zone in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly greater than) the Base Case model results (Table 18).

6.3.5 Sensitivity Analysis PW-BH Results

Sensitivity analysis PW-BH evaluated the effects of two bedrock ridges, which were assumed to have a hydraulic conductivity ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (Section 2.2.1) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water.

The flow field simulated by the PW-BH sensitivity analysis model was very different from the Base Case model, because the bedrock ridges significantly influence the flow field east and west of the site (Figure 19). Near the Envirocare facility, the modeled flow field is similar to the Base Case model, with a site-wide hydraulic gradient of 2.8×10^{-4} in the steady-state PW-BH simulation compared to 6.54×10^{-4} in the base case model.



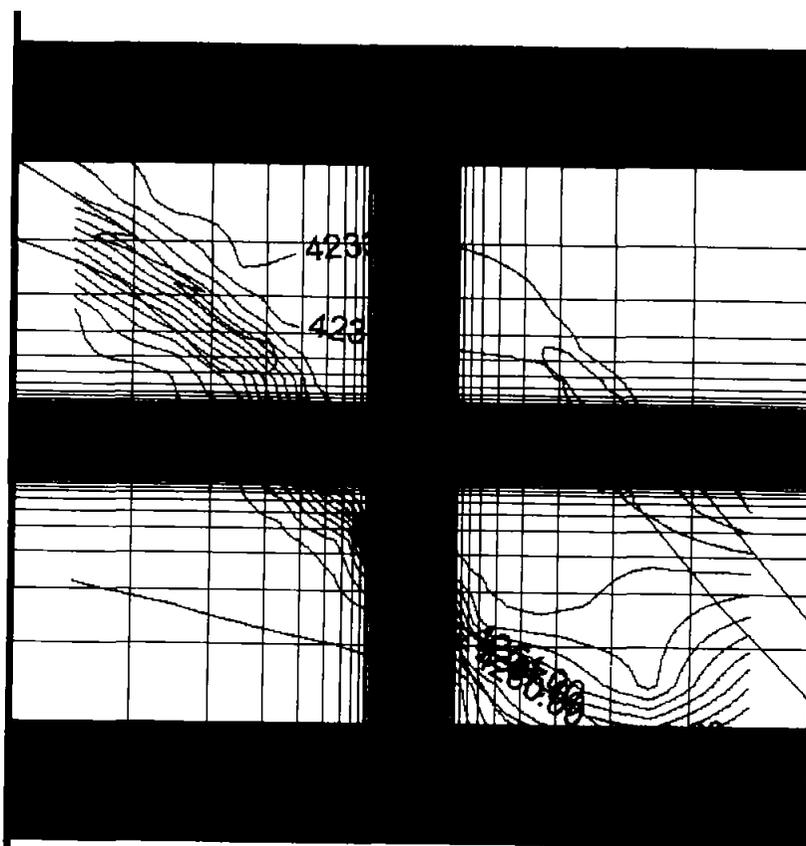


Figure 19. Steady-State Water Table Contours – Model Run PW-BH

The hydraulic gradients decrease during pumping, more so than in the Base Case. For example, the minimum gradient across the 11e.(2) cell during pumping and recovery was 85% of the steady-state calculated gradient. The minimum gradient across the site was approximately 94%, compared to 99.5% in the Base Case simulation (Table 19).

Maximum drawdown at the water table and in the pumping zone is summarized in Table 18. The maximum drawdown at the water table in Year 20 of the PW-BH sensitivity analysis was 1.2 ft, which is 61% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.581 ft, which is 17% greater than in the Base Case.

7. CONCLUSIONS

Model results indicate that pumping from two wells at a depth of 550 feet below ground surface at a combined rate of 400 gpm for 4 months per year for 20 years would result in 0.75 ft drawdown in the overlying shallow aquifer. The drawdown cone would be widespread, and hydraulic gradients would decrease slightly. The flow direction in the shallow aquifer, however, would not reverse. The reduction in gradient would slow the rate of transport of constituents in the aquifer downgradient of the site for the period of pumping and for an additional 10 years of water level recovery. Approximately 20 years after pumping, the water levels would be almost fully recovered and the flow field and transport rates would return to the normal (pre-pumping) condition.

In summary, pumping from two production wells screened from 550 to 600 feet below ground surface (bgs), pumped at 200 gallons per minute, 24 hours per day, 4 months per year (122 days), would create

-) approximately 0.75 feet of drawdown in the upper aquifer after 20 years. This drawdown will not increase the hydraulic gradient beneath the facility.

April 7, 2005

Prepared and submitted by:

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APPENDIX A
WELL DRILLER REPORTS
FOR DEEP WELLS

Prepared for:

*Envirocare of Utah, Inc.
605 North 5600 West
Salt Lake City, UT 84116*

Prepared by

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P.O. Box 1156
La Veta, Colorado 81055
719-742-5155
Document 4101U.050407*

April 7, 2005

State of Utah Division of Water Rights

For additional space, use "Additional Well Data Form" and attach

Well Identification: **WATER RIGHT APPLICATION: 16-816(A68876)**

Owner: *Note any changes*
Broken Arrow Incorporated
165 South Main
Tooele, UT 84074

Contact Person/Engineer: _____

Well Location: *Note any changes*
COUNTY: Tooele
NORTH 500 feet EAST 3800 feet from the SW Corner of
SECTION 29, TOWNSHIP 1S, RANGE 11W, SLB&M.

Location Description: (address, **In-Office** buildings, landmarks, ground elevation, local well #) _____

Drillers Activity: Start Date: 1-9-96 Completion Date: 1-18-96

Check all that apply: New Repair Deepen Abandon Replace Public Nature of Use: **OTH**

DEPTH (feet)	BOREHOLE	DRILLING METHOD	DRILLING FLUID
FROM TO	DIAMETER (in)		
0 620	9 7/8	MUD ROTARY	BENTONITE & Polymer

Well Log	W: A: T: E: R:	P: E: R: A: B: L: E:	UNCONSOLIDATED		CONSOLIDATED		ROCK TYPE	COLOR	DESCRIPTIONS AND REMARKS (include comments on water quality if known.)
			C S	S I	G C	B I			
0 4								X	TOP SOIL
4 50								X	
80 95								X	
95 182								X	SANDSTONE
182 483								X X	
483 487								X	
487 495								X	
495 505								X	
505 545								X	
545 620								X	

Static Water Level:
 Date: 1-18-96 Water Level: 84 feet Flowing? Yes No
 Method of Water Level Measurement: SOUND If Flowing, Capped Pressure: _____ PSI
 Point to Which Water Level Measurement was Referenced: GROUND LEVEL
 Height of Water Level reference point above ground surface: _____ feet Temperature: _____ °C _____ °F

**State of Utah
Division of Water Rights**

For additional space, use "Additional Well Data Form" and attach

Well Identification: **WATER RIGHT APPLICATION: 16-816(A68876)**

Owner: *Note any changes*
**Broken Arrow Incorporated
 165 South Main
 Tocoee, UT 84074**

Contact Person/Engineer: _____

Well Location: *Note any changes*
**COUNTY: Tocoee
 NORTH 500 feet EAST 3800 feet from the SW Corner of
 SECTION 29, TOWNSHIP 1S, RANGE 11W, SLB&M.**

Location Description: (address, ~~proximity~~ buildings, landmarks, ground elevation, local well #) _____

Drillers Activity: Start Date: 1-30-96 Completion Date: 1-30-96

Check all that apply:

New Repair Deepen Abandon Replace Public Nature of Use: **OTH**

DEPTH (feet) FROM TO	BOREHOLE DIAMETER (in)	DRILLING METHOD	DRILLING FLUID
0 620	9 7/8	MUD ROTARY	BENTONITE & Polymer

Well Log	WIP A T E R	P E A M E A B L E	UNCONSOLIDATED		CONSOLIDATED		ROCK TYPE	COLOR	DESCRIPTIONS AND REMARKS (include comments on water quality if known.)
			C	S	S	I			
DEPTH (feet) FROM TO			L	A	R	O	O	I	
			A	L	N	A	B	U	H
			Y	T	D	V	I	B	L
			E	L	D	R			
			L	E	E				
			S	R					

ABANDON

Static Water Level |
 Date _____ Water Level _____ feet Flowing? Yes No
 Method of Water Level Measurement _____ If Flowing, Capped Pressure _____ PSI
 Point to Which Water Level Measurement was Referenced _____
 Height of Water Level reference point above ground surface _____ feet Temperature _____ °C °F

APPENDIX B MODEL SENSITIVITY ANALYSIS

Prepared for
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April 7, 2005

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- Figure 19. Steady-State Water Table Contours – Model Run PW-BH
- Figure 20. Changes in Site Hydraulic Gradients Over Time – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)
- Figure 21. Drawdown and Water Level Recovery in the Shallow Aquifer – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)
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1. INTRODUCTION

A three-dimensional finite difference groundwater flow model was developed to evaluate the potential drawdown and gradient changes that could be associated with pumping from two water supply production wells proposed for installation near the Envirocare of Utah low-level radioactive waste disposal facility. The analysis was performed using the United States Geological Survey (USGS) MODFLOW software (McDonald and Harbaugh, 1988) and the Groundwater Vistas 3.0 pre/post-processor (Rumbaugh, 2002). The purpose of this appendix is to describe the model sensitivity analysis approach, results, and conclusions.

This appendix is not intended as a stand-alone document. The reader is referred to the main body of the report for a thorough documentation of the conceptual model, numerical model input parameters, and Base Case results.

2. BASE CASE MODEL

The Base Case model is described thoroughly in the main body of the report, and is summarized briefly in this appendix. The three-dimensional finite-difference MODFLOW model uses a telescoping grid with 102 cells in the x-direction, 102 cells in the y-direction, and 20 cells in the z-direction. The horizontal grid spacing ranges from a minimum of 100 feet near the proposed pumping wells to a maximum of 12,000 feet near the model boundaries. The model domain is 1,000 feet thick, is divided into 20 layers of uniform (50-ft) thickness, and contains 208,080 active cells. The electronic data files for the base case model runs are named "Model 20."

The model is oriented in the direction of groundwater flow (approximately N40°E). The model boundaries in all layers of the Base Case model were set to constant heads of 4,375 ft at the upgradient boundary (model north) and 4,230 ft at the downgradient boundary (model south). The constant head cells establish a very small uniform gradient of 0.000654 ft/ft (5.57×10^{-4}) in the steady-state model.

The Base Case model was first run without pumping to arrive at the steady-state solution (PW16ss). A double-precision (16-digit) version of the MODFLOW96 code (modflowdp.exe) was run external to the Groundwater Vistas pre/post-processor, using the pre-conditioned conjugate gradient (PCG2) solver. The numerical accuracy of the double precision code was necessary to simulate the extremely low gradient across the site.

The Base Case model was then run in the transient condition, to simulate pumping from the two proposed production wells, referred to as the Southwest Pond Well and the Section 29 Well. The wells simulate pumping from a 50-ft thick gravel layer located 550 to 600 ft below ground surface (3,725 to 3,775 ft elevation), that corresponds to the gravel layer identified in the Broken Arrow abandoned test well.

The model simulates a pumping rate of 200 gallons per minute (gpm) from each well for 4 months of the year (June 1 to September 30). The wells are modeled as pumping for 122 days at a rate of 38,503 ft³/day per well, or 77,006 ft³/day total. The wells are turned off from October 1 to May 31 (243 days). This equates to an average annual withdrawal of 107.8 acre-ft per well, or a total of 215.7 acre-ft per year. The transient simulation was run for 52 stress periods, 40 of which simulated 20 years of pumping and 12 of which simulated 20 years of water level recovery.

The results of the Base Case model indicate that a maximum drawdown of 3.034 ft is predicted at the Southwest Pond Well and 3.029 ft is predicted at the Section 29 Well in the pumping zone (Model Layer 12) at the end of 20 years pumping. Directly above the pumping wells, in Model Layer 1, drawdown in the shallow aquifer reaches a maximum of 0.75 ft at the end of 20 years. In that final year of pumping, drawdown at the water table directly above the pumping wells varies between about 0.59 ft and 0.75 ft as the well is cycled on and off (Figure 1).

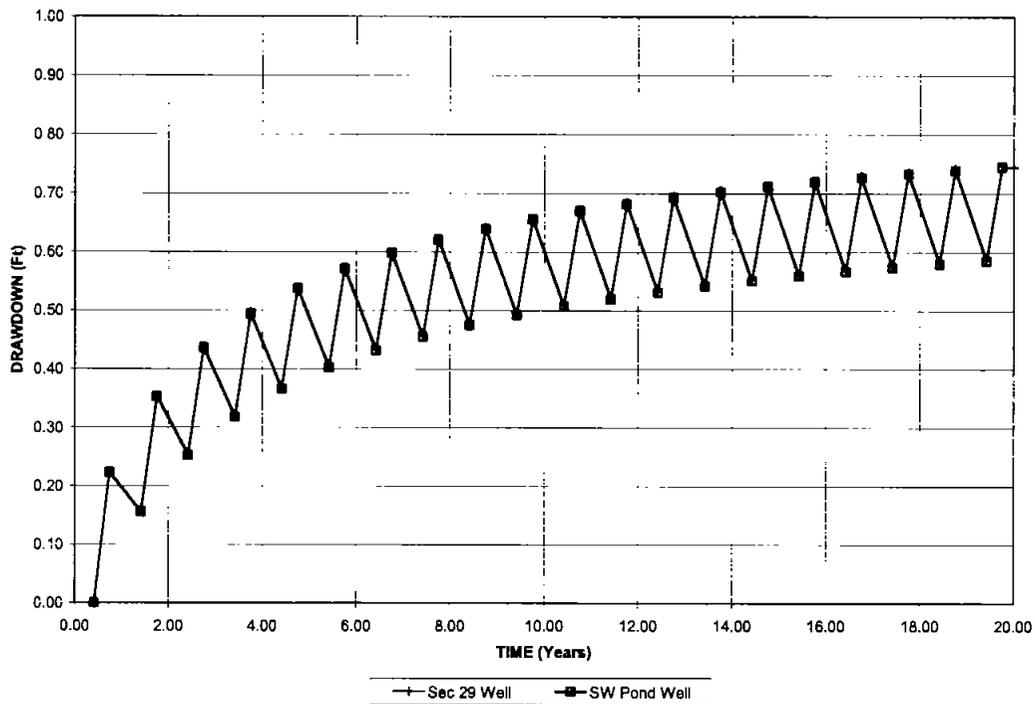


Figure 1. Modflow Model Results: Drawdown vs. Time in the Shallow Aquifer (Model Layer 1)

The water levels (heads) predicted by the Base Case modeling were used to calculate hydraulic gradients across the 11e.(2), LARW, and Mixed Waste disposal facilities and across the entire site, at the locations shown in Figure 2. The calculated gradients were compared to the hydraulic gradient limits specified in Condition I.H.2.c).2. of the Ground Water Quality Discharge Permit (GWQDP) for each disposal facility at the Envirocare site (Table 1). The predicted gradients for the Base Case simulation were well below the allowable limits (Figure 3).

Hydraulic gradients in the shallow aquifer *decrease* across the site in response to pumping from the two modeled production wells. Gradients beneath the disposal embankments are lowest during pumping and return to pre-pumping conditions within 3 years after the cessation of pumping (Figure 3). The gradients are lowest across the 11e.(2) cell, which is closest to the proposed Southwest Pond pumping well. Although the gradient decreases in response to pumping, it is never reversed. The hydraulic gradient increases slightly upgradient of the Southwest Pond pumping well. The effect of these small changes in hydraulic gradient in the shallow aquifer would be to slow the potential rate of migration of constituents in groundwater downgradient of the site. The existing fate and transport modeling performed for waste disposal cells at the site would be even more conservative, and would over-predict constituent migration rates in the shallow aquifer.

Table 1. Horizontal Hydraulic Gradient Limits Specified in the GWQDP

Disposal Cell	Horizontal Hydraulic Gradient Limit
Class A	1.00 E-3
LARW	9.67 E-4
Mixed Waste	9.67 E-4
11e.(2)	3.29 E-3

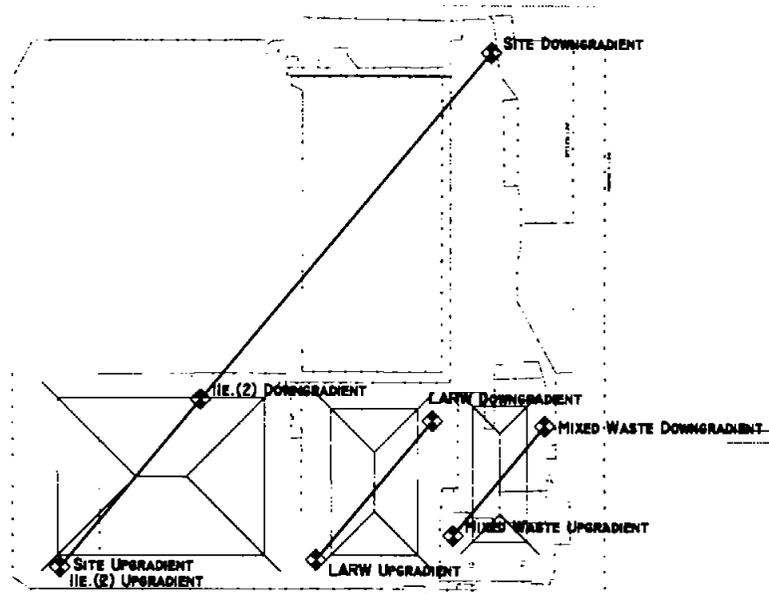


Figure 2. Locations for Horizontal Gradient Calculations

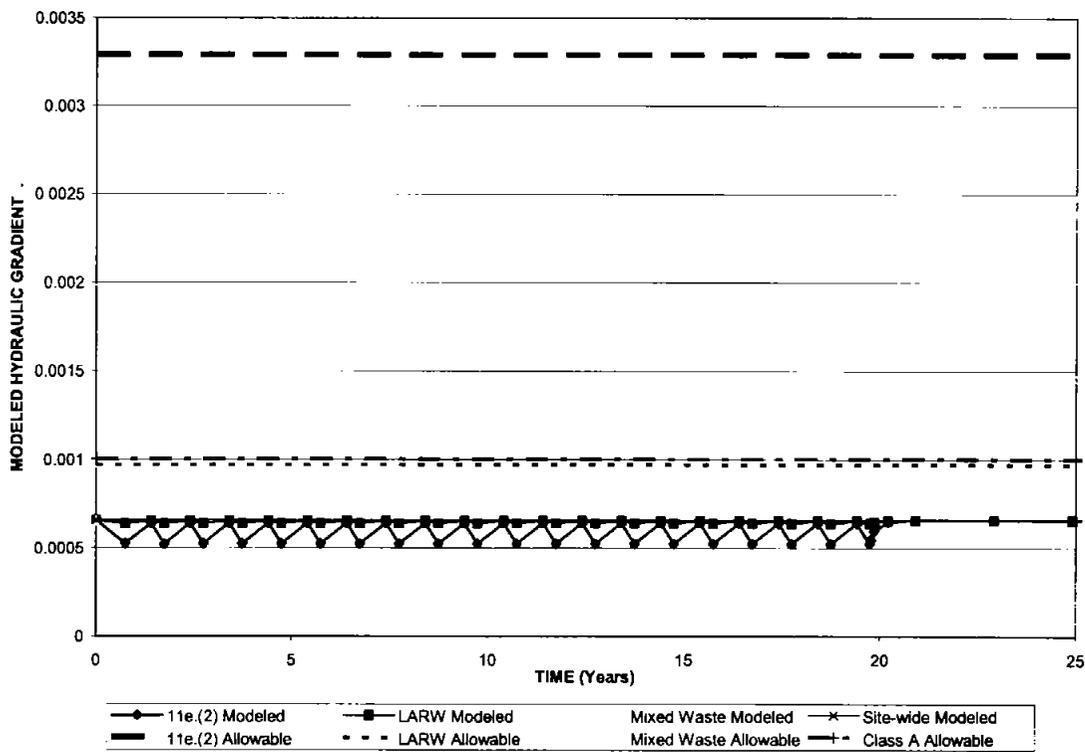


Figure 3. Changes in Site Hydraulic Gradients Over Time – Base Case Simulation

3. SENSITIVITY ANALYSES

Five sensitivity analyses were performed to investigate the effects of variations in aquifer thicknesses and boundary conditions. The file names and conditions are summarized in Table 2, and each case is described individually in the following sections.

Table 2. Sensitivity Analyses

CASE	Model Run (File Name)	Model Thickness	Boundary Conditions	Gradient	Specific Storage
Base Case	Model20	1000 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Bedrock Ridge	PW-BH	Variable: 1000 ft with bedrock high	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Shallow Bedrock	PW-6F	600 ft	Constant Head (4275 -> 4230)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Storage	PW-ST	1000 ft	Constant Head (4275 -> 4230)	5.81E-04	6.0E-3, 1.6E-3, 8.1E-4
Lower Gradient	PW-LG	1000 ft	Constant Head (4275 -> 4235)	7.12E-04	1.98E-4, 5.3E-5, 2.66E-5
Higher Gradient	PW-HG	1000 ft	Constant Head (4275 -> 4226)	6.54E-04	1.98E-4, 5.3E-5, 2.66E-5

3.1.1 Sensitivity Analysis PW-6F

Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model. The change in aquifer thickness was implemented by deleting the lower 8 model layers (400 ft), leaving a 12-layer model. No other modifications to the model were made.

3.1.2 Sensitivity Analysis PW-ST

Sensitivity analysis PW-ST evaluated higher storage coefficients. Storage values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model. The storage values used in the Base Case model and the PW-ST model runs are shown in Table 3.

Table 3. Storage Values Used in Base Case (Model 20) and Higher Storage (PW-ST) Sensitivity Analysis

Model Case	Description	Silty sand	Dense silty sand	Dense sandy gravel
Model-20	Base Case	6.04E-03 /ft	1.62E-03 /ft	8.10E-04 /ft
PW-ST	Higher Storage Sensitivity Analysis	1.98E-04	5.3E-05	2.66E-04
Applied to		Layer 1	Layers 2-11, 13-20	Layer 12

Lower storage coefficients (such as those used in the base case model) would cause the model to predict higher drawdown. Conversely, higher storage coefficients result in lower predicted drawdown.

3.1.3 Sensitivity Analysis PW-LG

Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis (5.81×10^{-4}) was 89% of the value used in the base case model (6.54×10^{-4}), and corresponds more closely

-) with the average gradient measured at the site in all unconfined wells during January 2003 (4.96×10^{-4}). The change in hydraulic gradient was implemented by changing the constant head elevations at the downgradient boundary from 4,230 to 4,235 ft, as shown in Table 4. No other changes were made to the model, and a steady-state simulation (PW-LGSS) was used to generate starting heads for the transient simulation.

Table 4. Calculation of Hydraulic Gradients Used in PW-LG and PW-HG Sensitivity Analyses

	Base Case (Model 20)	Jan 2003 Gradient	PW-LG Sensitivity Analysis	PW-HG Sensitivity Analysis
Upgradient Constant Head	4,275	4,275	4275	4,275
Downgradient Constant Head	4,230	4,234.92	4235	4,226
Distance (from center of boundary nodes)	68,822	68,822	68,822	68,822
Uniform Gradient	6.54E-04	4.96E-04	5.81E-04	7.12E-04
Percent of base case	100%	76%	89%	109%

3.1.4 Sensitivity Analysis PW-HG

-) Sensitivity analysis PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis (7.12×10^{-4}) was 109% of the value used in the base case model (6.54×10^{-4}). The change in hydraulic gradient was implemented by decreasing the constant head elevations at the downgradient boundary from 4,230 to 4,226 ft, as shown in Table 4. No other changes were made to the model, and a steady-state simulation (PW-HGSS) was used to generate starting heads for the transient simulation.

3.1.5 Sensitivity Analysis PW-BH

Sensitivity analysis PW-BH evaluated the effects of two bedrock ridges, which were assumed to have a hydraulic conductivity ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (described in the main body of this report) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water.

The location of the bedrock ridges were determined from geologic maps compiled by Bingham (1991, 1992) and Moore and Sorenson (1979). The Bingham compilation was based on work by Stephens (1974) and U.S. Department of Energy (1983). The bedrock outcrop is overlain on the model grid in Figure 4. The bedrock is exposed in two north-south trending structures. Lone Mountain is located approximately three miles east of the Envirocare site and a series of low-lying hills (50 to 100 ft in height) are located approximately one mile west of the site.

The Bingham (1991) compilation lists these bedrock outcrops as Pzu, chiefly limestone, dolomite and shale which locally includes sandstone, quartzite, and evaporates. Moore and Sorenson (1979) mapped the bedrock as PPsc, Lower Pennsylvanian / Upper Permian calcareous sandstone, quartzite, limestone, and dolomite. Moore and Sorenson (1979) mapped the Grayback Hills, located north-northwest of the Envirocare site, as Miocene and Pliocene basalt and basaltic andesite flows and shallow intrusives. The Bingham (1991, 1992) compilation shows the bedrock outcrops as surrounded by Quaternary alluvium.

-) Permeability data for the limestone and dolomite in this area were not identified. However, the general literature indicates that limestone and dolomite permeabilities may range from 10^{-7} cm/sec for unfractured limestone and dolomite to 10^{-3} cm/sec for fractured limestone and dolomite to 10 cm/sec for karst. For the

) model sensitivity analysis, the bedrock was assumed to have a permeability ten times lower than that of Quaternary lacustrine (lake bed) deposits at the site (Table 5).

Table 5. Hydraulic Conductivity Values Used in Sensitivity Analysis of Low-Permeability Bedrock High

Lithology	Parameter	Value (cm/sec)	Value (ft/day)	Data Source
Silts, silty clays, sandy silts	K_h	6.09E-04	1.7263	Average of 69 slug tests
	K_v	6.09E-05	0.1726	Assume $K_h = 10K_v$
Gravel layer	K_h	1.00E-01	283	Lower range in Freeze & Cherry
	K_v	1.00E-02	28.3	Assume $K_h = 10K_v$
Bedrock (PPsc)	K_h	6.09E-05	0.1726	Assumed 1 o.o.m. lower than QI
	K_v	6.09E-06	0.01726	Assume $K_h = 10K_v$

Notes: K_h = horizontal hydraulic conductivity
 K_v = vertical hydraulic conductivity
 PPsc = Pennsylvanian / Permian Calcareous sandstone, quartzite, limestone, and dolomite. (Lower Permian and Upper Pennsylvanian). Also includes Basalt and basaltic andesite flows and shallow intrusives (Miocene and Pliocene).
 QI = Quaternary lacustrine deposits
 o.o.m. = order of magnitude

) The simulation of lower bedrock hydraulic conductivity was implemented by changing the K values for model cells along the mapped bedrock outcrops in Layers 1 through 10 (Figure 5). The zone of bedrock was expanded in Layers 11 through 20 (Figure 6).

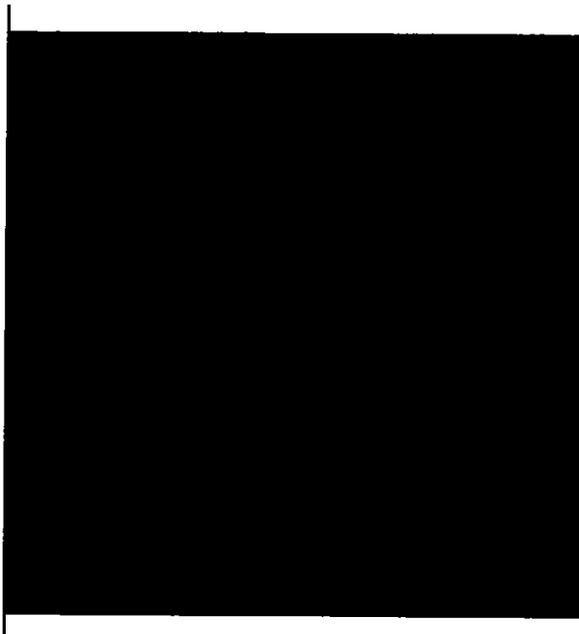


Figure 5. Hydraulic Conductivity Zones Applied to Layers 1-10 of the Low-Permeability Bedrock Sensitivity Analysis (PW-BH)

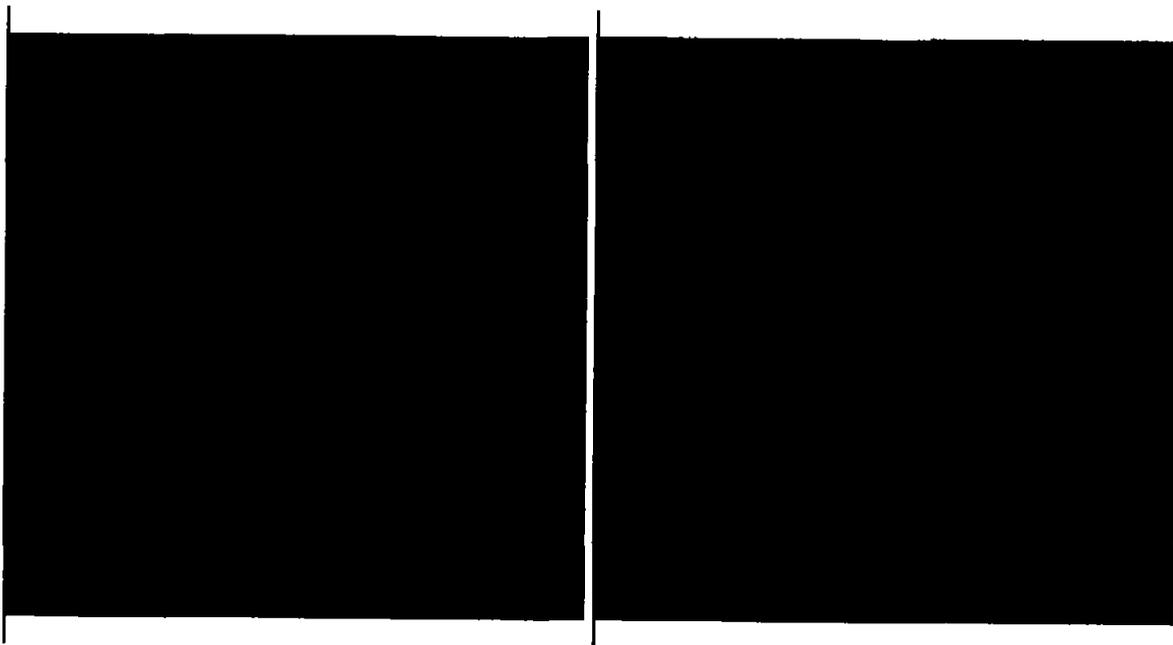


Figure 6. Hydraulic Conductivity Zones Applied to (a) Layer 12 and (b) Layers 11 and 13-20 of the Low-Permeability Bedrock Sensitivity Analysis (PW-BH)

3.2 Sensitivity Analysis Results

The results of the five sensitivity analyses are summarized in Table 6, which presents the maximum and minimum hydraulic gradients at three disposal cells and across the site as a percentage of the steady-state hydraulic gradient. Values less than 100% indicates that gradients decreased from the steady-state (pre-pumping) simulation, while values greater than 100% indicate increases in hydraulic gradient. None of the sensitivity analyses resulted in higher gradients during pumping than those modeled in the steady-state. After pumping, however, hydraulic gradients across the 11e.(2) and LARW cells increased very slightly above the pre-pumping gradients as water levels rebounded more quickly near the pumping well than at a distance. The highest modeled hydraulic gradient was 100.31% during the post pumping period in the PW-LG simulation. In no case did the modeled gradients exceed the allowable limits specified in the GWQDP.

Table 6. Summary of Model-Calculated Hydraulic Gradients (% of Starting Gradient)

Model Run (File Name)	Minimum Gradient Across 11e.(2) Cell	Minimum Gradient Across LARW Cell	Minimum Gradient Across Mixed Waste Cell	Minimum Gradient Across Site
Model20	96.10%	98.66%	99.22%	99.48%
PW-6F	95.99%	98.61%	99.19%	99.46%
PW-ST	96.17%	98.70%	99.25%	99.50%
PW-LG	95.63%	98.50%	99.13%	99.41%
PW-HG	96.40%	98.77%	99.29%	99.52%
PW-BH	85.29%	92.01%	93.59%	93.55%
Model Run (File Name)	Maximum Gradient Across 11e.(2) Cell	Maximum Gradient Across LARW Cell	Maximum Gradient Across Mixed Waste Cell	Maximum Gradient Across Site
Model20	100.27%	100.04%	100.00%	100.00%
PW-6F	100.29%	100.04%	100.00%	100.00%
PW-ST	100.29%	100.04%	100.00%	100.00%
PW-LG	100.31%	100.04%	100.00%	100.00%
PW-HG	100.25%	100.03%	100.00%	100.00%
PW-BH	98.39%	98.33%	100.00%	100.00%

3.2.1 Sensitivity Analysis PW-6F Results

Sensitivity analysis PW-6F evaluated a 600-ft thick aquifer, which is 60% of the thickness used in the base case model. The flow field simulated by the PW-HG sensitivity analysis model was nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly greater than in the base case (Model20) simulation. The hydraulic gradients across the site and across the individual disposal cells are shown in Figure 7.

Drawdown at the water table and in the pumping zone is shown in Table 7. The maximum drawdown at the water table in Year 20 of the PW-6F sensitivity analysis was 0.774 ft, which is 3.75% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.114 ft, which is 3.28% greater than in the Base Case.

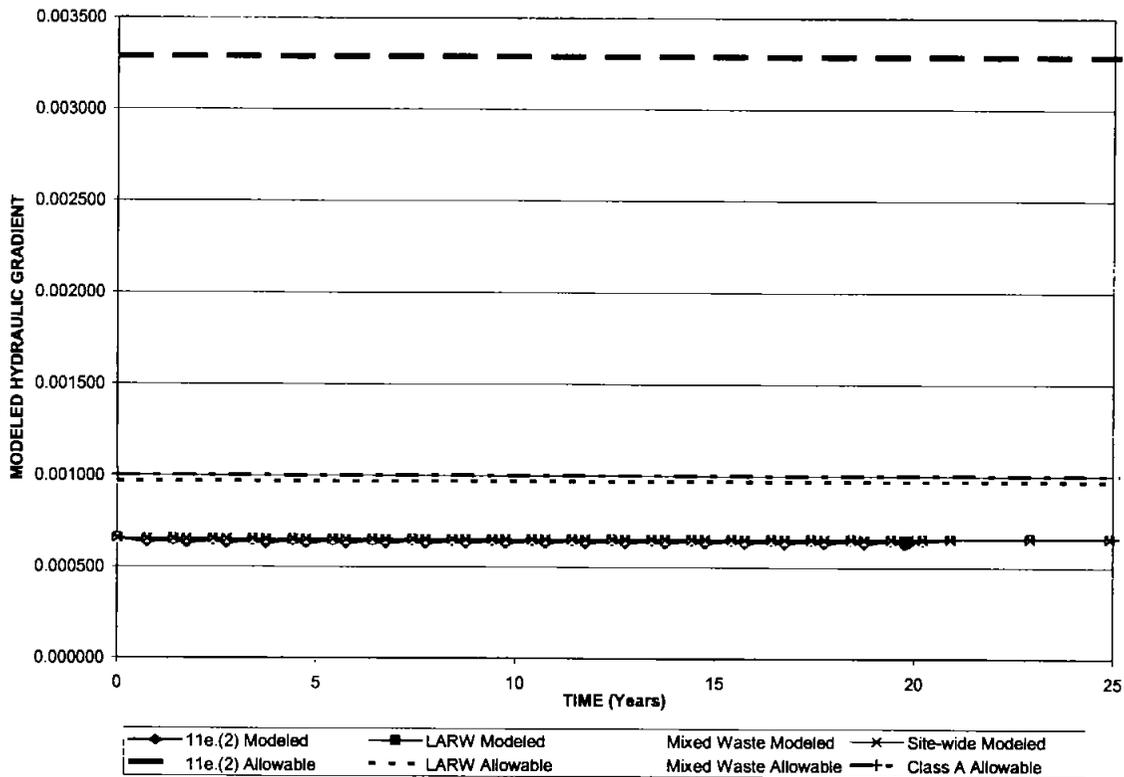


Figure 7. Changes in Site Hydraulic Gradients Over Time – Thinner Aquifer Sensitivity Analysis (Model Run PW-6F)

Table 7. Maximum Drawdown at Pumping Wells – 600-Ft Thick Aquifer Sensitivity Analysis (Model Run PW-6F)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.774
Section 29 Well	Pumping Zone (Layer 12)	3.100
Southwest Pond Well	Water Table (Layer 1)	0.772
Southwest Pond Well	Pumping Zone (Layer 12)	3.114

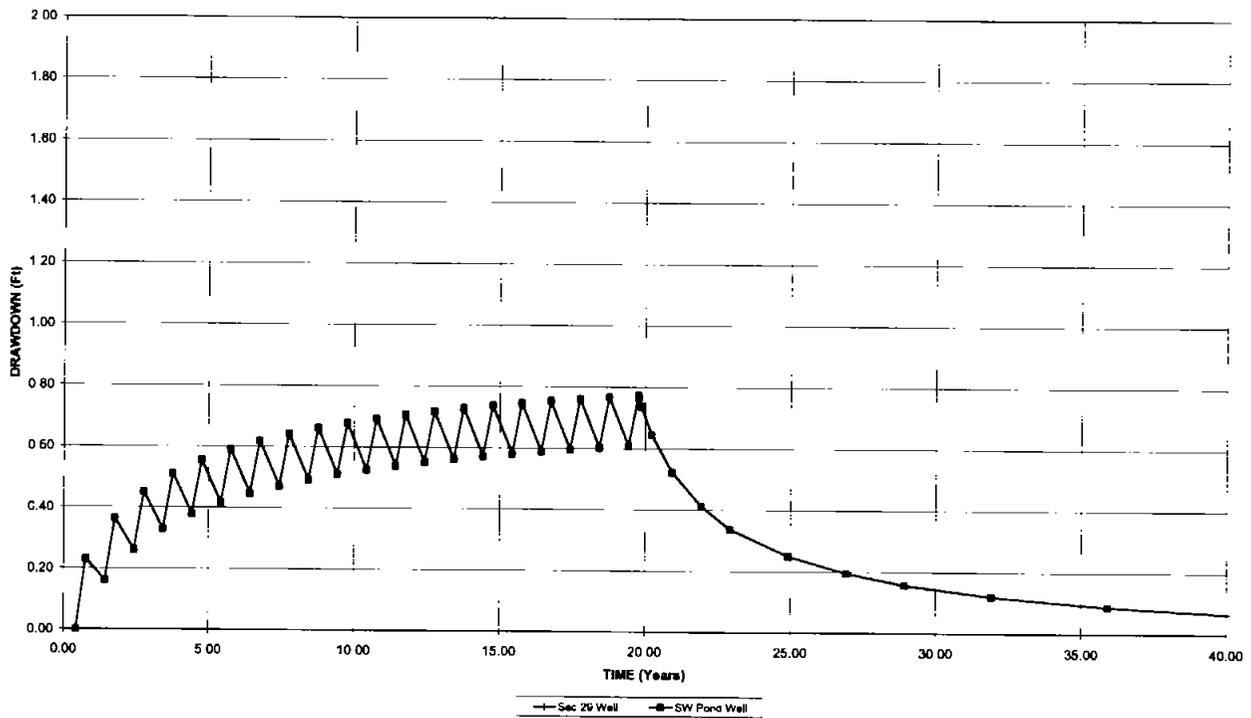


Figure 8. Drawdown and Water Level Recovery in the Shallow Aquifer – Thinner Aquifer Sensitivity Analysis (Model Run PW-6F)

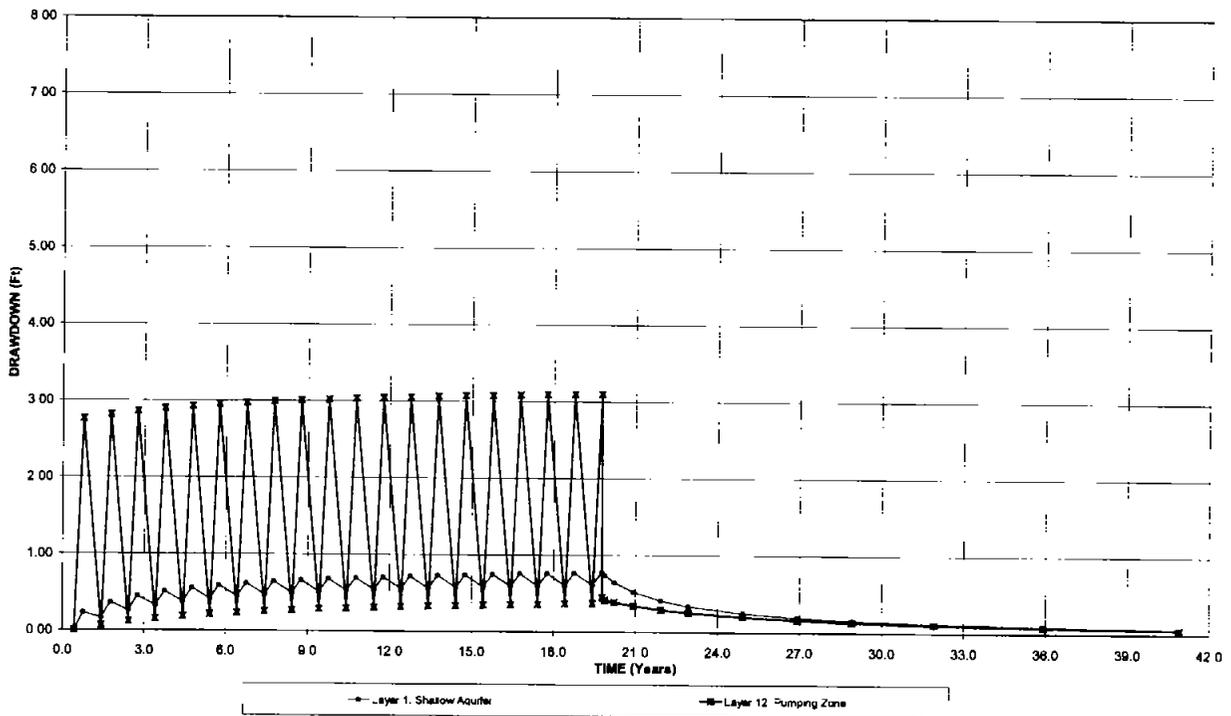


Figure 9. Drawdown and Water Level Recovery in the Pumping Well Zone – Thinner Aquifer Sensitivity Analysis (Model Run PW-6F)

3.2.2 Sensitivity Analysis PW-ST Results

Sensitivity analysis PW-ST evaluated higher storage coefficients. Storage values were 8.2 times (Layer 12), 30.4 times (Layers 2-11 and 13-20) and 114 times (Layer 1) the values used in the base case model. The flow field simulated by the PW-ST sensitivity analysis model was nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping and are the gradient reductions are comparable to those in the Base Case. The hydraulic gradients across the site and across the individual disposal cells in the PW-ST sensitivity analysis are shown in Figure 10.

Drawdown at the water table and in the pumping zone is shown in Table 8. The maximum drawdown at the water table in Year 20 of the PW-ST sensitivity analysis was 0.707 ft, which is 5.2% less than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 2.92 ft, which is 4.5% less than in the Base Case.

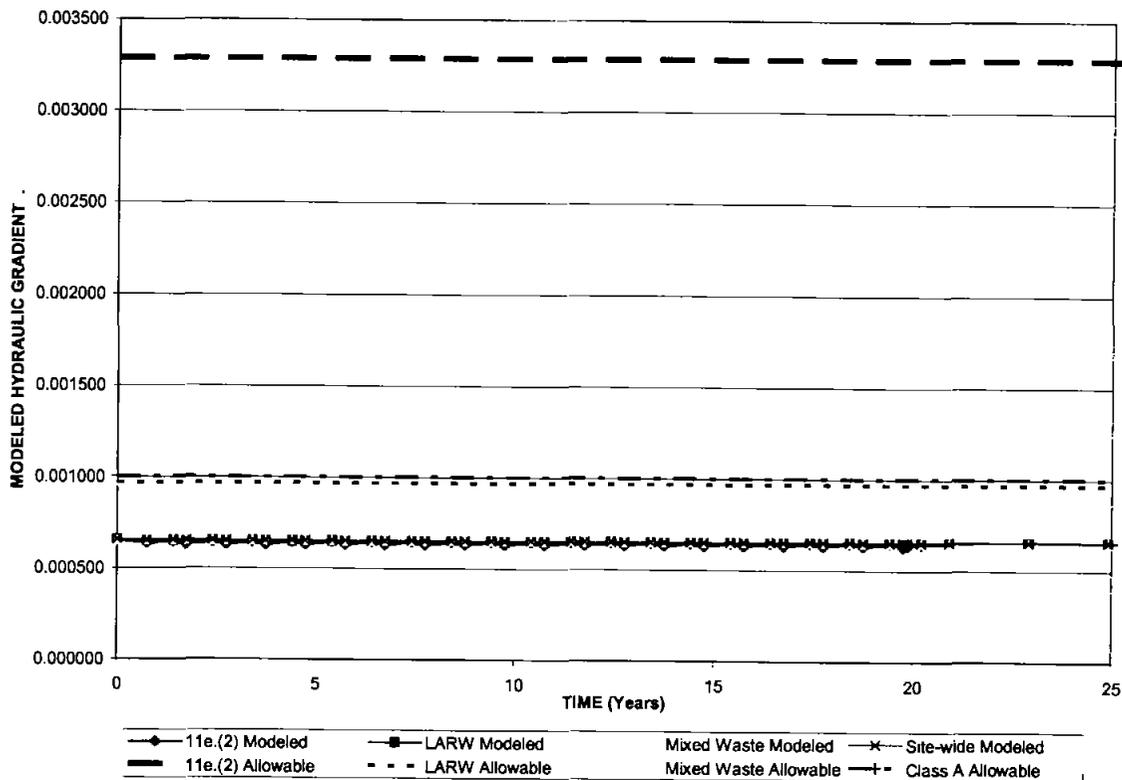


Figure 10. Changes in Site Hydraulic Gradients Over Time - Higher Storage Sensitivity Analysis (Model Run PW-ST)

Table 8. Maximum Drawdown at Pumping Wells – Higher Storativity Sensitivity Analysis (Model Run PW-ST)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.707
Section 29 Well	Pumping Zone (Layer 12)	2.907
Southwest Pond Well	Water Table (Layer 1)	0.705
Southwest Pond Well	Pumping Zone (Layer 12)	2.921

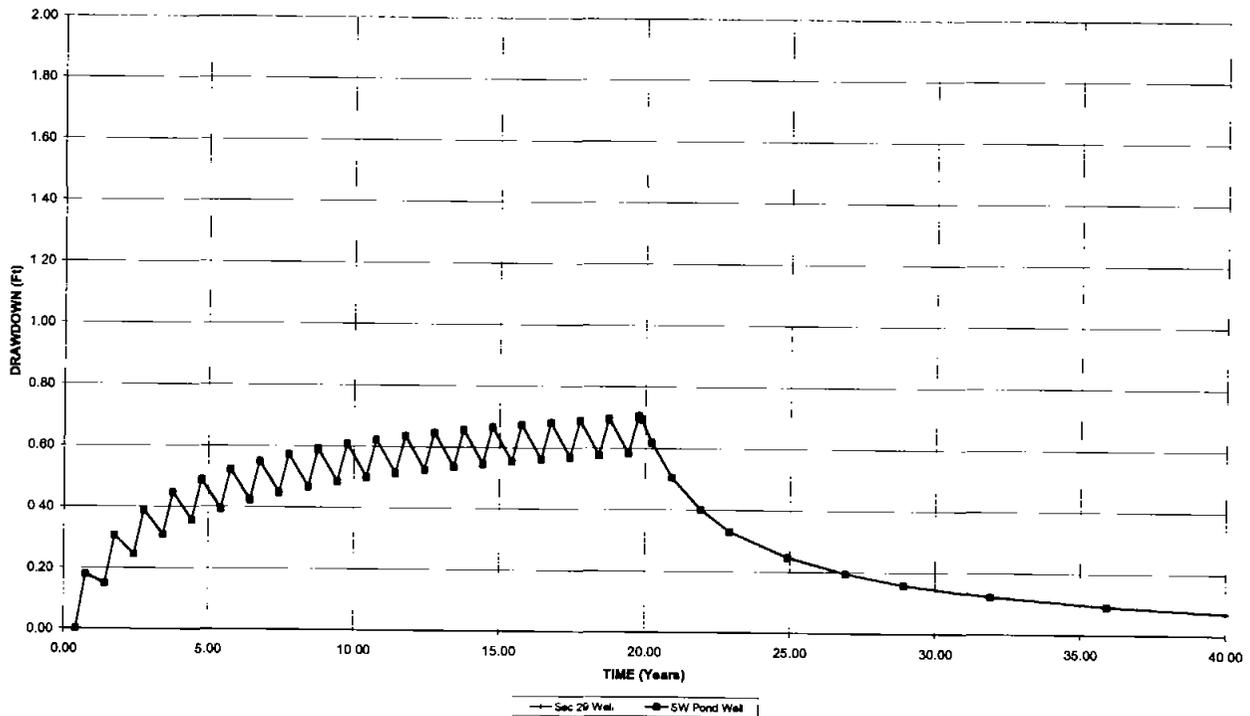


Figure 11. Drawdown and Water Level Recovery in the Shallow Aquifer – Higher Storage Sensitivity Analysis (Model Run PW-ST)

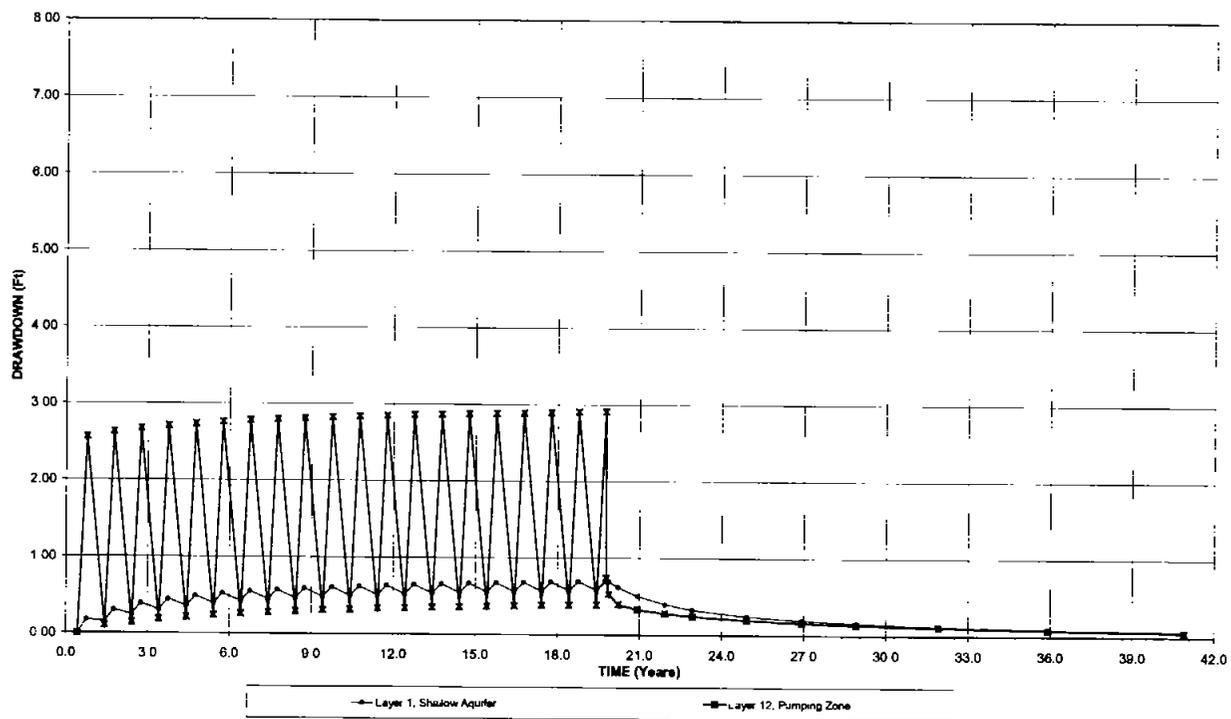


Figure 12. Drawdown and Water Level Recovery in the Pumping Well Zone – Higher Storage Sensitivity Analysis (Model Run PW-ST)

3.2.3 Sensitivity Analysis PW-LG Results

Sensitivity analysis PW-LG used a lower hydraulic gradient. The gradient in the sensitivity analysis (5.81×10^{-4}) was 89% of the value used in the base case model (6.54×10^{-4}). The flow field simulated by the PW-LG sensitivity analysis model is nearly identical to the Base Case model

The hydraulic gradients decrease during pumping, and the changes in hydraulic gradients are slightly greater than in the Base Case model results. The hydraulic gradients across the site and across the individual disposal cells are shown in Figure 13.

Drawdown at the water table and in the pumping zone is shown in Table 9. The maximum drawdown at the water table in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly less than) the Base Case model results.

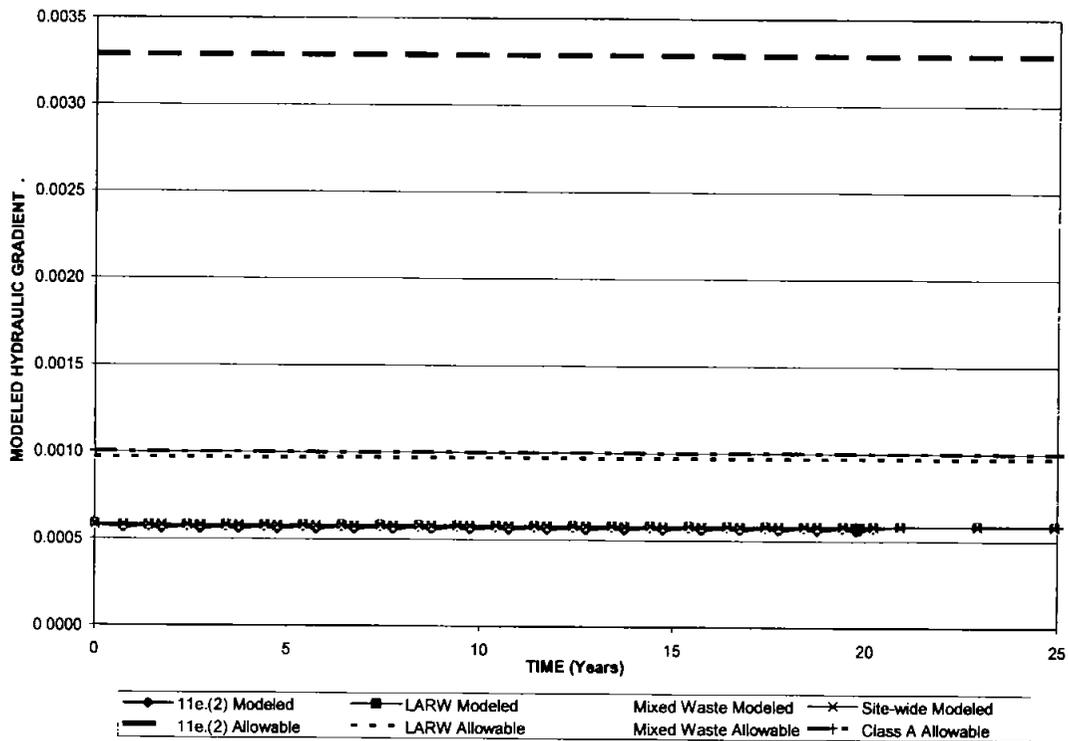


Figure 13. Changes in Site Hydraulic Gradients Over Time – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

Table 9. Maximum Drawdown at Pumping Wells – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.745
Section 29 Well	Pumping Zone (Layer 12)	3.036
Southwest Pond Well	Water Table (Layer 1)	0.744
Southwest Pond Well	Pumping Zone (Layer 12)	3.051

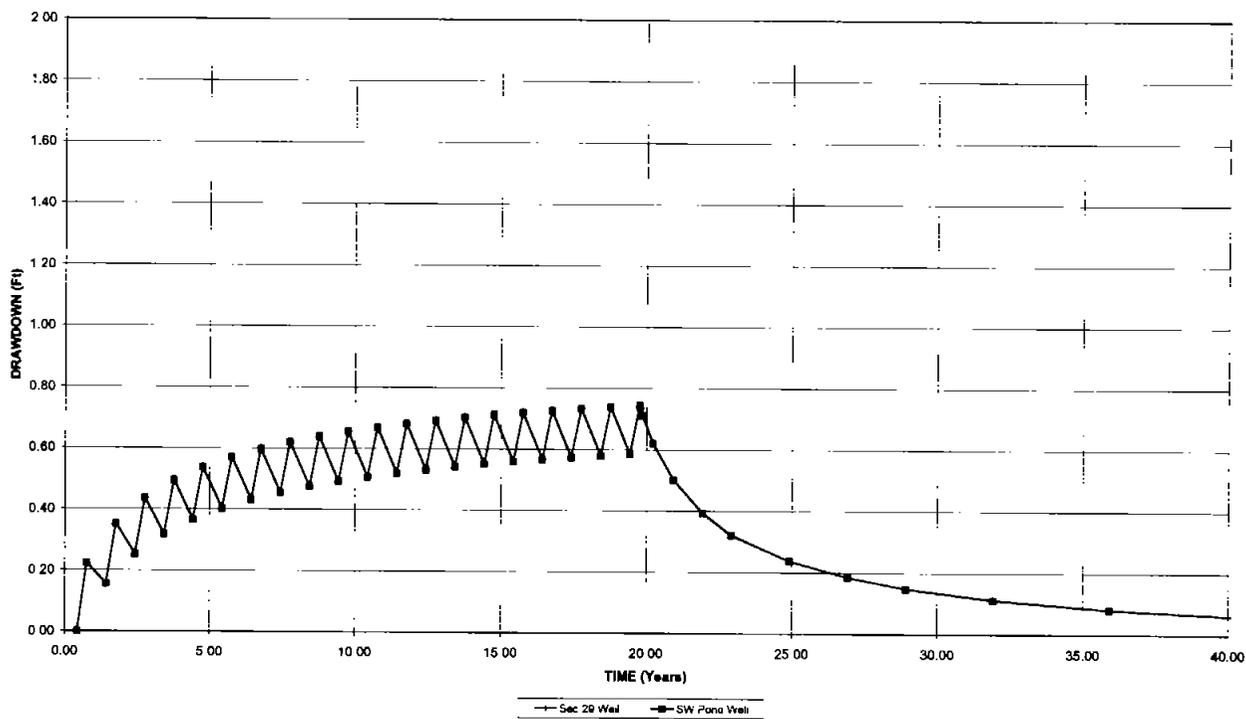


Figure 14. Drawdown and Water Level Recovery in the Shallow Aquifer – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

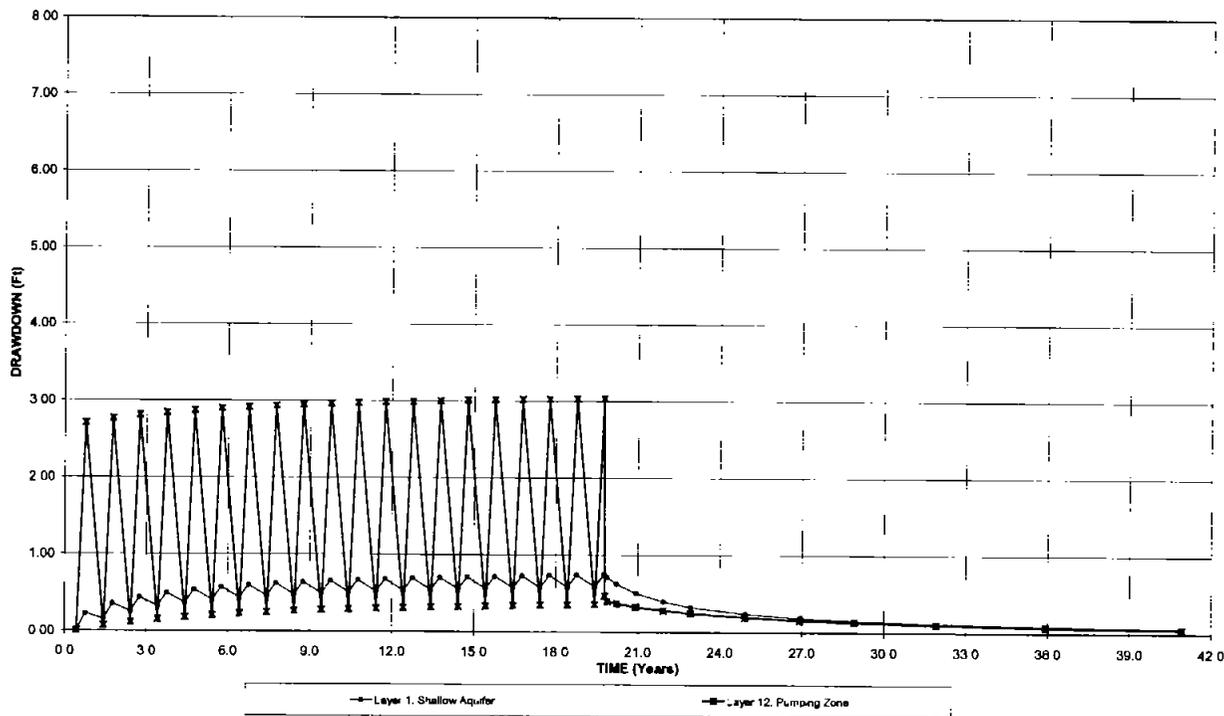


Figure 15. Drawdown and Water Level Recovery in the Pumping Well Zone – Lower Hydraulic Gradient Sensitivity Analysis (Model Run PW-LG)

3.2.4 Sensitivity Analysis PW-HG Results

Sensitivity analysis PW-HG used a higher hydraulic gradient. The gradient in the sensitivity analysis (7.12×10^{-4}) was 109% of the value used in the base case model (6.54×10^{-4}). The flow field simulated by the PW-HG sensitivity analysis model is nearly identical to the Base Case model.

The hydraulic gradients decrease during pumping, as in the base case, and the reductions in gradient are slightly less than in the base case (Model20) simulation. The hydraulic gradients across the site and across the individual disposal cells are shown in Figure 16.

Drawdown at the water table and in the pumping zone is shown in Table 10. The maximum drawdown at the water table in Year 20 of the PW-LG sensitivity analysis is nearly identical to (and very slightly greater than) the Base Case model results.

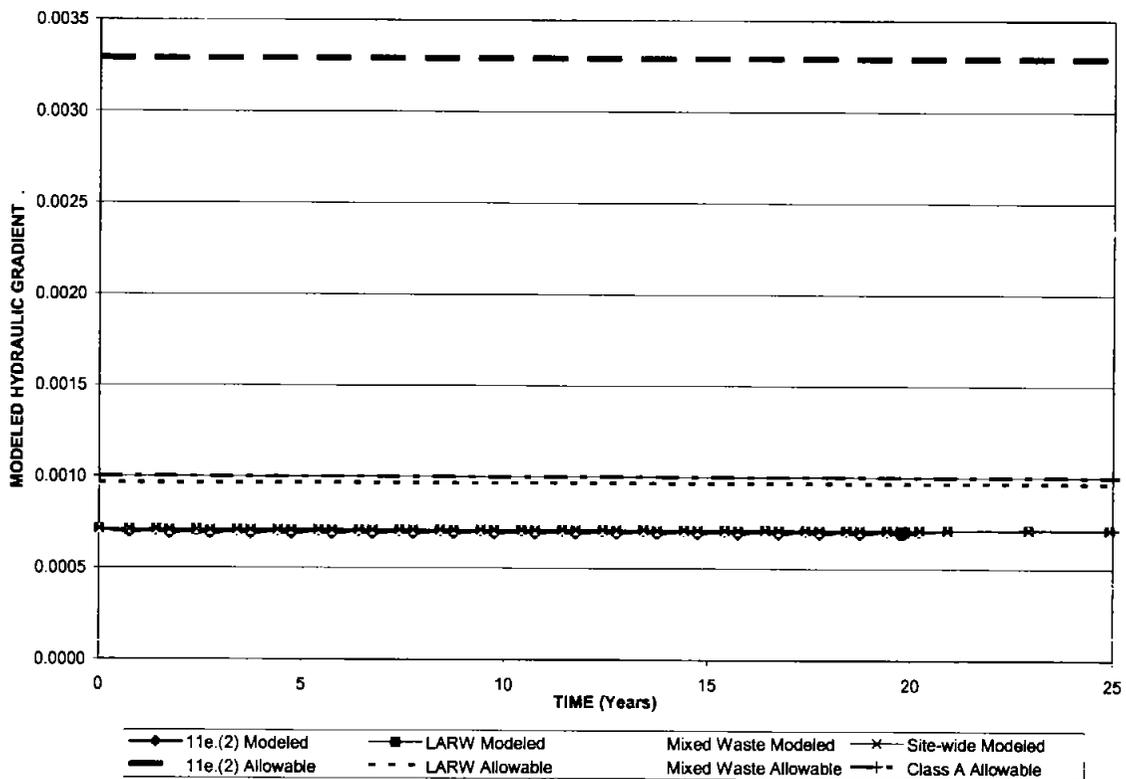


Figure 16. Changes in Site Hydraulic Gradients Over Time – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

Table 10. Maximum Drawdown at Pumping Wells – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	0.747
Section 29 Well	Pumping Zone (Layer 12)	3.037
Southwest Pond Well	Water Table (Layer 1)	0.745
Southwest Pond Well	Pumping Zone (Layer 12)	3.051

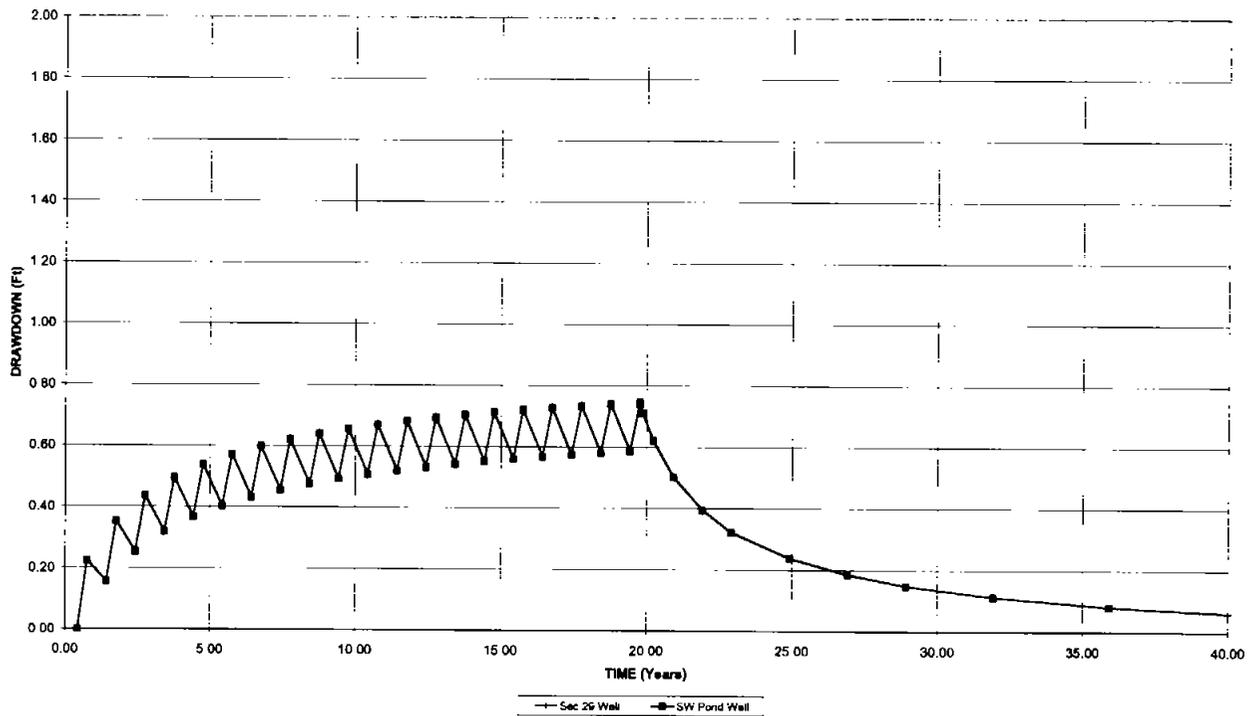


Figure 17. Drawdown and Water Level Recovery in the Shallow Aquifer – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

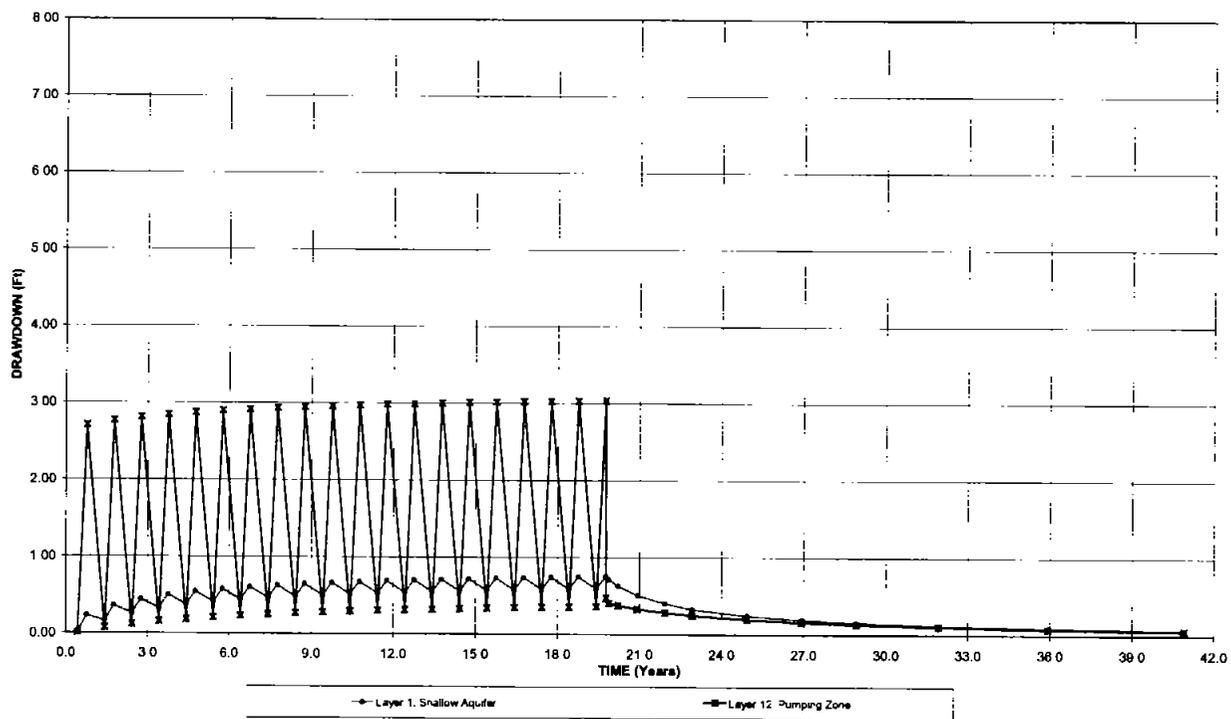


Figure 18. Drawdown and Water Level Recovery in the Pumping Well Zone – Higher Hydraulic Gradient Sensitivity Analysis (Model Run PW-HG)

3.2.5 Sensitivity Analysis PW-BH Results

Sensitivity analysis PW-BH evaluated the effects of two bedrock ridges, which were assumed to have a hydraulic conductivity ten times lower than that of the lacustrine sedimentary deposits. Although the conceptual hydrologic model of the regional aquifer (described in the main body of this report) indicates that the bedrock and alluvium act as a single hydrologic unit (DWR, 2001; Gates, 1987), the sensitivity analysis assumes that the bedrock transmits very little water.

The flow field simulated by the PW-BH sensitivity analysis model was very different from the Base Case model, because the bedrock ridges significantly influence the flow field east and west of the site (Figure 19). Near the Envirocare facility, the modeled flow field is more similar to the Base Case model, with a site-wide hydraulic gradient of 2.8×10^{-4} in the steady-state PW-BH simulation compared to 6.54×10^{-4} in the base case model.

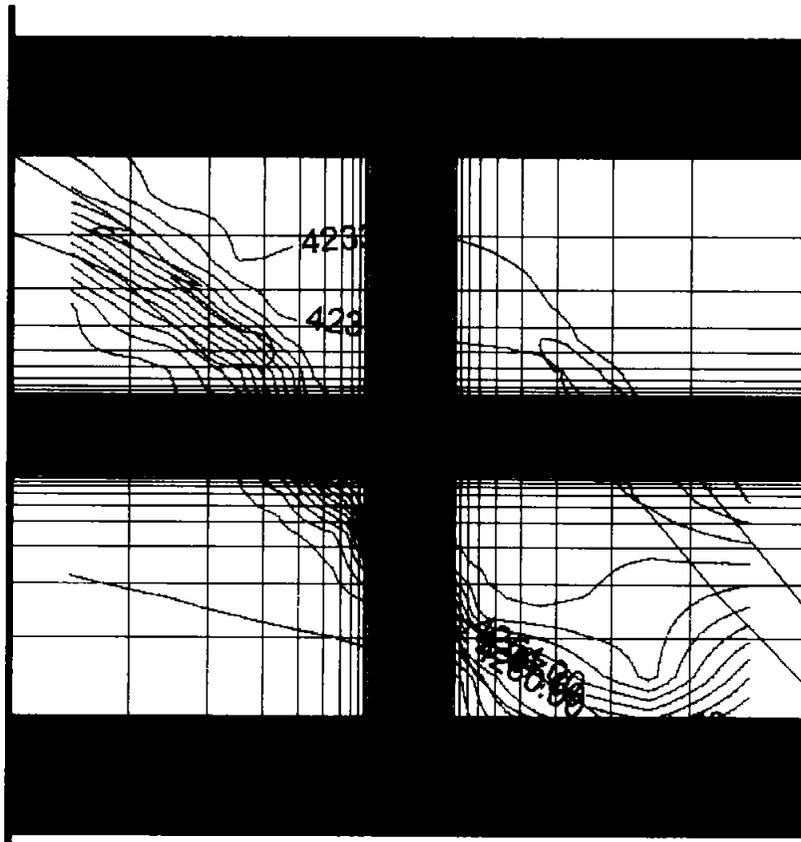


Figure 19. Steady-State Water Table Contours – Model Run PW-BH

The hydraulic gradients decrease during pumping, more so than in the Base Case. For example, the minimum gradient across the 11e.(2) cell during pumping and recovery was 85% of the steady-state calculated gradient. The minimum gradient across the site was approximately 94%, compared to 99.5% in the Base Case simulation. The hydraulic gradients across the site and across the individual disposal cells in the PW-BH sensitivity analysis are shown in Figure 20.

Drawdown at the water table and in the pumping zone is shown in Table 11. The maximum drawdown at the water table in Year 20 of the PW-BH sensitivity analysis was 1.2 ft, which is 61% higher than in the Base Case (0.746 ft.) Maximum drawdown in the pumping zone (Layer 12) was 3.581 ft, which is 17% greater than in the Base Case.

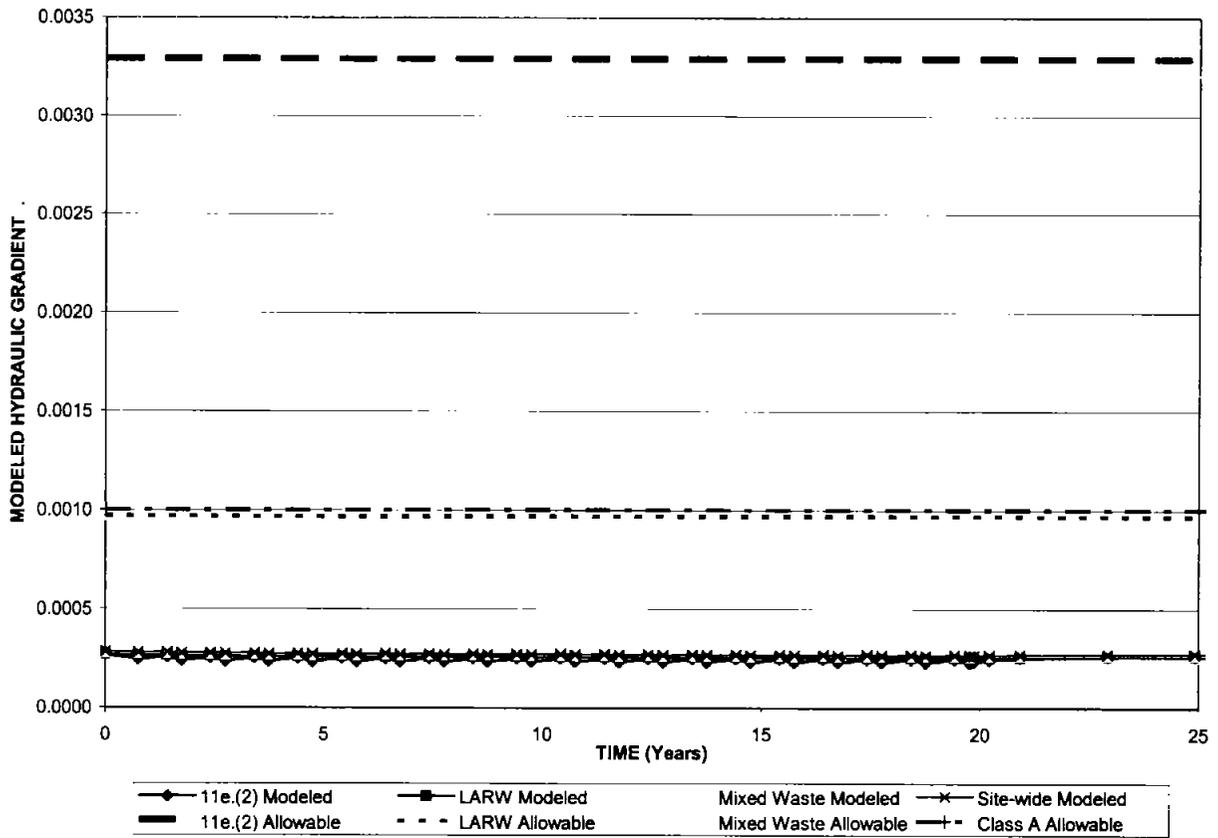


Figure 20. Changes in Site Hydraulic Gradients Over Time – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

Table 11. Maximum Drawdown at Pumping Wells – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

Well	Zone	Maximum Drawdown (ft)
Section 29 Well	Water Table (Layer 1)	1.100
Section 29 Well	Pumping Zone (Layer 12)	3.436
Southwest Pond Well	Water Table (Layer 1)	1.198
Southwest Pond Well	Pumping Zone (Layer 12)	3.581

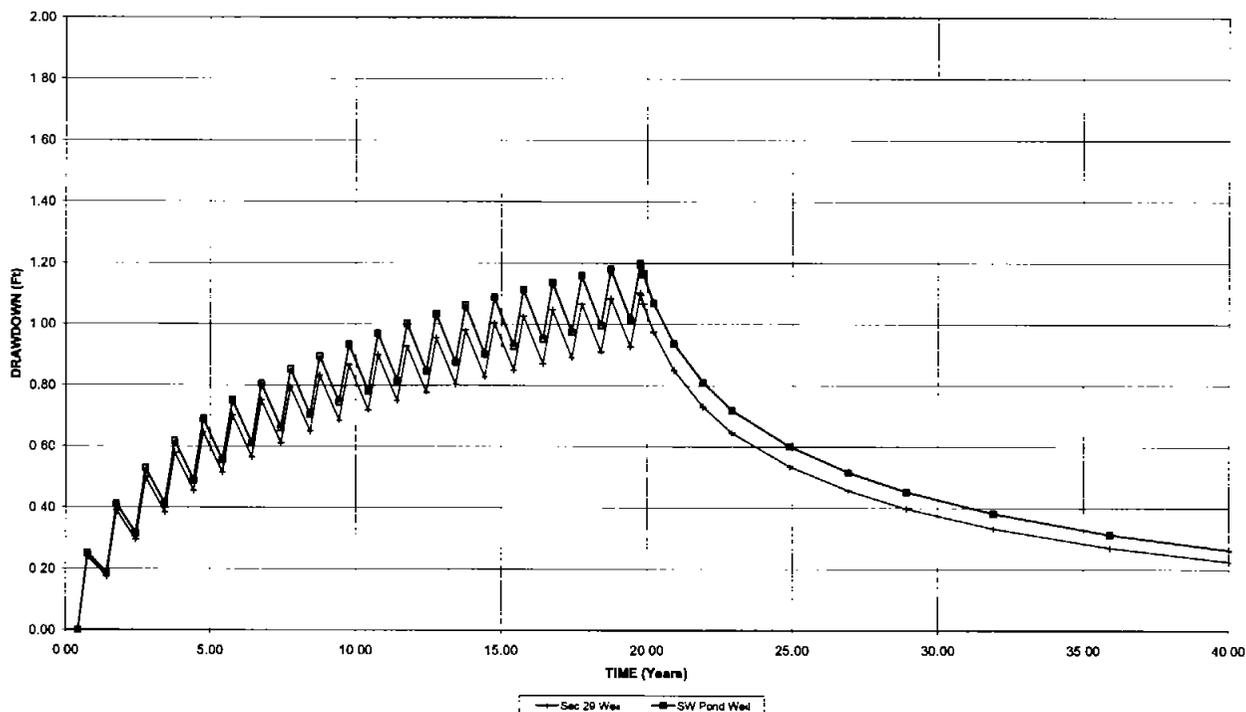


Figure 21. Drawdown and Water Level Recovery in the Shallow Aquifer – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

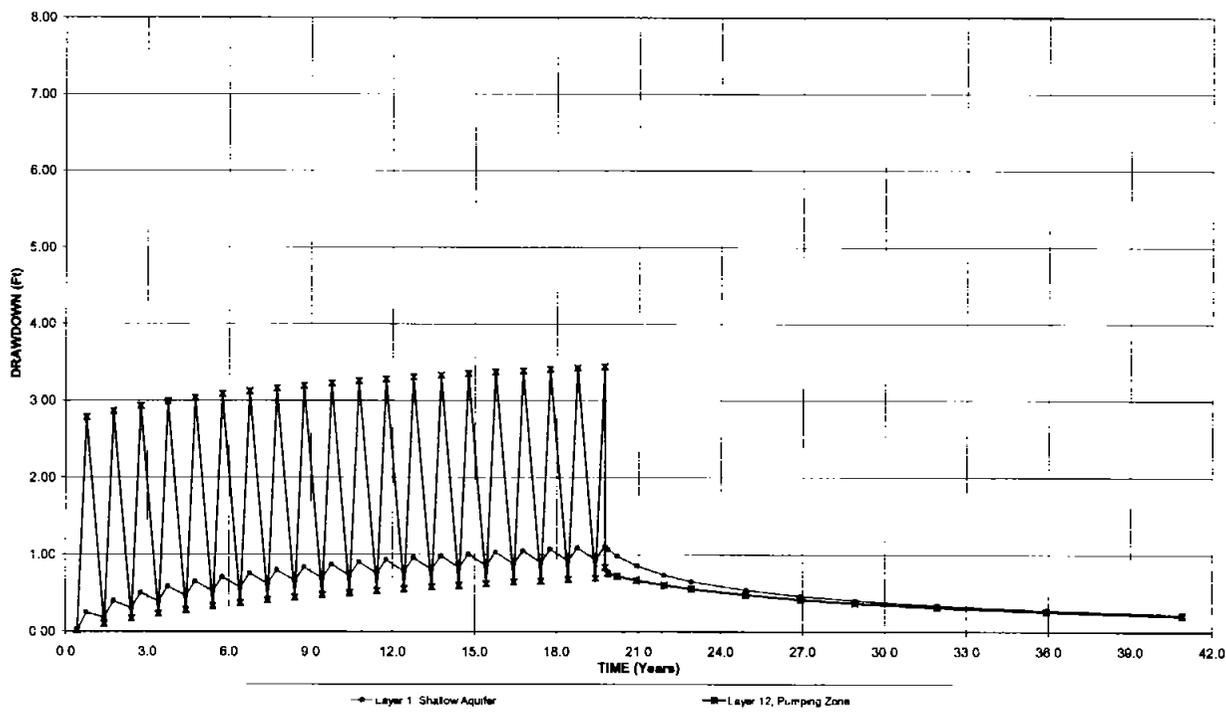


Figure 22. Drawdown and Water Level Recovery in the Pumping Well Zone – Low-Permeability Bedrock Ridge Sensitivity Analysis (Model Run PW-BH)

4. CONCLUSIONS

The results of the sensitivity analysis for the Envirocare Pumping Well Model indicate that changes in aquifer thickness, storage, hydraulic gradient have slight affects on the model results. Hydraulic gradients decrease during pumping in the Base Case and in all sensitivity analyses, in response to pumping from two wells at a depth of 550 feet below ground surface at a combined rate of 400 gpm for 4 months per year for 20 years. The flow direction in the shallow aquifer, however, would not reverse. The reduction in gradient would slow the rate of transport of constituents in the aquifer downgradient of the site for the period of pumping and for an additional 10 years of water level recovery. Approximately 20 years after pumping, the water levels would be almost fully recovered and the flow field and transport rates would return to the normal (pre-pumping) condition in all sensitivity analysis cases.

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APPENDIX C
MODFLOW MODEL
INPUT AND OUTPUT FILES (CDs)

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APPENDIX E

Responses to July 1, 2014 Round 3 Interrogatories

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1. INTRODUCTION

EnergySolutions, headquartered in Salt Lake City, Utah is a worldwide leader in the safe recycling, processing and disposal of nuclear material, providing innovations and technologies to the U.S. Department of Energy (DOE), commercial utilities, and medical and research facilities. At its Clive Facility, located 75 highway miles west of Salt Lake City, EnergySolutions operates a commercial treatment, storage and disposal facility for Class A low-level radioactive waste and Class A low-level mixed waste.

Historically, EnergySolutions' authorization for disposal of depleted uranium (DU) was approved by the Utah Division of Radiation Control at a concentration of 110,000 pCi/g beginning with License amendment 2 of Utah Radioactive Material License UT2300249, (approved December 3, 1990). This concentration was later increased to the specific activity of depleted uranium; i.e., pure form; with approval of the Performance Assessment submitted in support of the October 22, 1998 License renewal (limiting the depleted uranium within a container to no greater than 370,000 pCi/g, upon receipt). Under this License authorization, approximately 18,400 Ci of depleted uranium were safely disposed at Clive between 1990 and 2010.

In 2010, the Utah Radiation Control Board initiated rulemaking to require a site-specific analysis before authorizing the disposal of additional large quantities of depleted uranium. This rulemaking also applies to 3,577 metric tons (5,408 drums) of uranium trioxide (DUO₃) waste received by EnergySolutions from the Savannah River Site (SRS) in December 2009. In compliance with the depleted uranium Performance Assessment prerequisite, EnergySolutions is temporarily holding these drums in storage (awaiting Director approval of this depleted uranium Performance Assessment). In the future, EnergySolutions is also considering disposal of significant quantities of depleted uranium from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky.

As is illustrated in Figure 1-1, EnergySolutions is evaluating a new Federal Cell, using an evapotranspirative cover design, as the ultimate destination for significant quantities of depleted uranium. As initially submitted in 2009, the Federal Cell was named the "Class A South" cell, with a revised application and completeness review response package dated June 9, 2009 (EnergySolutions, 2009). EnergySolutions' records show that the Division indicated interrogatories on this design were under preparation, but not received prior to its withdrawal on May 2, 2011. The former Class A South cell included a clay isolation barrier as well as a proposed system for monitoring groundwater beneath this barrier; in order to differentiate the source of any potential groundwater contamination as being from Class A or 11e.(2) wastes. The former Class A South cell design was subjected to these additional buffer zone and monitoring requirements due to long-term stewardship being split between the State of Utah and DOE. The Federal Cell will be entirely within DOE stewardship and be physically and hydrologically separate from EnergySolutions' Class A West embankment; therefore, the additional requirements will not apply.



Figure 1-1, EnergySolutions' Proposed Federal Cell Location



On June 1, 2011, (in compliance with Condition 35.B of its Radioactive Material License UT2300249), EnergySolutions submitted to the Division the Report, “*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*,” documenting the depleted uranium Performance Assessment. In response, EnergySolutions received on October 25, 2013 from the Utah Department of Environmental Quality “*Task 1: Preliminary Completeness Review*.” Following examination of the Preliminary Completeness Review, EnergySolutions submitted revision 1 of its depleted uranium Performance Assessment Report titled, “*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*,” (EnergySolutions, 2013a).

On February 28, 2014, EnergySolutions received Round 1 Interrogatories from the Division, requesting clarification and additional information to support the Division’s continued review of EnergySolutions’ depleted uranium Performance Assessment. As a result of ongoing research EnergySolutions has conducted regarding cover design and in review of the Round 1 Interrogatories, EnergySolutions revised the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. As a result, EnergySolutions created version 1.2 of its depleted uranium Performance Assessment GoldSim model. In parallel to constructing the revised GoldSim model to address the performance of the evapotranspirative cover, EnergySolutions submitted responses on March 31, 2014 to the Round 1 Interrogatories. Version 1.199 of the depleted uranium Performance Assessment GoldSim model was provided to DEQ reviewers on May 2, 2014 with an update to version 1.2 provided on May 15, 2014.

On May 27, 2014, EnergySolutions received Round 2 Interrogatories from the Division, requesting additional clarification from some of the responses provided to the Round 1 Interrogatories. EnergySolutions submitted responses on June 17, 2014 to the Round 2 Interrogatories. On July 1, 2014, EnergySolutions received Round 3 Interrogatories from the Division, requesting additional clarification for version 1.2 of the Modeling Report (and its associated appendices). EnergySolutions has prepared responses contained herein to the Round 3 Interrogatories.

2. RESPONSES TO JULY 1, 2014 - ROUND 3 INTERROGATORIES

As part of the review and response preparation for the Round 1 Interrogatories, EnergySolutions revised the design of the Federal Cell to an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment (examined in version 1.2 of the DU PA Model). The Division's review of EnergySolutions' Round 1 responses resulted in a second round of interrogatories (which were responded to on June 17, 2014). Following delivery of the Round 2 Interrogatories to EnergySolutions, the Division proceeded to review version 1.2 of the Modeling Report (which documented the performance of the Federal Cell with evapotranspirative cover) and generate Round 3 Interrogatories specifically targeting the revised Model. Responses to the Round 3 revised Model Interrogatories are presented herein. Since Division compiled its Round 3 revised Model Interrogatories in parallel with EnergySolutions' efforts to respond to the Round 2 Interrogatories, the reader has been referred back to the applicable Round 2 Response for those Round 2 Interrogatories the Division chose to repeat below.

1. INTERROGATORY CR R313-25-19-01/3: INTERGENERATIONAL CONSEQUENCES

The Division continues to take issue with the cost values presented in FRV1.2 Section 6.4. That said, doubling the costs in FRV1.2 Table 10 would not change any of the conclusions of the as low as reasonably achievable (ALARA) analysis (i.e., "the ALARA costs involved are very small").

EnergySolutions' Response: Changes along the lines of those suggested were made to Appendix 12 Decision Analysis of Appendix A that were not also captured in the main text sections as noted in the interrogatory above. Further revisions have been made to these two sections of Appendix A.

It is recognized that NUREG/BR-0058 suggests the use of \$2,000 per person rem for: 1) discounted rates of 7% and 3% as indicated; 2) lower rates as deemed appropriate; 3) a zero discount rate; and, 4) a sensitivity analysis across a range of discount rates. For this application, considering how small the ALARA dose-related costs are, the results presented have been adjusted to address \$2,000 per person rem with no discounting. This addresses the range of options considered by NRC in NUREG/BR-0058 for intergenerational impacts. Given the small ALARA-based cost, the impact on decision making is negligible.

2. INTERROGATORY CR R313-25-8(5)(A)-02/1: DEEP TIME

Round 1 Interrogatory Response is satisfactory.

3. INTERROGATORY CR R313-25-8(5)(A)-03/3: DEEP TIME – SEDIMENT AND LAKE CONCENTRATIONS

As part of its response to this interrogatory, ES stated that in FRV1.2 (1) discrepancies between Table 14 and Figure 13 would be resolved, (2) concentrations for radionuclides in addition to U 238 would be provided, and (3) a clarification for why the uranium concentrations are considered “small” would be provided. However, a review of FRV1.2 indicates that none of these modifications have been made. Specifically, FRV1.2 Table 12, page 77, shows a peak U 238 sediment concentration of 1,530 pCi/g, whereas FRV1.2 Figure 12, page 78, shows the U 238 sediment concentration peaking at under 1.0e03 pCi/g. FRV1.2 Section 6.5 presents water and sediment concentrations (Tables 11 and 12, pages 76 and 77) for only U 238. Rather than clarifying why the U 238 concentrations are “small,” a paragraph added to the FRV1.2 Executive Summary states that background concentrations are about 1 pCi/g, implying that the Clive DU PA Model results are “large” relative to background. The FRV1.2 Executive Summary goes on to argue that, based on “other conservatisms” and “deterministic runs,” the Clive DU PA Model concentrations should be reduced to background levels. However, since “other conservatisms” and “deterministic runs” were not identified or provided, that argument is considered unsubstantiated.

We continue to disagree with ES on the need to present the results of the qualitative analysis in the form of doses rather than concentrations, and on the usefulness of the 40 CFR Part 192 Ra 226 ground concentration as a comparison metric.

In its June 17, 2014, Round 2 response to this interrogatory, ES provided a quote from NUREG-1573 as part of its justification for not determining doses during the deep time analysis. With regards to the ES interpretation of “qualitative analysis” for future model predictions beyond 10,000 years after facility closure, we refer to NUREG-1573, which states the following:

“However, it should be noted that for performance assessments carried out beyond 10,000 years, it may be necessary to ensure that the disposal of certain types of waste will not result in markedly high doses to individuals living at any time in the future. Potentially high doses relative to the performance objective could occur within a timeframe longer than 10,000 years, from disposing of large quantities of uranium or transuranics, or possibly by mobile long-lived radionuclides at arid sites with long ground-water travel times. If, at 10,000 years, a radionuclide shows evidence of breakthrough below a peak, the calculation should be continued, assuming the same set of conditions, processes, and events considered significant over the initial 10,000 years, until the radionuclide’s peak dose is reached regardless of when that occurs. For

example, a uranium-238 (²³⁸U) inventory resulting in a ²²⁶Ra dose at 10,000 years may indicate a potential ²²⁶Ra dose in excess of the performance objective beyond 10,000 years. The PAWG recommends that assessments beyond 10,000 years not be used for determining regulatory compliance with the performance objective. However, as a basis for making judgments about the magnitude of the estimated dose relative to the performance objective and its time of occurrence beyond the regulatory compliance period, such assessments may provide an important contribution to the site environmental evaluation. If, after considering the magnitude and time of the dose, and associated uncertainty, the regulatory authority decides that the dose is unacceptably high, either inventory limits would have to be imposed or the problem waste is not suitable for disposal as LLW at the site.” [page 3-16, second paragraph; emphasis added]

Based on this text from NUREG-1573, it is clear that the Performance Assessment Working Group (PAWG) is not recommending that doses not be calculated beyond 10,000 years. Thus, the request to ES to supply a deep time dose estimate does not invalidate the express purpose for the qualitative deep time analysis.

We also note that the June 17, 2014, ES response failed to address the need to evaluate future soil/sediment concentrations of Ra-226 near the disposal facility and compliance with the 15 pCi/g concentration requirements of R313-19-13(2)(a)(i)(B).

EnergySolutions’ Response: UAC R313-25-9(5)(a) and Condition 35.B of Radioactive Material License UT2300249 specifically require a Compliance Period of no less than 10,000 years. Version 1.2 of the DU PA Model has been developed to satisfy these mirrored requirements. Examination of the text highlighted as the basis for this Round 3 Interrogatory includes a condition that does not match that for the Clive DU PA Model,

*“If, at 10,000 years, a radionuclide shows evidence of breakthrough below a peak, the calculation should be continued, **assuming the same set of conditions, processes, and events considered significant over the initial 10,000 years** [are still applicable] . . .” [emphasis added] (NUREG 1573, pg 3-16)*

As is well documented in Appendix 13- Deep Time of Appendix A, the conditions, processes and events considered during the Compliance Period are not remotely similar to those projected for geologic time frames (thereby invalidating the condition under which this specific NRC guidance is applicable). Since the conditions, processes and events considered during geologic time include

dramatic changes in climate, substantial rises in sea levels, and even glaciations (none of which are reasonably projected to occur during the Compliance Period), the guidance originally cited by EnergySolutions in the Round 2 Response is more directly applicable,

*“consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose [i.e. exposure]” **[emphasis added]** (NUREG-1573, pg. 3-10)*

Even so, NRC guidance can be followed to estimate peak doses of 0.0 mrem/yr to individuals still living near the Federal Cell during the deep geologic times - since, *“an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose.”* (NUREG 1573, pg 3-10).

Whereas EnergySolutions understands the material provided in the references above, there are other, more compelling references that suggest that calculating dose beyond a few hundred years is unreasonable (ICRP, 1998 - ICRP. Radiation protection recommendations as applied to the disposal of long-lived solid radioactive waste: ICRP Publication 81. Annals of the ICRP 28:13-22, 1998). Calculating doses in “*deep time*” provides a false sense of understanding of the long-term performance of the disposal system. EnergySolutions also understands that the intent is to have a metric for interpreting results, but believes that concentration provides a more defensible metric. Concentrations can be compared directly to background concentrations, for example.

Nevertheless, before comparisons are made to background concentrations, the conservatism in the deep time model need to be considered, and ultimately removed.

The conceptual model put forward at this time by EnergySolutions suggests aeolian deposition prior to lake return that will both stabilize the disposal site to some extent, and will provide cover for the below grade disposal of the DU. This is followed by the return of a lake that disperses the above ground mound (above the aeolian deposits), then transports the U-238 and progeny into the lake, which dilutes throughout much of the lake and then settles out as the lake recedes.

Aeolian deposition will probably cover the existing sediments (rather than mixing with them completely as is currently modeled). This will result in considerably smaller concentrations in deep time than currently presented in the PA model, with the potential to be as low as, or even lower than, background concentrations. Note the in recent correspondence with Dr. Charles (Jack) Oviatt, the pit wall has been re-interpreted. Originally Dr. Oviatt interpreted the top 70 cm as reworked Gilbert Lake materials but now does not believe that the Gilbert Lake reached Clive, and, consequently, that the top 70 cm are probably aeolian deposits (Oviatt, C., April 26, 2014, personal communication). If this is the case, then aeolian deposition can play a more important role in site stability and site protection, including providing a layer of protection against radon transport

Within version 1.2 of the DU PA Model structure, an adjustment was made to the dispersal of the mound so that waste buried below grade are not available for dispersal. To implement this new assumption in the model, the following changes were made. Note that to simplify the changes made; only the Top Slope is considered for modification.

In \DeepTimeScenarios, the element ActivitySediment_VolConc needs to use a new element that sums the waste concentrations that are above grade instead of using TotalWasteActivity.

1. In \Disposal\ClassASouthCell\TopSlope\WasteLayers, create a summation element called "Waste_AboveGrade_TS" that sums all the waste layers above and including Waste_22.
2. In \Disposal\ClassASouthCell\CAS_Results, create a summation element called "TotalCttAboveGrade" that includes the TopSlope.Cap_TotalMass_TS and the element just created, Waste_AboveGrade_TS.
3. In \Disposal\ClassASouthCell\CAS_Results, create an expression element called "AboveGradeActivity" that converts the TotalCttAboveGrade mass to activity by multiplying the TotalCttAboveGrade by the Species.Specific_Activity.
4. In \DeepTimeScenarios, change the element ActivitySediment_VolConc by replacing "TotalWasteActivity_CAS" with "ActivityAboveGrade."

When version 1.2 of the Model is run in deterministic mode using mean values from the input distributions, the concentration of U-238 in sediment (ActivitySediment_MassConc) at the time of the first lake occurring (50,000 years) is about 0.003 Bq/g. When the original version 1.2 model is run in deterministic mode using input mean values, the concentration of U-238 in sediment at the time of the first lake is about 40 Bq/g. This is roughly a 4 order of

magnitude difference. Applying a similar difference to the probabilistic runs as well on the current model that disperses all the DU waste, then concentrations that are close to (or less than) background levels might be reasonable.

On the subject of concentrations of other radionuclides in the sediment, the following table provides the results. These were inadvertently omitted from the Round 2 response. Given the nature of the DU waste, U-238 has been used as a marker for concentration in deep time sediments because it is not possible for other radionuclides to reach the same concentration for a very long time. Once the deep time model is adjusted (see above), then the goal would be to compare to background concentrations, and this will be more relevant for U-238 than its progeny.

Table 1. Deep Time Lake Sediment Activity Concentrations

radionuclide	peak activity concentration in lake sediment (pCi/g)			time of peak mean value (y)
	mean	median	95 th %ile	
⁹⁰ Sr ^a	—	—	—	—
⁹⁹ Tc	0.10	—	0.49	35,000
¹²⁹ I	4.9×10^{-4}	3.0×10^{-11}	2.6×10^{-3}	40,000
¹³⁷ Cs ^a	—	—	—	—
²¹⁰ Pb	62	43	190	70,000
²²² Rn	18	11	58	65,000
²²⁶ Ra	62	43	190	70,000
²²⁸ Ra	4.0×10^{-5}	2.7×10^{-5}	1.2×10^{-4}	65,000
²²⁷ Ac	5.6	3.7	19	55,000
²²⁸ Th	4.0×10^{-5}	2.7×10^{-5}	1.2×10^{-4}	65,000
²²⁹ Th	12	8.2	41	55,000
²³⁰ Th	65	44	200	65,000
²³² Th	4.0×10^{-5}	2.7×10^{-5}	1.2×10^{-4}	65,000
²³¹ Pa	5.9	3.7	19	55,000
²³² U*	—	—	—	—
²³³ U	12	7.7	41	50,000
²³⁴ U	190	130	600	55,000
²³⁵ U	8.5	5.4	28	55,000
²³⁶ U	14	8.9	43	55,000
²³⁸ U	770	520	2400	55,000
²³⁷ Np	6.2×10^{-4}	3.9×10^{-4}	2.1×10^{-3}	55,000
²³⁸ Pu ^a	—	—	—	—

radionuclide	peak activity concentration in lake sediment (pCi/g)			time of peak mean value (y)
	mean	median	95 th %ile	
²³⁹ Pu	4.5×10^{-5}	— ^b	1.9×10^{-4}	35,000
²⁴⁰ Pu	1.1×10^{-6}	— ^b	7.2×10^{-6}	25,000
²⁴¹ Pu	—	—	—	—
²⁴² Pu ^c	—	—	—	—
²⁴¹ Am	—	—	—	—

Values are based on 1000 realizations of the Clive DU PA Model v1.2, specifically the model *Clive DU PA Model v1.2 UA r1000 s1.gsm*.

^a With short half-lives and no parents, these radionuclides no longer exist at these time frames.

^b GoldSim does not report these values, probably due to insufficient numbers of realizations that have generated results at this time step.

^c ²⁴²Pu has such a small inventory that no discernible sediment concentration exists.

4. INTERROGATORY CR R313-25-8(4)-04/1: REFERENCES

Round 1 Interrogatory Response is satisfactory.

5. INTERROGATORY CR R313-25-7(2)-05/2: RADON BARRIER

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

6. INTERROGATORY CR R313-25-7(2)-06/1: GULLY MODEL ASSUMPTIONS

Round 1 Interrogatory Response is satisfactory.

7. INTERROGATORY CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

8. INTERROGATORY CR R313-25-8(4)(A)-08/1: GROUNDWATER CONCENTRATION ENDPOINTS

Round 1 Interrogatory Response is satisfactory.

9. INTERROGATORY CR R313-25-19-09/1: DEFINITION OF ALARA

Round 1 Interrogatory Response is satisfactory.

10. INTERROGATORY CR R313-22-32(2)-10/3: EFFECT OF BIOLOGICALS ON RADIONUCLIDE TRANSPORT

While ES speculates that the effect of biointrusion (e.g., by ants) on radionuclide transport might be small, Gaglio et al. (2001) demonstrated in one study that “infiltration rates of water into soils with ant nests was approximately eight times faster than soils without ant nests.”

Higher rates of infiltration are also induced by other types of biointrusion. Biointrusion can, in some instances, dramatically increase downward water movement. Dwyer et al. (2007), for example, state that “biointrusion can lead to increased infiltration and preferential flow of surface water through the cover system as well as contribute to the change in the soil layer’s hydraulic properties.”

Laundre (1993) shows that burrowing by ground squirrels can increase the amount of snowmelt infiltration into soils in the spring by as much as 34%. Hakonson (1999) indicates that pocket gophers can increase rates of infiltration by 200 to 300%. Breshears et al. (2005) report that burrows made by pocket gophers in simulated landfills dramatically increased infiltration rates (i.e., by about one order of magnitude). Badger burrows at the Hanford site are reported to have captured much runoff and allowed the runoff to infiltrate into soils deeper than elsewhere on site. Measurements by researchers of moisture in soils under the burrows after artificial rainfall events demonstrated this impact: “These measurements confirmed that larger mammal burrows can and do cause the deep penetration of precipitation-generated runoff at Hanford” (Link et al., 1995). The PA should account for greater infiltration through the cover system as a result of biointrusion by animals in general.

Biointrusion by plant roots can also damage cover systems, increase infiltration, and hasten migration of contaminants. This is done by increasing the hydraulic conductivity of cover-system soils penetrated by roots. This can be especially problematic at radon barriers. Waugh and Smith (1988) indicate that at a U.S. Department of Energy (DOE) low-level waste (LLW) site at Burrell, Pennsylvania, the hydraulic conductivity increased by two orders of magnitude at locations where roots penetrated the radon barrier. This is yet another reason why in-service hydraulic conductivity values of all near-surface (i.e., within 10 feet of ground surface) cover-system soils should be increased in modeling over as-built values to values within the ranges given by NRC guidance in NUREG/CR-7028.

Higher rates of infiltration are typically associated with higher contaminant transport rates. Infiltration should be minimized (see UAC R313-25-24(3) and (4)). ES should account in its modeling for greater infiltration through the cover system at the Federal Cell embankment due to biointrusion by plant roots and by animals. One way to achieve this would be to simultaneously increase all cover-system soil hydraulic conductivities to values in ranges provided in NUREG/CR-7028. These values are designed to account for changes in soil hydraulic conductivity occasioned collectively by biointrusion activity and other types of soil disturbance.

EnergySolutions' Response: EnergySolutions concurs that biointrusion can result in increased saturated hydraulic conductivities (K_s) within waste cover layers, and possibly subsequent increased infiltration depending on other factors. However, it is notable that some studies have reported no change in water storage and infiltration between lysimeters with and without animal burrows. For example, Landeen (1994, p.47) reports:

“The data did not indicate that any long-term water storage had occurred as a direct result of animal burrowing activity. The soil moisture profile graphs generated from all five tests [lysimeters containing animals and lysimeters serving as controls (no animals)] were similar. This study did not indicate that animal burrows at the Hanford Site facilitate the retention of water at depth.”

With regard to biointrusion by plant roots, please refer to the response to Interrogatory CR R313-25-8(4)(A)-28/3: BIOTURBATION EFFECTS AND CONSEQUENCES. In particular, the following text from Interrogatory 28/3:

“Site-specific observations of soil disturbance due to natural vegetation and demonstrated practices for minimizing disturbance were documented by SWCA (2013). Multiple soil excavations at the site demonstrated root growth behavior indicating that roots would tend to accumulate in locations to take advantage of available water rather than penetrate the radon barrier clay. These excavations showed that greasewood tap roots and other biotic activity such as fine roots and tunnels did not extend below the compacted clay layer at 24 inches. Rather, both taproots and fine roots were found to extend laterally along the upper surface of the compacted clay layer, likely making use of any water that is perched above the clay (SWCA, 2013).”

With regard to infiltration modeling, the Division suggests the following:

“ES should account in its modeling for greater infiltration through the cover system at the Federal Cell embankment due to biointrusion by plant roots and by animals. One way to achieve this would be to simultaneously increase all cover-system soil hydraulic conductivities to values in ranges provided in NUREG/CR-7028. These values are designed to account for changes in soil hydraulic conductivity occasioned collectively by biointrusion activity and other types of soil disturbance.”

However, it is important to note that the cover-system soil hydraulic conductivities currently are within ranges provided in NUREG/CR-7028. For example, mean values of the K_s of store-and-release layers of in-service covers are listed in Table 6.6 of Benson et al. (2011). The geometric mean of these results is 8.7×10^{-7} m/s or 7.5 cm/day. This value is less than twice the value used for the infiltration modeling for the Surface and Evaporative Zone layers in the Clive ET cover system. The value for K_s recommended by Benson et al. (2011, p. 10-3) for modeling in-service cover layers is 5×10^{-7} m/s which is well within the distribution used in version 1.2 of the Clive DU PA Model’s infiltration analysis. Refer to the response to Interrogatory CR R313-25-8(4)(A)-28/3: BIOTURBATION EFFECTS AND CONSEQUENCES for additional discussion of how infiltration-modeled K_s are also within the ranges provided by Benson et al. (2011).

11. INTERROGATORY CR R313-25-20-11/2: INADVERTENT HUMAN INTRUDER

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

12. INTERROGATORY CR R313-25-20-12/2: SELECTION OF INTRUSION SCENARIOS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

13. INTERROGATORY CR R313-25-7-13/1: REFERENCE FOR LONG-TERM CLIMATIC CYCLES

Round 1 Interrogatory Response is satisfactory.

14. INTERROGATORY CR R313-25-8(4)(D)-14/2: SEDIMENT MIXING

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

15. INTERROGATORY CR R317-6-6.3(Q)-15/2: URANIUM CHEMICAL TOXICITY

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

16. INTERROGATORY CR R313-25-8(4)(A)-16/1: RADON PRODUCTION AND BURROWING ANIMALS

Round 1 Interrogatory Response is satisfactory.

17. INTERROGATORY CR R317-6-6.3(Q)-17/1: URANIUM PARENTS

Round 1 Interrogatory Response is satisfactory.

18. INTERROGATORY CR R313-25-8(5)(A)-18/3: SEDIMENT ACCUMULATION

Text similar to that given in the ES response was added to Section 3.3, pages 13–15, of the Deep Time Assessment report (Appendix 13 to FRV1.2). However, since the concerns identified above remain, this interrogatory remains open.

Note that there are two Oviatt et al. 1994 references in the list on page 44 of the Deep Time Assessment report. ES needs to modify the text so that it is clear which one is being referenced at which locations.

EnergySolutions' Response: The text in Appendix 13 - Deep Time of Appendix A has been extensively revised to clarify discussions on small, medium, and large lakes, and to clarify sedimentation rates for large and medium sized lakes. In addition, discussions of aeolian sedimentation rates have been revised. For example, reference to a rate of 0.1 to 3 mm/year has been removed. Note that sedimentation rates for aeolian deposition were not used in the model. The first intermediate or deep lake was assumed to destroy the disposal mound.

Appendix 13 - Deep Time of Appendix A has also been revised to clarify which Oviatt et al. (1994) reference is which by adding 1994a and 1994b to these two references.

- Oviatt, C. G., McCoy, W. D., and Nash, W. P., 1994a. Sequence stratigraphy of lacustrine deposits: a Quaternary example from the Bonneville basin, Utah. Geological Society of America Bulletin, 106: 133-144.
- Oviatt, C.G., G.D. Habiger and J.E. Hay, 1994b. Variation in the Composition of Lake Bonneville Marl: A Potential Key to Lake-Level Fluctuations and Paleoclimate, Journal of Paleolimnology, Vol 11, p. 19-30.

19. INTERROGATORY CR R313-25-8(5)(A)-19/1: REFERENCE FOR SEDIMENT CORE RECORDS

Round 1 Interrogatory Response is satisfactory.

20. INTERROGATORY CR R317-6-2.1-20/2: GROUNDWATER CONCENTRATIONS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

21. INTERROGATORY CR R313-25-8(4)(D)-21/2: INFILTRATION RATES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

22. INTERROGATORY CR R313-25-7-22/1: DEFINITION OF FEPS

Round 1 Interrogatory Response is satisfactory.

23. INTERROGATORY CR R313-25-7(2)-23/1: CANISTER DEGRADATION AND CORROSION

Round 1 Interrogatory Response is satisfactory.

24. INTERROGATORY CR R313-15-101(1)-24/3: UTAH REGULATIONS

Section 1.3 of FRV1.2 should have been revised to cite UAC R313-25-9(5)(a) as the source for the quotation on page 18. However, this revision was not made. Revisions were also not made to Section 4.2.1, page 22, of the Conceptual Site Model report.

ES had also stated that governing Utah rules would be cited in Sections 1 and 1.3 of the Conceptual Site Model report. No such changes have been made to Section 1, and there is no Section 1.3 in either FRV1 or FRV1.2.

EnergySolutions' Response: The Conceptual Site Model Report (Appendix 2 of Appendix A) has been revised.

25. INTERROGATORY CR R313-25-7(9)-25/1: DISPOSITION OF CONTAMINANTS IN UF6

Round 1 Interrogatory Response is satisfactory.

26. INTERROGATORY CR R313-25-8(4)(A)-26/1: RADON DIFFUSION IN THE UNSATURATED ZONE

Round 1 Interrogatory Response is satisfactory.

27. INTERROGATORY CR R313-25-8(4)(A)-27/3: DIFFUSION PATHWAY MODELING

ES stated on page 29 of its response to the Round 2 Interrogatories that “no further revision or PA maintenance is planned to version 1.2 of the Modeling Report.” Therefore, ES should provide modeling that quantitatively accounts for these processes and effects, taking into account NRC guidance such as that in NUREG/CR-7028. Note that Section 7.1.3.1, page 38, of the revised Conceptual Site Model report (Appendix 2 to FRV1.2) states that: “efforts at quantification could be included as part of future cover modeling as part of PA maintenance.” In keeping with its Round 2 response, ES needs to modify this statement.

In its Round 1 responses to four other interrogatories (i.e., 28, 78, 155, and 162), ES stated that “PA Maintenance” would address the issue. ES should revise the Round 1 responses to those four interrogatories to indicate how the information is to be provided without further model revision or PA maintenance.

EnergySolutions' Response: Version 1.2 of the DU PA Goldsim DU PA model represents an enhanced assessment of the performance of the store and release layers in the upper part of the cover and the radon barriers. A statistical experimental design was developed to provide net infiltration and water content results using the variably saturated flow and transport model HYDRUS. The purpose of the experimental design was to capture the effect of variable hydraulic properties on water balance parameters for abstraction to the DU PA Model.

The Benson et al. (2011) report published by the NRC (NUREG/CR-7028) provides recommendations for ranges of hydraulic parameters that may be used to represent in-service conditions of store-and-release and barrier layers in covers.

The Surface and Evaporative Zone layers in the Clive ET cover system correspond to store-and-release layers. For the infiltration modeling, values of the van Genuchten parameter alpha for these two layers were drawn from a statistical distribution with a mean of 0.016 1/cm. The value for alpha recommended for in-service layers by Benson et al. (2011, p. 10-4) is 0.2 1/kPa which corresponds to a value of 0.02 1/cm, similar to the mean used for the infiltration simulations. The distribution used for the van Genuchten n parameter for the HYDRUS simulations had a mean of 1.32. The value for n recommended for in-service layers by Benson et al. (2011, p. 10-4) is 1.3. A single value of 4.46 cm/day based on site-specific measurement was used in the experimental design for the saturated hydraulic conductivity (K_s) of the Surface and Evaporative Zone layers. Mean values of the K_s of store-and-release layers of in-service covers are listed in Table 6.6 of Benson et al. (2011). The geometric mean of these results is 8.7×10^{-7} m/s or 7.5 cm/day. This value is less than twice the value used for the infiltration modeling.

The experimental design for the infiltration modeling used a K_s distribution developed from a minimum value of 4×10^{-3} cm/day corresponding to the design specification for the upper radon barrier (Whetstone 2007, Table 8), and 50th and 99th percentile values of 0.7 cm/day (7.5×10^{-8} m/s rounded to 8×10^{-8} m/s) and 52 cm/day (6×10^{-6} m/s), respectively, which are from a range of in-service (“naturalized”) clay barrier K_s values described by Benson et al. (2011, Section 6.4, p. 6-12). The value for K_s recommended by Benson et al (2011, p. 10-3) for modeling in-service cover layers is 5×10^{-7} m/s which is well within the distribution used for the Clive DU PA infiltration modeling. Single values of alpha and n determined from site-specific measurements were used for the radon barrier in the infiltration modeling. A value of 0.003 1/cm was used for alpha and a value of 1.17 was used for n. Benson et al. (2011, p. 10-4) recommend using the result from a single measurement at a single site for alpha. This is a value of 0.02 1/cm. Two other values are available for sample sizes considered to be unaffected by scale for the K_s measurements (Benson et al, 2011, Table 6-9). The geometric mean of the three measurements is 0.002 1/cm. A range from 1.2 to 1.4 is recommended by Benson et al. (2011) for the n parameter. The value used for the infiltration modeling is slightly below the low end of that range. More detailed descriptions of distribution development and abstraction to the DU PA Model are provided in Appendix 5 - Unsaturated Zone Modeling of Appendix A.

Version 1.2 of the Clive DU PA Model address the impact burrowing animals, plant roots, and similar mechanisms would have on the radon diffusion upwards to the surface. Radon diffusion is given by the product of the radon concentration gradient and the effective diffusion coefficient. The effective diffusion coefficient is a function of the air-filled porosity, increasing with increasing porosity. The model for the volumetric water content of the radon barriers

developed from the HYDRUS simulations described above and used in the DU PA model is

$$\theta = 0.3 - 0.00361 K_s + 0.314 \alpha - 0.013 n$$

where

- θ is the volumetric water content [-]
- K_s is the saturated hydraulic conductivity of the radon barrier [cm/day]
- α is a van Genuchten hydraulic model parameter [1/cm] for the Surface and Evaporative Zone layers
- n is a van Genuchten hydraulic model parameter [-] for the Surface and Evaporative Zone layers.

As an example, consider using mean values from the distributions for α and n of 0.016 1/cm and 1.32 for the Surface and Evaporative Zone layers and calculating the air-filled porosity for K_s values of 4×10^{-3} cm/day (4.6×10^{-10} m/s) and 51.8 cm/day (6×10^{-6} m/s) which represent the minimum value and the 99th percentile of the distribution for K_s used in version 1.2 of the DU PA model. The volumetric water contents for the low and high K_s values are 0.29 and 0.10, respectively. For a porosity of 0.43 the air contents for the low and high K_s values are 0.14 and 0.33, respectively.

For version 1.2 of the DU PA Model, the effective diffusion coefficient is calculated as the product of the diffusion coefficient in free air and the tortuosity. The equation for tortuosity used in the model is

$$\tau_a = \frac{\theta_a}{\phi^{2/3}}$$

where

- θ_a is the air-filled porosity
- ϕ is the total porosity.

It can be seen that the tortuosity is directly proportional to the air-filled porosity so the radon flux for a given concentration gradient will be directly proportional to the air-filled porosity. For the example above, changing the saturated hydraulic conductivity of the radon barrier from the as-built value to an in-service value will more than double the radon flux due to diffusion.

28. INTERROGATORY CR R313-25-8(4)(A)-28/3: BIOTURBATION EFFECTS AND CONSEQUENCES

This interrogatory remains open for the following reasons: (1) none of the information from EnergySolutions 2013d and EnergySolutions 2014 has been incorporated, (2) the ET cover appears not to perform as claimed in the ES responses to the Round 1 Interrogatories, (3) FRV1.2 Section 7.1, page 83, specifically states that the “impact of gullies has not been fully developed in terms of their effect on biotic activity, radon transport, or infiltration,” and (4) there is no indication when/if the updated “mammal burrowing model” will be ready for review.

The ES response to Round 1 Interrogatories states that “Detailed analysis conducted by SWCA demonstrating negligible degradation of the Evapotranspirative Cover’s radon barrier from animal borrow and root penetration has previously been conducted (Appendix C of EnergySolutions, 2013d).” However, DRC staff members reviewing that document indicate that it is still in the process of review and that they have many interrogatories and concerns pertaining to it.

ES also stated in its response that “The sensitivity of cover infiltration to changes in radon barrier integrity has been evaluated (EnergySolutions, 2014) for the ET cover design. These analyses demonstrated that an increase of 3 orders of magnitude in radon barrier hydraulic conductivity resulted in no increase in infiltration.” However, hydraulic conductivities of all cover-system soil layers were not changed simultaneously, with corresponding correlated changes in van Genuchten alpha values. Hence, the conclusion, “Therefore, no further assessment of the impact of a compromised radon barrier is necessary in the model,” is also flawed. See also Interrogatories CR R313-25-7(2)-05/2: Radon Barrier, CR R313-25-8(4)(a)-112/2: Hydraulic Conductivity, and CR R313-25-7(2)-189/3: Modeling Impacts of Changes in Federal Cell Cover-System Soil Hydraulic Conductivity and Alpha Values.

EnergySolutions’ Response:

- (1) The proposed ET cover was designed to mimic local, native ecosystems (SWCA, 2013). Beginning at the top of the cover the layers above the waste used for the ET cover design are:
 - Surface layer: This layer is composed of native vegetated Unit 4 material with 15 percent gravel mixture on the top slope and 50 percent gravel mixture for the side slope. This layer is 6 inches thick.
 - Evaporative Zone layer: This layer is composed of Unit 4 material. The thickness of this layer is 12 inches.

- Frost Protection Layer: This material ranges in size from 16 inches to clay size particles. This layer is 18 inches thick. The purpose of this layer is to protect layers below from freeze/thaw cycles, wetting/drying cycles, and inhibit plant, animal, or human intrusion.
- Upper Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.
- Lower Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.

The upper layers of silty clay provide storage for water accumulating from precipitation events, enhance losses due to evaporation, and provide a rooting zone for plants that will further decrease the water available for downward movement. The upper layers duplicate site soil depths observed in association with the target vegetation community and have the properties of the native soils on and near the Clive site that are associated with the vegetation community planned for the cover (SWCA, 2013). The frost-protection layer is the primary biointrusion barrier proposed for the cover. This layer consists of a 10–16 inches (25–41 cm) gravel and cobble mixture in-filled with small gravel, sand, and other fines (cobble and gravel to 16 inches diameter). SWCA (2013) describes the functioning of this layer to prevent biointrusion by using,

“1) large- and medium-sized cobble that is large enough that it cannot be moved by small animals; 2) pore sizes that cannot be circumvented by small animals; and 3) gravel and fines-filled interspaces that are a further deterrent to small burrowing animals.”

The frost protection layer material provides a barrier of cobbles that are much larger than the prey species but with pore sizes between the cobbles that are too small for these species to penetrate or inhabit. Many pore spaces between the cobbles will be filled with gravel and fines that have been demonstrated to be unattractive to burrowing animals (SWCA, 2013). An additional impediment to biointrusion to the radon barriers is the overlying soil layer that is deep enough to allow for some biointrusion and soil displacement to occur without impacting the lower layers (SWCA, 2013).

Another important component of effective biointrusion barriers is an overlying soil layer that is sufficiently deep to allow for some burrowing and soil displacement without compromising underlying layers. Additional factors influencing the extent of burrowing are the proposed ET cover vegetation composition and low shrub densities that will act to limit densities of small mammals and thus limit predator foraging (SWCA, 2013).

Based on site-specific observations and documented demonstrated practice SWCA (2013) concludes that,

“It is not expected that the biointrusion prevention mechanisms included in the cover design will eliminate all biointrusion into lower soil layers or the frost protection zone, but that these measures will minimize any biointrusion to an insignificant level.”

Site-specific observations of soil disturbance due to natural vegetation and demonstrated practices for minimizing disturbance were documented by SWCA (2013). Multiple soil excavations at the site demonstrated root growth behavior indicating that roots would tend to accumulate in locations to take advantage of available water rather than penetrate the radon barrier clay. These excavations showed that greasewood tap roots and other biotic activity such as fine roots and tunnels did not extend below the compacted clay layer at 24 inches. Rather, both taproots and fine roots were found to extend laterally along the upper surface of the compacted clay layer, likely making use of any water that is perched above the clay (SWCA, 2013). The impact of natural vegetation disturbance at the site was summarized by SWCA (2013).

“The potential natural vegetation that will develop on the ET cover will not result in significant levels of soil disturbance in upper soil layers, or penetration of compacted clay layers due to the presence of multiple inhibitory layers (cobble, capillary barriers) that physically prevent root growth, or direct root growth laterally toward available water below the frost protection zone rather than vertically into clay barriers.”

The effect of burrowing ants will not have a large influence on transport because ant nests will not penetrate to the waste layer, which is about 5m or more below ground surface for the disposal configurations considered. This is based on site-specific investigations indicating most ant burrowing occurs in the upper layers of the cover and be minimal below a depth of 42 inches (SWCA, 2013).

- (2) The reduction in infiltration between the rock armor cover and the ET cover described in the Critique relates to a comparison using single, deterministic values for the hydraulic model parameters. The Goldsim DU PA model (v1.2) represents an enhanced assessment of the performance of the store and release layers in the upper part of the cover and the radon barriers. This assessment is provided in addition to the biological surveys described above that indicated insignificant disturbance of the cover due to plant and animal intrusion.

A statistical experimental design was developed to provide net infiltration and water content results to version 1.2 of the Clive DU PA Model using the

variably saturated flow and transport model HYDRUS. The purpose of the experimental design was to capture the effect of variable hydraulic properties on water balance parameters for abstraction to the DU PA Model.

The Critique comments on hydraulic properties are closely linked to the Benson et al. (2011) report published by the NRC (NUREG/CR-7028). This report provides recommendations for ranges of hydraulic parameters that may be used to represent in-service conditions of store-and-release and barrier layers in covers. While this is a useful report, the topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources.

The Surface and Evaporative Zone layers in the Clive ET cover system correspond to store-and-release layers. For the infiltration modeling, values of the van Genuchten parameter alpha for these two layers were drawn from a statistical distribution with a mean of 0.016 1/cm. The value for alpha recommended for in-service layers by Benson et al. (2011, p. 10-4) is 0.2 1/kPa which corresponds to a value of 0.02 1/cm, similar to the mean used for the infiltration simulations. The distribution used for the van Genuchten n parameter for the HYDRUS simulations had a mean of 1.32. The value for n recommended for in-service layers by Benson et al. (2011, p. 10-4) is 1.3. A single value 4.46 cm/day based on site-specific measurement was used in the experimental design for the saturated hydraulic conductivity (K_s) of the Surface and Evaporative Zone layers. Mean values of the K_s of store-and-release layers of in-service covers are listed in Table 6.6 of Benson et al. (2011). The geometric mean of these results is 8.7×10^{-7} m/s or 7.5 cm/day. This value is less than twice the value used for the infiltration modeling.

The experimental design for the infiltration modeling used a K_s distribution developed from a minimum value of 4×10^{-3} cm/day corresponding to the design specification for the upper radon barrier (Whetstone 2007, Table 8), and 50th and 99th percentile values of 0.7 cm/day (7.5×10^{-8} m/s rounded to 8×10^{-8} m/s) and 52 cm/day (6×10^{-6} m/s), respectively, which are from a range of in-service (“naturalized”) clay barrier K_s values described by Benson et al. (2011, Section 6.4, p. 6-12). The value for K_s recommended by Benson et al. (2011, p. 10-3) for modeling in-service cover layers is 5×10^{-7} m/s which is well within the distribution used for the Clive DU PA infiltration modeling. Single values of alpha and n determined from site-specific measurements were used for the radon barrier in the infiltration modeling. A value of 0.003 1/cm was used for alpha and a value of 1.17 was used for n. Benson et al. (2011, p. 10-4) recommend using the result from a single measurement at a single site

for alpha. This is a value of 0.02 1/cm. Two other values are available for sample sizes considered to be unaffected by scale for the K_s measurements (Benson et al, 2011, Table 6-9). The geometric mean of the three measurements is 0.002. A range from 1.2 to 1.4 is recommended by Benson et al. (2011) for the n parameter. The value used for the infiltration modeling is slightly below the low end of that range. More detailed descriptions of distribution development and abstraction to the DU PA Model are provided in Appendix 5 - Unsaturated Zone Modeling of Appendix A.

- (3) Effects of gully formation on biotic activity, radon transport, and infiltration are discussed in more detail in the response to INTERROGATORY CR R313-25-8(4)(A)-120/3: GULLIES AND RADON.
- (4) In the response to the Round 2 Interrogatory an updated animal burrowing model was discussed with separate distributions for soil movement by small mammals (deer mice, kangaroo rats, and ground squirrels) which occur frequently on the site, and large mammals (badger, coyote, kit fox) which occur in much lower densities at Clive and the surrounding area. With the current design specifying the DU waste to be placed below grade, the changes in the animal burrowing distributions described in the response to the Round 2 Interrogatory would have a negligible influence on results.

29. INTERROGATORY CR R313-25-8(5)(A)-29/2: LIMITATION TO CURRENT CONDITIONS OF SOCIETY AND THE ENVIRONMENT

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

30. INTERROGATORY CR R313-25-8(5)(A)-30/1: INCLUSION OF SRS-2002 DATA IN THE SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

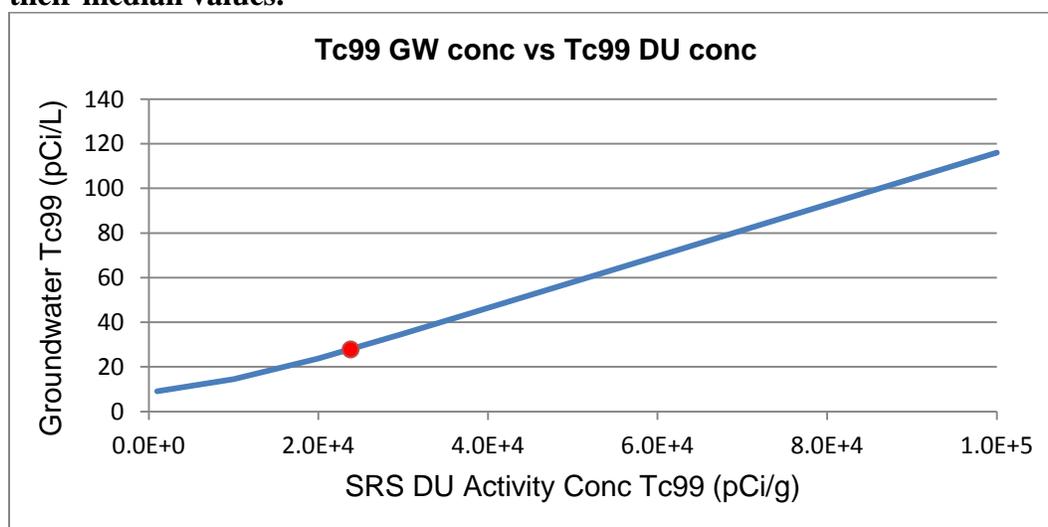
31. INTERROGATORY CR R313-25-8(5)(A)-31/3: TC-99 CONTENT IN THE WASTE AND INCLUSION IN THE SENSITIVITY ANALYSIS

In its Round 1 response, ES stated that a questioned statement would be removed, and this was done in the revised Waste Inventory report (Appendix 4 to FRV1.2). However, as noted above, ES stated that further analysis is being performed to show how the results change as a function of Tc-99 concentrations. The only relevant information we could find in the revised PA documents is the results of a global sensitivity analysis for 500 years in Appendices 15(I) and 15(II). Contrary to the ES response, this information does not show how dose results change as a

function of changes only in the Tc-99 concentration, nor does it provide any indication as to how the sensitivity changes over longer timeframes.

EnergySolutions' Response: The Tc-99 concentrations have an approximately linear impact on the model results, if all other variables are held constant at their median values, as shown in Figure A. The slope of this almost linear fit is about 0.0016 for the upper concentrations. So, for an increase of 2000 pCi/g in the inventory, the output increases by 32 pCi/L. The lack of pure linearity is associated with the solubility limit.

Figure A: Change in groundwater concentrations of Tc-99 as a function of change in the input concentration, holding all other variables constant at their median values.



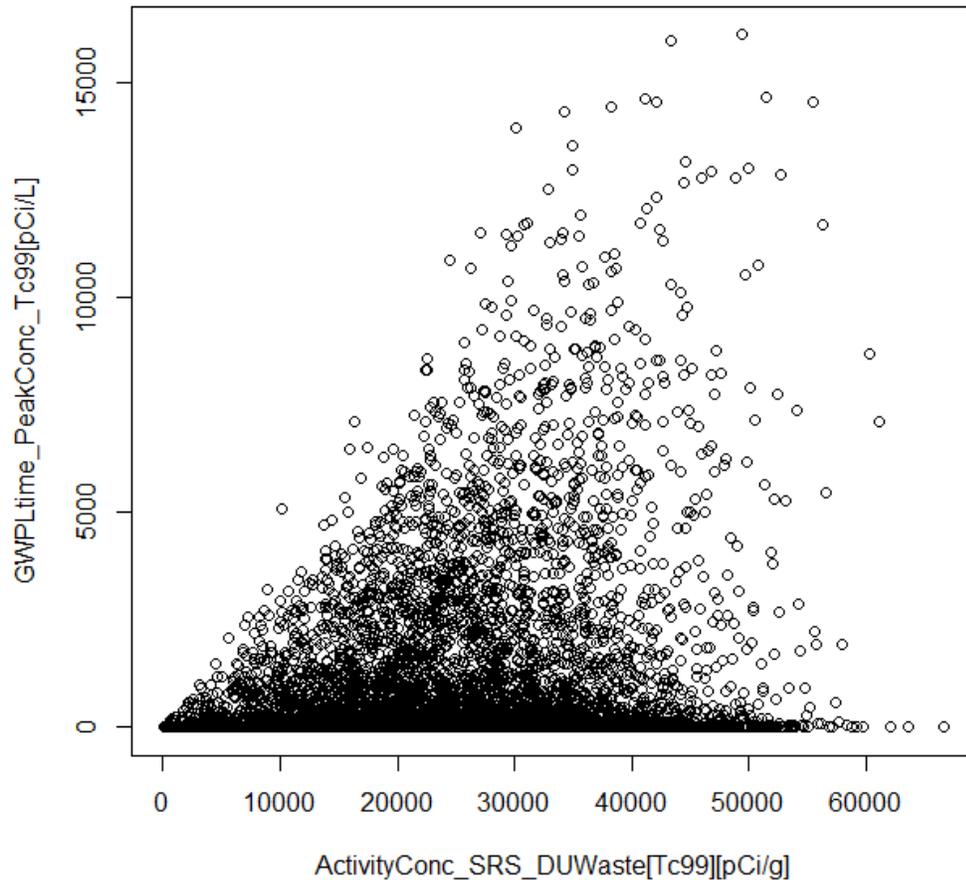
However, changing a single variable is not relevant in a probabilistic model. What is important is how the model behaves as a whole. The global sensitivity analysis explains how the model functions, and what the model drivers are. As shown in the global sensitivity analysis for the model, the inventory of Tc-99 is not a sensitive parameter for any of the model outputs. Instead, the K_d of Tc-99 is the dominant factor.

The PA has been built probabilistically and, to the extent possible every effort has been made to develop realistic input distributions. However, some conservatism remains in the model, particularly in the deep time model. A probabilistic model is built to represent the current understanding of the system, including uncertainty that characterizes how much is known (or not known). NRC has moved in the direction of probabilistic modeling for several years, and all low-level waste PAs under DOE Orders now include probabilistic models. In addition, high-level waste and TRU waste PAs have probabilistic performance objectives. The advantages of probabilistic PAs should be clear enough, but the support offered

by NRC and DOE for various radioactive waste programs provides clear practical indication of those benefits. Global sensitivity analysis is used to evaluate probabilistic models, and essentially varies all input variables simultaneously. This is not only an effective model evaluation technique, but also identifies the most sensitive parameters in the model. This also means that other parameters in the model are not important for projecting model outputs.

Figure B shows the relationship between the output concentrations of Tc-99 in groundwater and the Tc-99 inventory using simulated data from version 1.2 of the Model. This is an appropriate one-at-a-time sensitivity analysis for a probabilistic model. In particular, the output here is the peak groundwater concentration, which always occurs at 500 years in the model simulations. So, 10,000 values are shown on this plot. This plot shows quite clearly that the input concentration of Tc-99 does not predict the output groundwater concentrations. There does appear to be some form of ceiling effect, so that an input concentration cannot project groundwater concentrations above some level, but otherwise, the ability of Tc-99 inventory concentration to predict groundwater concentration is very limited. This is because of the effect of K_d (in sand) of Tc-99. This is the dominant factor. Figure B probably indicates that low K_d values are associated with relatively large groundwater concentrations, whereas high K_d values produce close to zero groundwater concentrations. The actual input concentration is not particularly important. For example, a groundwater concentration of 1000 pCi/L could have been produced from an inventory concentration of anywhere from about 500 to 5000 pCi/g in the inventory. Or, a groundwater concentration of 5000 pCi/L could have been produced from an inventory concentrations of anywhere from about 1000 to 5000 pCi/g in the inventory.

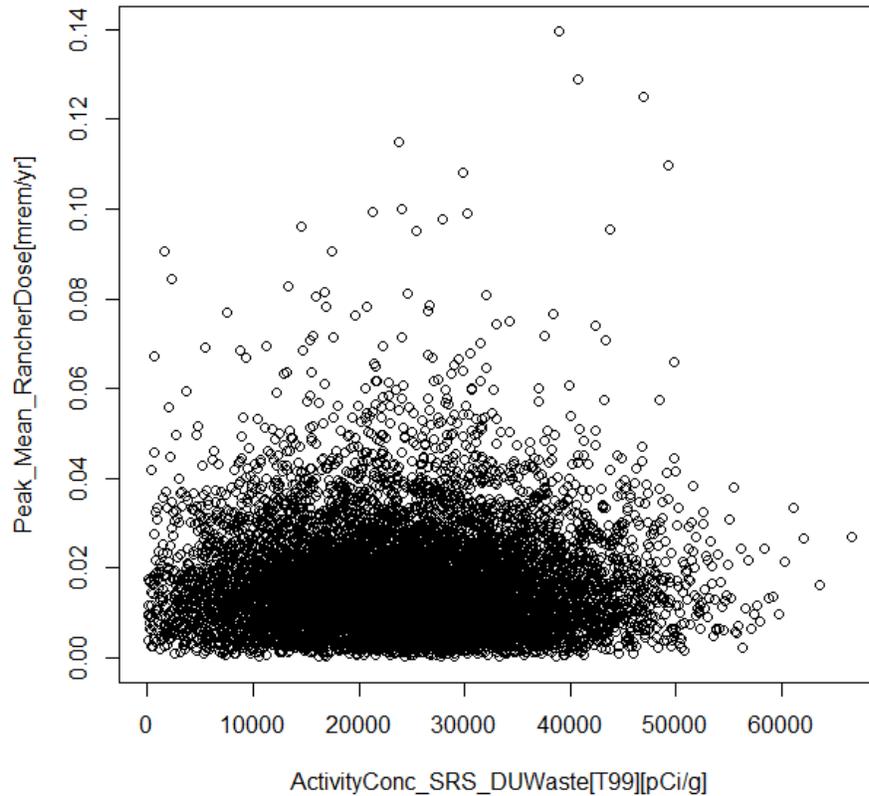
Figure B: Change in groundwater concentrations of Tc-99 as a function of change in the input concentration of Tc-99 from the probabilistic model.



In summary, roughly speaking groundwater concentrations of Tc-99 increase approximately linearly with inventory concentrations when all other inputs are held constant at their median values. However, this misses the point that K_d is the main driver of the groundwater concentrations.

For the model endpoint of rancher dose the ability of I-129 to predict the output is essentially non-existent. This is because the output doses are driven primarily by the radon escape/production ratio, and not by Tc-99 inventory concentrations. Note that the dose outputs are all driven by radon, and hence have nothing to do with Tc-99. Figure C provides a scatter plot of the relevant data points.

Figure C: Change in rancher dose as a function of change in the input concentration of Tc-99 from the probabilistic model.



32. INTERROGATORY CR R313-25-8(4)(A)-32/3: EFFECT OF OTHER POTENTIAL CONTAMINANTS ON PA

The revised Sensitivity Analysis Results report (Appendix 15(II) to FRV1.2) shows that the effect of other potential contaminants to the intruder doses is trivial. However, based on new groundwater utilization scenarios, this may not be the case for intruder and member of the public doses.

EnergySolutions' Response: As is reflected in the Round 2 Response to CR R313-25-19-182/2, the acute doses to an inadvertent industrial well driller and the chronic doses to an inadvertent industrial well user are negligible. NRC defines it as inappropriate to project doses to members of the general public from the actions of an inadvertent intruder,

“Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite [that may result in subsequent exposure to members of the general public].”
(NUREG-1573, pg. 3-11).

See also the Round 2 Response to Interrogatories CR R313-25-8(4)(B)-07/2:APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS (Appendix D).

33. INTERROGATORY CR R315-101-5.3(6)-33/1: CLARIFICATION OF THE PHRASE “PROOF-OF-PRINCIPLE EXERCISE” AND SENSITIVITY TO URANIUM ORAL REFERENCE DOSE FACTORS

Round 1 Interrogatory Response is satisfactory.

34. INTERROGATORY CR R313-25-8(5)(A)-34/3: INTENT OF THE PA

ES added the revision to FRV1.2 Section 2.1, page 24, as indicated in its responses to the Round 1 Interrogatories; however, the edits recommended above were not incorporated.

EnergySolutions' Response: The revisions recommended by the Division are inconsistent with the purposes of a Performance Assessment, as defined in UAC R313-25-9(5)(a) and reflected in condition 35.B of Radioactive Material License UT2300249. The Division seeks the expand beyond regulation a Performance Assessment's purpose to include,

“(1) quantitative PA modeling for at least 10,000 years and (2) complete additional PA simulations for a 1,000,000 year timeframe”

However, the applicable regulatory reference specifically requires that,

“For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years. Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively” [UAC R313-25-9(5)(a)];

and condition 35.B requires,

“For purposes of this performance assessment, the compliance period will be a minimum of 10,000 years. Additional simulations will be performed for a minimum 1,000,000-year time frame for qualitative analysis.” [UAC R313-25-9(5)(a)].

Since one of the objectives of the Performance Assessment referenced in Section 2.1 of Appendix A is satisfaction of UAC R313-25-9(5)(a) and License Condition 35.B, it is unnecessary and inappropriate to expand the text to incorporate the Division’s recommendation.

35. INTERROGATORY CR R313-25-19-35/1: REFERENCE FOR COST PER PERSON-REM

Round 1 Interrogatory Response is satisfactory.

36. INTERROGATORY CR R313-25-8(4)(A)-36/1: ANT NEST EXTRAPOLATIONS

Round 1 Interrogatory Response is satisfactory.

37. INTERROGATORY CR R313-25-8(5)(A)-37/2: DISTRIBUTION AVERAGING

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

38. INTERROGATORY CR R313-25-8(5)(A)-38/3: FIGURES 5 AND 11 IN FRV1

A recent ES submission to the DRC, “2013 Groundwater Withdrawal Survey, Part LH. 13 GWQDP No. UGW450005,” indicates that its water-right 16-722 with a 10-inch-diameter underground well at S 1900 ft W 1400 ft from NE co, Sec 18, T1S, R11W, SLBM is capable of producing groundwater at a rate of 0.72 cfs and that it produced 2,941,200 gallons of groundwater in 1993 alone. The well reportedly had produced about 15,313,800 gallons of groundwater by 2008.

As previously mentioned, pumping from deeper wells has the potential to pull down groundwater from shallow depths to the screens of deeper wells with continued pumping over time. This is a regular occurrence in many parts of the world, as observed by DRC staff members over years of consulting with companies dealing with industrial contamination. This occurrence could, over some period of time, drive contaminants into a deeper, more productive aquifer.

Therefore, the PA needs to include investigation of deeper aquifers, analysis of potential hydraulic connections between shallow aquifers and deeper aquifers, protection of groundwater in the shallow aquifer from radioactive contamination, analysis of inadvertent intruder uses of deeper groundwater, and estimation of potential inadvertent intruder doses.

Deeper wells penetrating shallow aquifers also provide potential for leakage along casing or through fractured or incomplete annular seals. This may provide a conduit for preferential flow and contaminant migration down to a deeper aquifer. We recognize that drilling regulations require boreholes to be sealed. In Tooele County, borehole sealing inspections are performed by the county health department. However, failure to properly seal the annular space is not unusual in well drilling. A thorough investigation of the potential for deeper drilling at the site, along with studies of other, related aspects of deeper groundwater at the site, are integral parts of complying with applicable rules and guidance in developing the PA. Thus far, ES has presented to the DRC no reliable information for deeper aquifers (e.g., >500 feet deep) on site, either as to hydraulic head, hydraulic conductivity, flow rate, or water quality. ES needs to obtain all of this information before the PA can be approved. This is consistent with Utah rule UAC R313-25-3(5):

The plan approval siting application shall include hydraulic conductivity and other information necessary to estimate adequately the ground water travel distance.

Likewise, UAC R313-25-3(6) states the following:

The plan approval siting application shall include the results of studies adequate to identify the presence of ground water aquifers in the area of the proposed site and to assess the quality of the ground water of all aquifers identified in the area of the proposed site.

Similar requirements also apply when a candidate seeks a license under Utah Environmental Quality Code 19-3-305(1), which calls for the following:

- identification of “the presence of any groundwater aquifers in the area of the proposed site”
- assessing “the quality of the groundwater of all aquifers identified in the area of the proposed site”
- providing “reports on the monitoring of vadose zone and other near surface groundwater”

- supplying “reports on hydraulic conductivity tests”
- giving “any other information necessary to estimate adequately the groundwater travel distance”
- including a site description involving geologic, geochemical, geotechnical, hydrologic and ecologic information and description for aquifers on site

Since none of these tasks has yet been completed for the deeper gravel strata, layers, or zones of the confined aquifer (e.g., at 450–700 feet) on site, this remains to be done as part of the PA, or, at the very least, prior to a new or modified license being signed. This is one of the critical deficiencies of the current PA.

The groundwater exposure pathways discussed in this interrogatory need to be examined and the results compared to the R313-25-19 groundwater dose limit. Obtaining this information will require, among other things, drilling of deeper wells (e.g., down to 600–700 feet) in the area upgradient or to the sides of the waste area and conducting pumping tests, or, possibly slug tests, in the deeper wells to assess hydraulic conductivity. Pumping tests should be employed if the hydraulic conductivity is 1×10^{-3} cm/s or higher.

After the additional information discussed here is provided, disposition of this and related interrogatories can be addressed. These include the following:

- Interrogatory CR R313-25-8(4)(a)-96/3: Current and Future Potability of Water
- Interrogatory CR R313-25-8(4)(a)-97/3: Need for Potable and/or Industrial Water
- Interrogatory CR R313-25-8(4)(a)-105/3: Human Use of Groundwater
- Interrogatory CR R313-25-8(4)(a)-106/3: Desalination Potential
- Interrogatory CR R313-25-8(5)(a)-163/3: Groundwater Compliance for 10,000 Years
- Interrogatory CR R313-25-19-182/2: Groundwater Exposure Pathways

EnergySolutions’ Response: See the Round 2 Responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS in Appendix D.

39. INTERROGATORY CR R313-25-8(5)(A)-39/1: FIGURE 6 CAPTION

Round 1 Interrogatory Response is satisfactory.

40. INTERROGATORY CR R313-25-8(5)(A)-40/3: FIGURES 7, 8, 9, 10, AND 11

FRV1.2 Section 6.1.2 now includes a reference to “Appendix 19, Sensitivity Analysis Results.” However, the correct appendix is Appendix 15(II), and the appropriate section within the appendix is not cited. In addition, the appendix is not cited in FRV1.2 Sections 6.2.2 or 6.3.2.

EnergySolutions’ Response: Sections 6.1.2, 6.2.2, and 6.3.2 of Appendix A has been revised.

41. INTERROGATORY CR R315-101-5.3(6)-41/3: TABLE 7

Two tables are no longer provided in FRV1.2 Section 6.3.1, page 70. The text has been revised as follows:

The uranium HI results are summarized in Table 6, which shows the statistics for mean uranium HI for all receptors.

The HIs for uranium are extremely small relative to threshold of 1.0, indicating essentially no possibility of observing health effects from uranium toxicity. Similar to the dose results presented above, this indicates that disposal of DU waste below grade, at the bottom of the embankment, is protective of human health and the environment. These values are in compliance with the regulatory standards.

The title of the associated table is as follows:

Table 6. Peak uranium hazard index: statistical summary

However, the text refers to “mean uranium HI” and the table title to “peak uranium HI,” so the original issue with consistency (“mean” vs. “peak”) appears to be unresolved.

We also note that until the other intruder scenarios requested in these interrogatories have been addressed, it cannot be assumed that the HIs are small relative to the 1.0 threshold.

EnergySolutions’ Response: The Main Report has been edited to clarify that the summary statistics presented in Tables 2, 4 and 6 represent peak of the means from the simulations. Note that the model outputs in these tables are derived entirely from the last time step in the model. That is, the mean of the peaks and the peak of the means are identical. In the tables of results in Section 6.0 of the Main Report, the mean, median, and 95th percentile of the peak of the mean values are presented.

42. INTERROGATORY CR R315-101-5.3(6)-42/1: HAZARD QUOTIENT IN TABLES 7 AND 8

Round 1 Interrogatory Response is satisfactory.

43. INTERROGATORY CR R313-25-19-43/1: PEAK DOSE IN TABLE 11

Round 1 Interrogatory Response is satisfactory.

44. INTERROGATORY CR R313-25-8(5)(A)-44/2: OCCURRENCE OF INTERMEDIATE LAKES

Round 2 Interrogatory Response is satisfactory.

45. INTERROGATORY CR R313-25-7(2)-45/1: INACCURATE CROSS-REFERENCE

Round 1 Interrogatory Response is satisfactory.

46. INTERROGATORY CR R313-25-7(1)-46/1: TORNADOS

Round 1 Interrogatory Response is satisfactory.

47. INTERROGATORY CR R313-25-7(1)-47/1: SELECTION OF BIOME

Round 1 Interrogatory Response is satisfactory.

48. INTERROGATORY CR R313-25-7(9)-48/3: SOURCE AND COMPOSITION OF DU WASTE

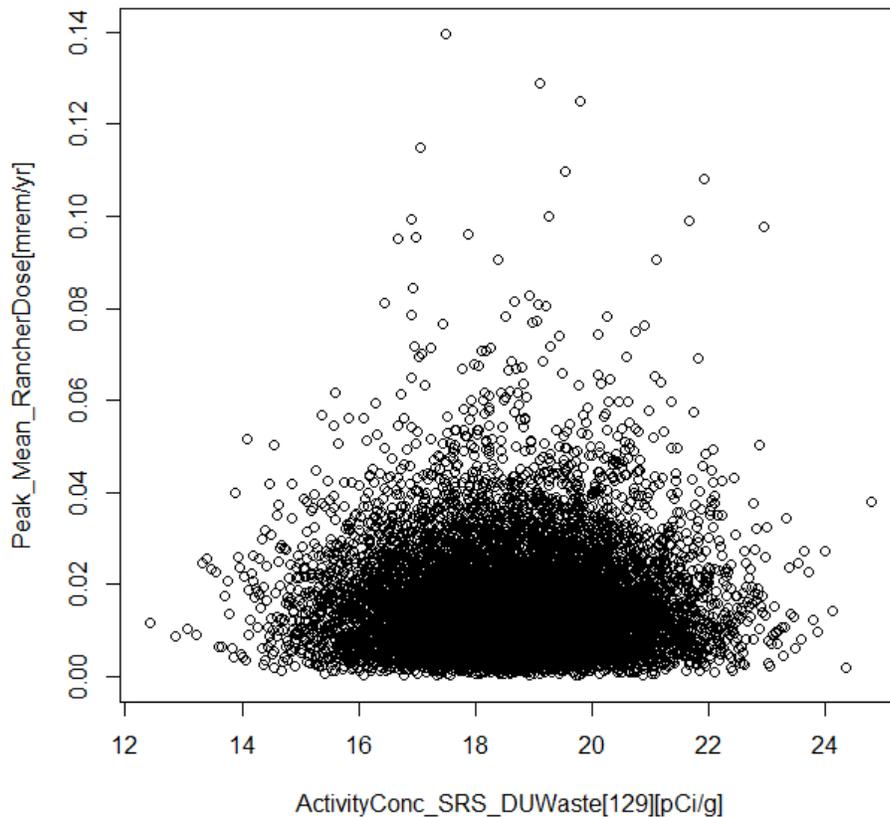
ES has provided useful information showing that the I-129 concentration is grossly overstated (see footnote 1 in the revised Waste Inventory report (Appendix 4 to FRV1.2)). However, ES has not performed the proposed actions described in its response to the Round 1 Interrogatory.

EnergySolutions' Response: Also see the Round 3 Response to Interrogatory CR R313-25-8(5)(A)-31/3: TC-99 CONTENT IN THE WASTE AND INCLUSION IN THE SENSITIVITY ANALYSIS.

Figure A below shows the simulated input data from the I-129 inventory distributions and the rancher dose. This is the most appropriate way to evaluate the one-at-a-time sensitivity of a single input variable. There is no relationship between the input and the output in the probabilistic model. This is because rancher dose is driven by radon (from the DU) rather than by the I-129 inventory.

Note that the full global sensitivity analysis was performed in log-space for the output rancher dose. In this case the scatter plots make the lack of correlation even more obvious. This is presented in Figure B.

Figure A: Change in rancher dose as a function of change in the input concentration of I-129 from the probabilistic model.

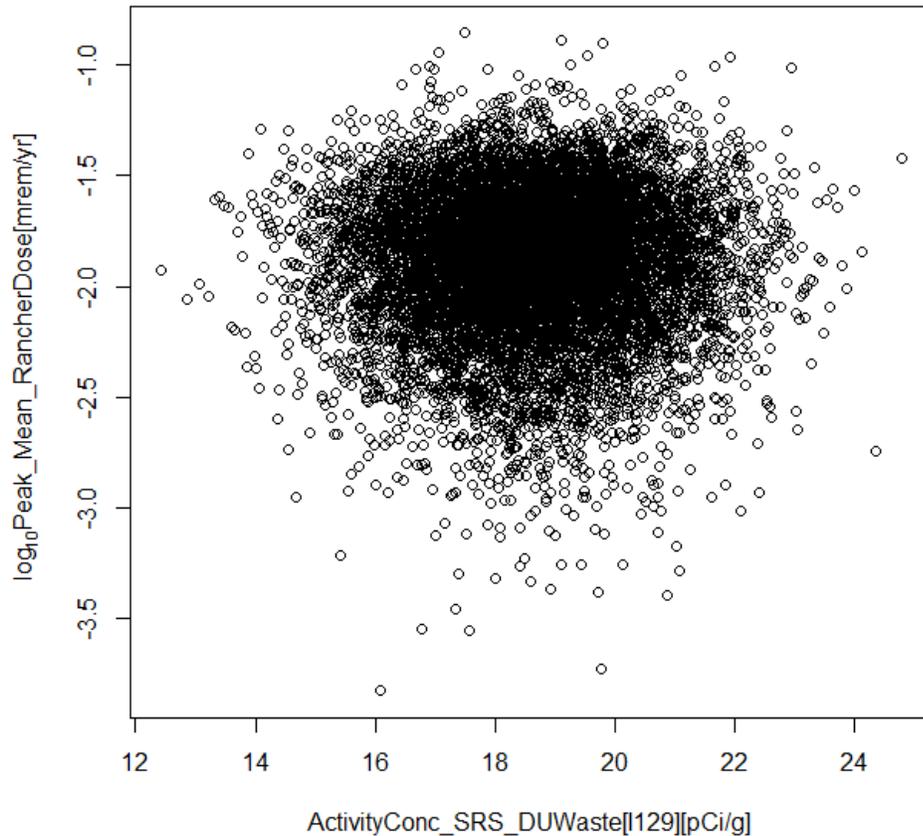


Note also that EnergySolutions disagrees with the V1.2 Critique statement that

“Given the high does conversion factor, it is very important to use a conservative approach for I-129.”

The primary reason for using a conservative approach in a probabilistic model is that it (the inventory of I-129) makes no difference. I-129 does not affect dose at all (dose is driven almost entirely by radon from the DU itself). There is no need to refine (i.e. improve) the I-129 input distribution because it will not change the results of the model. If the I-129 inventory is a sensitive parameter, then there would be reason to look more closely at its distribution.

Figure B: Change in log-rancher dose as a function of change in the input concentration of I-129 from the probabilistic model.



49. INTERROGATORY CR R313-25-7(9)-49/3: COMPOSITION OF MATERIAL MASS

Section 2.2.2, page 6, of the revised Radioactive Waste Inventory report (Appendix 4 to FRV1.2) states that: “The mass of the empty drums is assumed to be approximately 108 Mg, so the total waste mass is 3577 Mg of drummed waste – 108 Mg drum mass = 3469 Mg of DU waste which is a mix of uranium isotopes and contaminants, and where the uranium is assumed to be in the form of DUO3.” We interpret this to mean that the mass of 3,469 Mg refers to DUO3 containing 83.6% DU. This interpretation does not appear to be reflected in Table 1, where the total mass of SRS DUO3 is listed as 3,577 Mg. This is also the mass listed in the Table 39, page 26, of the Model Parameters report (Appendix 16 to FRV1.2).

EnergySolutions' Response: Input parameters are the total mass of drummed SRS DUO₃ waste (3,577 Mg), and the mass of one drum (20 kg) times the number of drums (5,408), the product of which is 108,160 kg (~108 Mg) of total mass of the drums. These calculations are performed in the \Inventory\SRS_DU_Inventory container in version 1.2 of the Model.

Table 1 from Appendix 4 – Waste Inventory of Appendix A and its surrounding text have been revised to clarify the mass of DUO₃ (drummed) versus the mass of just the DUO₃.

The value documented in Table 39 of Appendix 16 – Model Parameters from Appendix A is called the “ShippedMass_Proposed_UT”, which is identified as the mass from the shipping manifest, including drums. The subtraction of the mass of the drums is done within version 1.2 of the Clive DU PA Model. Therefore, Appendix 16 – Model Parameters from Appendix A is correct and has not been changed.

50. INTERROGATORY CR R313-25-7(9)-50/3: SAMPLES COLLECTED

ES did not implement the proposed correction.

EnergySolutions' Response: The text is now corrected in Appendix 4 - Waste Inventory in Appendix A.

51. INTERROGATORY CR R313-25-7(9)-51/3: NATURE OF CONTAMINATION

We could not ascertain that any significant amendments to the text of the revised Waste Inventory report (Appendix 4 to FRV1.2) were made based on the ES review and evaluation of the 17 cited documents, although several were added to the reference list. ES did state the following in Section 1.0, pages 2–3, of the Waste Inventory report:

However, these studies and reports do not provide specific information on concentrations that can be used directly to develop input probability distributions. Until adequate information concerning DU inventory is received from the GDPs, which may not happen until the DU oxide product has been produced and sampled, the actinides and fission products are assumed to be in relative concentrations in the DUF₆ waste equal to those in the SRS DUO₃ waste, as shown in Table 2. This is only a rough approximation and will need to be revised as data from the GDP waste are provided.

Our reading of the usefulness of these documents is different. We believe that they contain data on concentrations of contaminants that can be used in performance assessment. ES needs to explain why the data, particularly those contained in Hightower et al. (2000), cannot be used to characterize contaminant concentrations of species such as Tc-99.

This concern is discussed more fully in Interrogatory CR R313-25-7(9)-89/3: Contamination Levels in DUF6.

EnergySolutions' Response: See the Round 3 response to Interrogatory CR R313-25-7(9)-89/3: CONTAMINATION LEVELS IN DUF6.

52. INTERROGATORY CR R313-25-7(9)-52/1: MEASUREMENT TYPES FOR SAMPLING EVENTS

Round 1 Interrogatory Response is satisfactory.

53. INTERROGATORY CR R313-25-7(9)-53/1: SUBSCRIPTS IN EQUATION 1

Round 1 Interrogatory Response is satisfactory.

54. INTERROGATORY CR R313-25-7(9)-54/1: PARTITIONING IN THE SENSITIVITY ANALYSIS

Round 1 Interrogatory Response is satisfactory.

55. INTERROGATORY CR R313-25-8(5)(A)-55/1: URANIUM ISOTOPE DISTRIBUTIONS

Round 1 Interrogatory Response is satisfactory.

56. INTERROGATORY CR R313-25-7(9)-56/1: INTERPRETATION OF BOX PLOTS

Round 1 Interrogatory Response is satisfactory.

57. INTERROGATORY CR R313-25-7(9)-57/1: DASHED LINES IN FIGURE 4

Round 1 Interrogatory Response is satisfactory.

58. INTERROGATORY CR R313-25-7(9)-58/1: REFERENCE FOR PERSONAL COMMUNICATION

Round 1 Interrogatory Response is satisfactory.

59. INTERROGATORY CR R313-25-7(2)-59/2: BATHTUB EFFECT

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

60. INTERROGATORY CR R313-25-7(3)-60/2: MODELED RADON BARRIERS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

61. INTERROGATORY CR R313-25-8(4)(A)-61/2: MASS-BALANCE INFORMATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

62. INTERROGATORY CR R313-25-7(2)-62/1: NUMERICAL TESTING OF RUNGE-KUTTA METHOD

Round 1 Interrogatory Response is satisfactory.

63. INTERROGATORY CR R313-25-8(4)(A)-63/2: AIR-PHASE ADVECTION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

64. INTERROGATORY CR R313-25-8(4)(A)-64/3: YUCCA MOUNTAIN STUDIES

Table 2, page 2, of the revised Geochemical Modeling report (Appendix 6 to FRV1.2) lists U₃O₈ with an expected low solubility. ES should indicate whether U₃O₈ allowed to oxidize to schoepite or some other oxidized phase within this model. If U₃O₈ represents a significant amount of the waste and is able to oxidize to a more soluble form, the modeled aqueous uranium concentrations could be significantly underestimated. Section 5.1.14.1, page 24, states that: "The solubility of U₃O₈ is also incorporated into the GoldSim model." However, Section 5.1.14.3, page 29, includes a "Note" on the Goldsim model that indicates that the model cannot include both UO₃ and U₃O₈. The text implies, but does not clearly state, that U₃O₈ was ignored (since UO₃ is the primary control of solubility). If this is indeed the case, then all of the discussion of U₃O₈ is superfluous. The section could be shortened to one statement that the solubility of

U3O8 is orders of magnitude lower than UO3 (with proper references), so UO3 is considered the dominant phase.

In addition, the headings in Table 4, page 3, note that these are solubility values in salt water. ES should provide the parameters for this “salt water,” as this could be quite a wide range.

EnergySolutions’ Response: Versions 1.0 and 1.2 of the Clive DU PA Model take a very simple approach to solubility calculations. The Model itself does nothing with respect to chemical speciation or environmental conditions. It performs contaminant fate and transport calculations based on stochastic definitions of solubility, soil/water partitioning, and the like. Accounting for redox conditions and chemical speciation is done in the development of the solubility distribution that is input to the Model.

For the first 10,000 years of the Clive DU PA Model, all DU is assumed to be in the form of UO3. Since UO3 has a greater solubility than other forms, uranium moves more readily through the system, e.g., to groundwater. (The user may, however, run the model using the solubility of U3O8 for the first 10,000 yr instead, as a way of evaluating sensitivity to this parameter.) U3O8 solubility is used to control uranium solubility in the Deep Time model (over 10,000 yr).

If the UO3 solubility were used in the Deep Time model, or if the U3O8 solubility were increased, greater lake-water concentrations would be calculated. However, before making such changes, the geochemical assumptions for Deep Time require revision, including aqueous carbonate concentrations.

The headings on Table 4 were changed to remove “Salt Water.” The term “Salt Water” refers to the geochemistry of the Clive Site, as compared to fresh water.

65. INTERROGATORY CR R317-6-6.3(Q)-65/3: COLLOID TRANSPORT

ES added text in Section 2.0 of the Geochemical Modeling report (Appendix 6 to FRV1.2) describing the conditions expected at the site and those of mobile colloids. However, the logic of not including something because it is complex is not sufficient. Since the presence of colloids is “unknown and currently speculative” (page 6), it seems the best way to determine the potential for colloid transport would be to measure for pore water colloid concentrations at the site or gather data from a similar site.

Note that the reference in Section 3.0, page 10, to the figure is missing, as is the reference to the section number in Section 4.1 on page 13.

EnergySolutions' Response: Although research of the transport of radionuclides via colloids is ongoing, reasonable conclusions are formulated for the likelihood of colloid transport at the Clive site. Measuring colloids in pore space at the Clive site do not provide helpful information for how colloids affect solubility or adsorption for this site. Most likely colloids come from the waste that is emplaced at the site. However, EnergySolutions has yet to place the DU wastes currently held in storage. Because of this, container degradation and other long-term site conditions are currently unobservable. Therefore, the most promising approach to better characterizing colloid behavior at the Clive site is via literature. This is the approach taken in Appendix 6 – Geochemical Modeling of Appendix A.

The phrase “*unknown and currently speculative*” cited from Appendix 6 refers to the presence of colloid sorption sites in the Clive DU waste. In the first round of interrogatories, the Division requested that some discussion be made as to “*explain how these phenomena [colloids] might affect radionuclide soil-water partitioning (K_d) coefficients.*” Since it is expected that colloids at the Clive site are immobile, they could provide additional adsorption sites for radionuclide adsorption. It is likely that adsorption to colloids could be as strong as or stronger than mineral phases, but there is no evidence to justify the presence of colloids or how strong this adsorption would be. Gathering site-specific data is not productive, as discussed above. The adsorption distributions are based on adsorption to minerals and do not include colloid sorption. If colloids are considered for adsorption coefficients, radionuclides would probably be less mobile than they are in version 1.2 of the Clive DU PA Model.

That is true for other assumptions, as well. For example, if adsorption of Tc on the metal waste containers were considered, Tc would be less mobile than it is in the current model. Clarification has been added to Section 2.0 of Appendix 6 – Geochemical Modeling from Appendix A.

The reference in Section 3.0 of Appendix 6 – Geochemical Modeling of Appendix A is not missing. There are references to both Figure 1 and Figure 2 on page 10. The reference to a missing section number in Section 4.1 on page 13 (and others) has been corrected.

66. INTERROGATORY CR R313-25-8(4)(A)-66/2: COLLOID RETENTION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

67. INTERROGATORY CR R313-25-8(4)(A)-67/3: SOLUBILITY AND SPECIATION OF RADIONUCLIDES

Section 5.0, page 20, of the revised Geochemical Modeling report (Appendix 6 to FRV1.2) states that: “The high ionic strength brine found in the shallow aquifer at Clive can increase the solubilities of some actinides (DOE 2009) and this influence was incorporated into the decision making for solubility selection and modeling.” The interrogatory asked ES to “Consider the solubility and speciation work with radionuclides in high ionic strength brines performed to support the Waste Isolation Pilot Plant. If it is not relevant, explain how solubility and speciation in high ionic strength brines are addressed.” The added text does not sufficiently explain how the high ionic strength systems were treated. This is not a trivial problem and should be addressed.

The same paragraph also states: “However, the three locations do also have very different mineralogy and soil properties that can influence the ion-exchange and sorption constraints in this model.” ES should clarify whether it is implying that the ionic strength will change across the site, and if so indicate the expected range. Only an average value was given (0.73 M) on page 9 of the report based on the data in Table 8.

In addition, Table 11, page 28, of the Geochemical Modeling report lists only U(VI) aqueous species. ES should clarify whether any U(IV) species were considered; we assume that they were in order to calculate the solubilities of U₃O₈ without redox coupling within Visual MINTEQ (as previously discussed). Therefore, Table 11 should also list the U(IV) species. Although not necessary, it would significantly strengthen the case being made with this model if the stability constants for each species and the reference for the constant were reported as well.

EnergySolutions’ Response: Changes have been made to Appendix 6 – Geochemical Modeling of Appendix A to address the issues of high ionic strength, including some of the work done at the WIPP site.

The statement: “*However, the three locations do also have very different mineralogy and soil properties that can influence the ion-exchange and sorption constraints in this model*” is made in Section 5.0 of Appendix 6 – Geochemical Modeling of Appendix A to say that the DOE 2009 reference and other sites like Yucca Mountain can provide information as to the effects of high ionic strength on geochemistry at Clive. However, because each site differs in mineralogy and other soil properties, one must keep all the factors in mind when choosing geochemical parameters for the model. Clarification has been added to the text.

For clarity, Table 11 of Appendix 6 – Geochemical Modeling of Appendix A has been revised to note that the values are U(VI) species.

68. INTERROGATORY CR R313-25-8(4)(A)-68/2: DISTRIBUTION OF HYDRAULIC GRADIENTS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

69. INTERROGATORY CR R313-25-8(4)(A)-69/2: LONGITUDINAL DISPERSIVITY

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

70. INTERROGATORY CR R313-25-7(2)-70/3: GULLY SCREENING MODEL

Section 2.1, page 3, of the revised Erosion Modeling report (Appendix 10 to FRV1.2) states that: "However, sheet erosion is not included in the Clive DU PA Model since the top slope of the cover is nearly horizontal and since the side slope will not have DU waste buried beneath it." However, the Executive Summary of FRV1.2, page 3, states that: "The impact of sheet and gully erosion in the Model is evaluated by the application of results of landscape evolution models of hillslope erosion loss and channel development conducted for a borrow pit at the site." The documents should clarify whether or not sheet erosion is included in the Clive DU PA Model. As noted above, ES should ensure that the model includes an analysis of the effects of gully formation on cover systems infiltration, radon emanation, and groundwater contamination, as well as other factors such as changes in cover-system soil hydraulic conductivity over time.

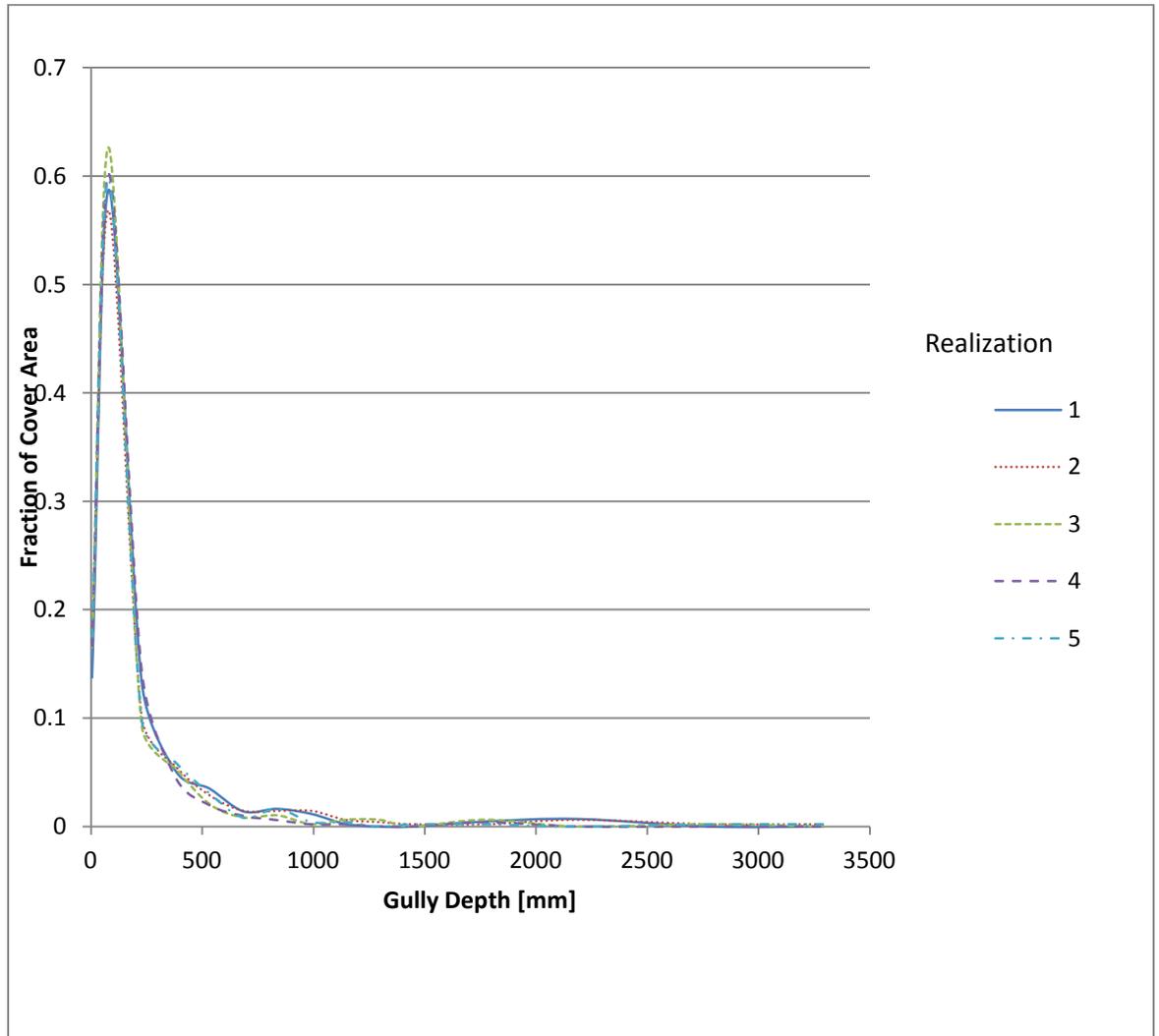
EnergySolutions' Response: The text in Section 2.1 of the Appendix 10 - Erosion Modeling of Appendix A has been revised to

"While both sheet and gully erosion are considered in the Clive DU PA Model (v1.2) little contamination is likely to be transported by sheet erosion, and gully erosion is expected to be far more significant"

making the descriptions of sediment transport mechanisms considered in the model consistent between the Erosion Modeling report and the Final Report V1.2.

The influence of gully formation on infiltration and radon transport is negligible given the current below grade disposal design. In addition, analysis of the projected SIBERIA modeling results indicate that only a small fraction of the cover would have gullies extending through the surface and evaporative zone layers to the top of the frost protection layer. Figure 2 from Appendix 10 copied

below is a plot of 5 realizations of the percent of the total cover area projected to 10,000 years containing gullies of a given depth. Gullies as deep as 1 cm are found on 16 percent of the cover surface on average while another 60 percent of the cover has gullies as deep as 15 cm. Gullies ranging from 15 cm to 30 cm are found on 11 percent of the cover and only 13 percent of the cover has gullies extending to or deeper than the top of the frost protection layer.



71. INTERROGATORY CR R313-25-8(4)(A)-71/1: BIOTIC PROCESSES IN GULLY FORMATION

Round 1 Interrogatory Response is satisfactory.

- 72. INTERROGATORY CR R313-25-8(4)(A)-72/1: DE MINIMIS DOSE VALUE**
Round 1 Interrogatory Response is satisfactory.
- 73. INTERROGATORY CR R313-25-19-73/1: ALARA CONCEPT**
Round 1 Interrogatory Response is satisfactory.
- 74. INTERROGATORY CR R313-25-8(5)(A)-74/1: TAILORED DISCUSSION OF SENSITIVITY ANALYSIS**
Round 1 Interrogatory Response is satisfactory.
- 75. INTERROGATORY CR R313-25-7(9)-75/1: BRANCHING FRACTIONS**
Round 1 Interrogatory Response is satisfactory.
- 76. INTERROGATORY CR R313-25-7(10)-76/1: QUALITY ASSURANCE PROJECT PLAN SIGNATURE PAGE**
Round 1 Interrogatory Response is satisfactory.
- 77. INTERROGATORY CR R313-25-7(10)-77/1: QUALITY ASSURANCE PROJECT PLAN PAGE NUMBERING**
Round 1 Interrogatory Response is satisfactory.
- 78. INTERROGATORY CR R313-25-7(10)-78/2: GOLDSIM MODEL CALIBRATION**
A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.
- 79. INTERROGATORY CR R313-25-7(10)-79/1: CRITICAL TASKS AND SCHEDULE**
Round 1 Interrogatory Response is satisfactory.
- 80. INTERROGATORY CR R313-25-7(10)-80/2: TESTING OF GOLDSIM ABSTRACTIONS**
A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

81. INTERROGATORY CR R313-25-7(2) AND 7(6)-81/2: COMPARISON OF DISPOSAL CELL DESIGNS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

82. INTERROGATORY CR R313-25-20-82/2: LIMITATION ON INADVERTENT INTRUDER SCENARIOS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

83. INTERROGATORY CR R313-25-20-83/2: INTRUDER-DRILLER AND NATURAL RESOURCE EXPLORATION SCENARIOS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

84. INTERROGATORY CR R313-25-7(6)-84/3: BELOW-GRADE DISPOSAL OF DU

ES contends that there is no requirement for an intruder barrier, let alone one that will last for 10,000 years. The latter is, in fact, not required. However, intruder barriers, coupled with natural soil and groundwater conditions, must be such so as to prevent doses to the general public above standards over a 10,000-year period, based on UAC R313-25-9(5)(a).

Barriers for wastes do degrade over time. Concrete, for example, may only last decades to centuries. Yet some radionuclides last much longer than concrete. For example, Tc-99 has a half-life of over 200,000 years. Defense against undue radioactive exposure to inadvertent intruders and other members of the general public over the long-term future may involve such factors as design of embankments and selection of surrounding site hydrogeological conditions, which may be more important in the long run than specific containers used as intruder barriers.

DU and associated waste as proposed for disposal in the Federal Cell contain radionuclides that will increase in concentration over time, ultimately even beyond Class B and C limits. This was not considered when NRC devised the Draft Environmental Impact Statement for 10 CFR Part 61, which created the radioactive waste classification system over 30 years ago. Rather than provide definitive statements as to whether DU waste can be disposed of, NRC has left this issue up to individual states to decide. Therefore, with this unanalyzed

condition at hand, it becomes important for the State of Utah to pay close scrutiny to whether or not disposal of blended and processed waste under the cover system proposed may pose any hazards that need to be addressed. Development of a rigorous PA, supported fully by available scientific and engineering knowledge, is therefore required.

ES errs in assuming that regulations do not require that Class A waste be disposed of with intruder barriers. UAC R313-25-8(6) specifies that minimum requirements for disposal of radioactive waste include designs for types of intruder barriers that the Licensee will be constructing. The definition of intruder barrier is given in UAC R313-25-2:

“Intruder barrier” means a sufficient depth of cover over the waste that inhibits contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in R313-25, or engineered structures that provide equivalent protection to the inadvertent intruder.

The DRC staff does not find adequate justification by ES that a minimum of 4.5 feet of cover (as proposed in the PA) above the temporary cover provides “a sufficient depth of cover over the waste that inhibits contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in R313-25.” Greater depth of cover at the embankment than currently proposed is needed in order to meet site-specific performance objectives, including prevention of excessive radioactive doses to inadvertent intruders and other members of the general public.

EnergySolutions’ Response: Intruder barriers, by definition, are designed to protect the inadvertent individual from directly intrusion into waste. However, NRC finds it inappropriate to connect such intrusion to project doses to members of the general public,

“Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity offsite [that may result in subsequent exposure to members of the general public].”
(NUREG-1573, pg. 3-11).

The Division has erroneously claimed that the 4.5 feet of evapotranspirative cover above the temporary cover provides insufficient depth of cover over the waste to inhibit contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in R313-25. The Division further claims, without technical justification, that

“greater depth of cover at the embankment than currently proposed is needed in order to meet site-specific performance objectives, including prevention of excessive radioactive doses to inadvertent intruders and other members of the general public.”

However, since EnergySolutions has focused this Performance Assessment on their commitment to limit disposal of Depleted Uranium below-grade, a significant defense-in-depth is offered by the engineered cover of over 20 meters in thickness (including any degradation that may occur over time – as modeled in version 1.2 of the Model) and the height of the Federal Cell (further discouraging inadvertent excavation in pursuit of sands and clays). As such, the Performance Assessment in fact does successfully demonstrate that the defense-in-depth of the cell design, the natural soil, and groundwater conditions protect the general public within the applicable Compliance Period (even with any degradation during the Compliance Period).

Furthermore, the concentration limits in UAC R313-15-1009 apply to classification at the time of disposal. While one of the stated purposes of the Performance Assessment is to evaluate the long-term implications of increasing concentration of U-238 daughter products, the claim that ultimately classification will exceed Class B and C limits is not applicable at some arbitrary future time. Since, in support of its license UT2300249, EnergySolutions demonstrated (with the exception of three highly mobile radionuclides), it can safely dispose of wastes up to the Class A limit, continued disposal of depleted uranium (even in the Federal Cell configuration) is not an unanalyzed condition.

See also the Round 2 Response to Interrogatories CR R313-25-8(4)(B)-07/2:APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS (Appendix D).

85. INTERROGATORY CR R313-25-8(4)(A)-85/1: UNCERTAINTY DISTRIBUTIONS ASSIGNED TO DOSE CONVERSION FACTORS

Round 1 Interrogatory Response is satisfactory.

86. INTERROGATORY CR R313-25-8(5)(A)-86/3: CONSEQUENCES OF SEDIMENTATION ON DISPOSAL CELL

In its responses to Round 2 Interrogatories (EnergySolutions 2014), ES stated that with “the current disposal configuration placing all depleted uranium waste below grade, the dispersal mechanisms previously considered in the Deep Time component of version 1.0 of the Model are no longer applicable.” This statement only strengthens the argument for evaluating additional pathways. For example, a lake removes the entire embankment but leaves the below-grade DU in place. Although some sediment would cover the DU, it would not be as thick or as

robust as the embankment. Thus, an individual who stands on the sediment directly above the DU would be exposed at a much higher level than an individual who stands on top of the embankment.

EnergySolutions' Response: The GoldSim model can be adjusted to consider a case for which none of the below grade waste is dispersed. This is more reasonable than dispersing the below grade material. Version 1.2 of the Model disperses the disposal mound completely upon the return of an intermediate (or large) lake. This creates some depth or thickness of material above grade that ranges from 0-1m, so the below grade waste is not fully exposed. However, the “cover” might be quite thin under this scenario. Note that the model is not currently set up to properly handle transport of the below grade uranium towards the surface once a lake returns and the water table is at grade or higher.

This approach reduces some of the conservatism in the Deep Time model. That is, it removes the conservative assumption that the activity of contaminants in the total waste column (from cap through to the top of the groundwater) is dispersed and used to estimate lake sediment activity concentrations. A more realistic assumption is that the above-grade mass of the embankment is used to estimate lake sediment activity concentrations.

To implement this new assumption in the model, the following changes were made to version 1.2 of the Clive DU PA Model. Note that to simplify the changes made, only the Top Slope is considered for modification.

In \DeepTimeScenarios, the element ActivitySediment_VolConc needs to use a new element that sums the waste concentrations that are above grade instead of using TotalWasteActivity.

1. In \Disposal\ClassASouthCell\TopSlope\WasteLayers, create a summation element called “Waste_AboveGrade_TS” that sums all the waste layers above and including Waste_22.
2. In \Disposal\ClassASouthCell\CAS_Results, create a summation element called “TotalCttAboveGrade” that includes the TopSlope.Cap_TotalMass_TS and the element just created, Waste_AboveGrade_TS.
3. In \Disposal\ClassASouthCell\CAS_Results, create an expression element called “AboveGradeActivity” that converts the TotalCttAboveGrade mass to activity by multiplying the TotalCttAboveGrade by the Species.Specific_Activity.

4. In \DeepTimeScenarios, change the element ActivitySediment_VolConc by replacing “TotalWasteActivity_CAS” with “ActivityAboveGrade.”

When version 1.2 of the Model is run in deterministic mode using mean values from the input distributions, the concentration of U-238 in sediment (ActivitySediment_MassConc) at the time of the first lake occurring (50,000 years) is about 0.003 Bq/g. When the original version 1.2 model is run in deterministic mode using input mean values, the concentration of U-238 in sediment at the time of the first lake is about 40 Bq/g.

The lake sediment concentrations are much lower when the waste is below grade. There are further considerations. The revisions to version 1.2 of the Model does not address migration of U-238 from below grade to other locations (solubility, diffusion, etc.). It also does not account for the aeolian deposition that is occurring now. The deep time model was intended to be a simple screening model to provide some insight into what might happen in the long-distant future. However, it was built with some very conservative inputs regarding sediment mixing, dispersion in a water column that is only on top of the dispersed mound, and a lack of aeolian deposition in the interim. With the waste placed below grade, the concentrations are quite small.

Consequently, EnergySolutions disagrees with the premise of the V1.2 Critique that:

“This statement only strengthens the argument for evaluating additional pathways. For example, a lake removes the entire embankment but leaves the below-grade DU in place. Although some sediment would cover the DU, it would not be as thick or as robust as the embankment. Thus, an individual who stands on the sediment directly above the DU would be exposed at a much higher level than an individual who stands on top of the embankment.”

The conceptual model put forward at this time by EnergySolutions suggests aeolian deposition prior to lake return that will both stabilize the disposal site to some extent, and will provide cover for the below grade disposal of the DU. This is followed by the return of a lake that disperses the above ground mound (above the aeolian deposits), then transports the U-238 and progeny into the lake, which dilutes throughout much of the lake and then settles out as the lake recedes. Aeolian deposition will probably cover the existing sediments (rather than mixing with them completely as is currently modeled). This will result in considerably smaller concentrations in deep time than currently presented in current PA model, with the potential to be as low as, or even lower than, background concentrations.

Note the in recent correspondence with Dr. Charles (Jack) Oviatt, the pit wall has been re-interpreted. Originally Dr. Oviatt interpreted the top 70 cm as reworked Gilbert Lake materials but now does not believe that the Gilbert Lake reached Clive, and, consequently, that the top 70 cm are probably aeolian deposits (Oviatt, C., April 26, 2014, personal communication). If this is the case, then aeolian deposition can play a more important role in site stability and site protection.

87. INTERROGATORY CR R315-101-5.3(6)-87/2: ORAL TOXICITY PARAMETERS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

88. INTERROGATORY CR R313-25-19-88/1: COLLECTIVE DOSE AND ALARA

Round 1 Interrogatory Response is satisfactory.

89. INTERROGATORY CR R313-25-7(9)-89/3: CONTAMINATION LEVELS IN DUF6

After reviewing additional literature, ES did not make any changes in the initial approach to quantifying contamination in the GDP DU. Rather, ES chose to continue to use data from SRS DUO3 as a surrogate for contaminant species such as technetium, neptunium, and plutonium in the GDP DU. As outlined in this interrogatory, this approach appears to be non-conservative in the case of Tc-99. Using the SRS data as a surrogate for the GDP DU, it can be estimated that the total mass of Tc-99 is 25.7 kg. Using data from Hightower et al. (2000), the mass of Tc-99 is estimated to be 95.6 kg.

ES needs to demonstrate that a nearly four-fold increase in Tc-99 concentration will have no significant impact on compliance with the GWPLs or groundwater pathway doses to at least 10,000 years.

EnergySolutions' Response: A comparison is provided in the Interrogatory bases of information in Hightower et al. (2000) to information in the Clive DU PA Model v1.2:

“Using the SRS data as a surrogate for the GDP DU, it can be estimated that the total mass of Tc-99 is 25.7 kg. Using data from Hightower et al. (2000), the mass of Tc-99 is estimated to be 95.6 kg.”

However, the value of 25.7 kg calculated in the Interrogatory Basis is based on the central tendency of the distribution used in version 1.2 of the Model, where the value of 95.6 kg taken from Hightower et al. (2000) is an upper bound value (see, for example, Table 6.6 of Hightower et al. (2000)). It is more appropriate to compare central tendency values from both, but Hightower et al. (2000) does not provide any information on the uncertainty associated with its bounding values, and does not provide an estimate of central tendency. Comparing upper bound values is always fraught with difficulty, because the basis for such values is never fully clear (i.e., upper bound of what)? This could be an estimated maximum, but in the case of concentration this is not well defined (expect in the sense of one million parts per million, which is not useful), or it could represent a percentile of a data distribution, or upper confidence bound of a distribution of the mean. The question of whether it represents a percentile of data or confidence bound of a mean can be thought of as a scaling issue.

Table A (below) shows a comparison of central tendency values for the three radionuclides of interest, and Table B shows a comparison of “upper bound values”. The central tendency values calculated by the reviewers are close to the median values in version 1.2 of the Clive DU PA Model. The “*upper bound value*” for 99Tc is slightly greater in Hightower et al. (2000) than in the Model.

Table B. Comparison of interrogatory and Clive DU PA Model central tendency estimates of the total mass of selected contaminants in the inventory of DUF₆ from the GDPs.

result	interrogatory estimate (text before Table 1)	Clive DU PA Model estimate
⁹⁹ Tc in DUF6 inventory	25,700 g	30,400 g
²³⁷ Np in DUF6 inventory	152 g	173 g
total Pu in DUF6 inventory	0.4 g	0.49 g

Table C. Comparison of interrogatory and Clive DU PA Model upper bound estimates of the total mass of selected contaminants in the inventory of DUF₆ from the GDPs.

result	upper bound from Hightower et al. (2000) (this Interrog. Table 3)	upper bound from the Clive DU PA Model (10,000 realiz'ns)
⁹⁹ Tc in DUF6 inventory	95,650 g	75,424 g
²³⁷ Np in DUF6 inventory	12,100 g	292 g
total Pu in DUF6 inventory	24.6 g	0.67 g

The dominant portion of the ^{99}Tc inventory comes from the cylinder heels. There is little question, therefore about the contamination of the DUF6 itself, which, as Hightower et al. (2000) indicate, is perhaps not contaminated at all. Focusing on the heel contamination, the basis for the upper bound values in Hightower is not clear. The upper bound values from the Model represent the maximum simulated value from 10,000 simulations. This is based on an upper bound of the mean concentration of ^{99}Tc . It seems likely that the upper bound value in Hightower is based instead on process knowledge, and it is not clear what it represents. Hightower (2000) does not provide the data needed for statistical estimation of the concentrations or masses of contaminants in the heels, and the goal of Hightower was worker safety and compliance rather than needs of radioactive waste disposal, so the data and information are not always directly compatible with the needs of performance assessment.

The distribution used in version 1.2 of the Clive DU PA Model is considered sufficient considering how close the “*upper bound values*” are, and that the basis for the value in Hightower is unclear. In addition, the amount of information in Hightower in this regard is very limited – for example, it is not possible to reproduce the numbers contained in Hightower. The distribution used in version 1.2 of the DU PA Model is based on actual data, admittedly for the SRS DU waste. Since both waste streams (SRS and the GDP waste) are produced from similar processes, it is not clear why the distribution obtained from the SRS DU sampling and analysis is not reasonable. Also, the distribution developed from the data available from the SRS sampling and analysis that has been performed is not very different than the upper bound values provided in Hightower.

In addition, the SRS DU waste represents a final waste form – DUO_3 , with its contaminants. The data provided in Hightower represent DU prior to processing as waste. It is not clear what the deconversion process will do, but to the extent that any contaminant material is contained in or entrained with the DUF6 itself, this material will probably be removed to some extent from the DU during deconversion, similarly to the way in which these contaminants have plated out during gaseous diffusion. A likely difference is that the GDP DU waste will be in the form of DU_3O_8 , but it is not clear what difference this would make. Ultimately, better information might be obtained if the GDP cylinder heels are sampled. Until that time, the SRS data provide the best surrogate information available.

Note also that the order in which the GDP cylinders are processed is also likely to be important. The clean cylinders will be deconverted first to avoid, to the extent possible, contaminating the deconversion facilities. The small fraction of contaminated cylinders will be processed last. It is not clear yet exactly how the heels will be managed, but indications are that they will remain in the cylinders. It

is possible, for a couple of reasons, that contaminated GDP DU waste will not be received at Clive, either because the heels could be cleaned from the cylinders (thereby creating a different waste stream for the deconversion plants) or because of volume limitations of the Clive facility for accepting DU waste below grade.

Version 1.2 of the Clive DU PA Model models the GDP DU waste conservatively, by using the SRS contaminant concentration distributions. The factor of 4 indicated in the interrogatory is almost accommodated with the current model when comparing “*upper bound values*” from the Model and those from Hightower, and seems conservative given the distribution of the input is scaled to the long term effects of the inventory. Version 1.2 of the DU PA Model is built probabilistically so that uncertainty can be properly managed. The benefits of a probabilistic model have been described in the main report, white papers and interrogatory responses. Probabilistic modeling is also, at the very least, preferred by NRC, and has been agreed upon as the most appropriate approach to modeling the Clive disposal system for disposal of DU.

Waste management note: Washing the cylinders may remove the heels from those cylinders, but it does not eliminate them. The heels in washwater would be yet another waste stream that would require disposal. It is important to recognize that if it can be shown that allowing the heels to remain in the cylinders does not cause an unacceptable increase in risk, the practice is sound as it solves at once the entire waste management problem that is the DUF6 cylinders.

90. INTERROGATORY CR R313-25-7(1-2)-90/2: CALIBRATION OF INFILTRATION RATES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

91. INTERROGATORY CR R313-25-7(2)-91/1: DESIGN CRITERIA FOR INFILTRATION

Round 1 Interrogatory Response is satisfactory.

92. INTERROGATORY CR R313-25-20-92/2: INADVERTENT INTRUDER DOSE STANDARD AND SCENARIOS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

93. INTERROGATORY CR R313-25-22-93/2: STABILITY OF DISPOSAL SITE AFTER CLOSURE

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

94. INTERROGATORY CR R313-25-3(8)-94/1: ULTIMATE SITE OWNER

Round 1 Interrogatory Response is satisfactory.

95. INTERROGATORY CR R313-25-8(4)(A)-95/1: ESTIMATION OF I-129 CONCENTRATIONS

Round 1 Interrogatory Response is satisfactory.

96. INTERROGATORY CR R313-25-8(4)(A)-96/3: CURRENT AND FUTURE POTABILITY OF WATER

Pumping of groundwater from the deeper aquifer with subsequent reverse osmosis treatment also takes place at the Clean Harbors – Aragonite facility, a commercial hazardous waste incinerator owned by Clean Harbors located about 4 miles east of Clive, where two deep wells exist (between 700 and 800 feet bgs) (Earthfax, 1999). Both of these deep wells, located directly to the northeast of the Aragonite facility, are currently being pumped and put through a reverse osmosis system to supply groundwater to meet industrial needs and to help meet the sanitation requirements of approximately 100 employees. Safe yield pumping rates for the two wells are listed in the State of Utah Public Water System Inventory Report (UTAH23067) as 138 gpm and 25 gpm. Tank sizes are 572,000 gallons and 22,500 gallons. According to Clean Harbors – Aragonite Environmental Manager Lonnie Brown (personal communication with DRC Staff member David Edwards, January 2014), employees at the facility formerly consumed the potable reverse osmosis-treated groundwater. The State of Utah water right (16-757) also lists the use of the groundwater for culinary purposes for 150 employees. Therefore, the PA should consider and model a drinking water scenario in an industrial setting using water from a deep well in the confined aquifer outside the facility’s boundaries. This is needed to satisfy UAC R313-25-20, which requires a licensee to show that “No greater than 0.04 mSv (0.004 rem) committed effective dose equivalent or total effective dose equivalent to any member of the public shall come from groundwater.”

There is neither statutory nor regulatory basis for excluding groundwater at a LLW waste disposal facility from consideration as a potential exposure pathway simply because the groundwater, like most other water used for public drinking supply, needs to be treated before it is rendered potable. Anderson and Sloan (2001) state that, of drinking water systems in the United States, more than 98%

use disinfection via chlorine-based compounds for treatment. Other forms of treatment are also used, depending on need. Brackish or saline groundwater, if not contaminated by radionuclides (some of which cannot be fully removed via reverse osmosis), can be treated via reverse osmosis to greatly reduce TDS and therefore be made drinkable. In fact, as noted above, brackish or saline groundwater in the region near Clive has been regularly treated and used for a variety of uses at several regional facilities, and one of these uses has been consumption.

EnergySolutions' Response: See the Round 2 Response to Interrogatory CR R313-25-8(4)(A)-96/2: CURRENT AND FUTURE POTABILITY OF WATER (Appendix D).

97. INTERROGATORY CR R313-25-8(4)(A)-97/3: NEED FOR POTABLE AND/OR INDUSTRIAL WATER

ES fails to discuss groundwater head, hydraulic conductivity, hydraulic gradient, or groundwater water quality in the higher yielding deeper gravel zones of the confined aquifer at the site (e.g., at 450–700 feet). These deeper gravel zones of the confined aquifer are clearly observable in well logs for the Broken Arrow wellbore drilled in Section 29, just to the north of the Clive facility, and the two Clean Harbors – Aragonite groundwater production wells, located 4 miles to the east, which produce from similar deeper gravel zones. The gravel zones in both the Broken Arrow Well and the two Clean Harbors – Aragonite groundwater production wells appear to have sediment particles similar in size, and they may originate from similar higher-elevation sources. Furthermore, on April 11, 2005, ES submitted a modeling report discussing two proposed deep water wells on the site. The accompanying letter from Dan Shrum to Dane Finerfrock, also dated April 11, 2005 (Shrum, 2005), referred to modeling of a requested “production well screened from 550 to 600 feet below ground surface (bgs), pumped at 200 gallons per minute, 24 hours per day, 4 months per year...” on site. While this particular well was never drilled, ES’ request supports the concept that an inadvertent intruder might consider drilling a deep well on site and pumping it at considerably higher rates than the shallow aquifer is capable of yielding. It is important for ES to study the hydrogeology of the deeper gravel zones and to model potential hydraulic connections between these when the deeper gravel zones are pumped at relatively high rates.

As discussed under Interrogatory CR R313-25-8(4)(a)-96/3: Current and Future Potability of Water, ES fails to mention a nearby well that has been used for dust suppression and equipment decontamination.

Interrogatories CR R313-25-8(5)(a)-38/3: Figures 5 and 11 in FRV1 and CR R313-25-8(4)(a)-96/3 further show that groundwater from the deeper parts of the

confined aquifer has been used historically for drinking at the Clean Harbors – Aragonite incinerator facility. Also, groundwater treated by reverse osmosis is currently used by Delle Auto Truck Stop for drinking purposes. If the shallow aquifer becomes contaminated, then the deeper aquifer, which contains groundwater with potentially beneficial uses for citizens of the state, may become contaminated by groundwater from the shallow, unconfined aquifer after the deeper portions of the confined aquifer are pumped for a sufficiently long time. ES must therefore investigate the deeper portions of the confined aquifer and the drinking of groundwater from the deeper portions of the confined aquifer as an exposure pathway by which receptors might receive radioactive doses. It is assumed that groundwater obtained from the deeper confined aquifer could become contaminated from pollution in the overlying water table aquifer and cause exposure of surface workers. Likewise, future treatment of the deep confined aquifer could render this water beneficial for other industrial applications and drinking water. These possibilities need to be examined in the PA.

EnergySolutions' Response: See the Round 2 Response to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS.

98. INTERROGATORY CR R313-25-7(1)-98/1: MONTHLY TEMPERATURES

Round 1 Interrogatory Response is satisfactory.

99. INTERROGATORY CR R313-25-7(1)-99/1: EVAPORATION

Round 1 Interrogatory Response is satisfactory.

100. INTERROGATORY CR R313-25-7(1)-100/2: GROUNDWATER RECHARGE FROM PRECIPITATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

101. INTERROGATORY CR R313-25-7(1)-101/2: NATURE OF UNITS 1 AND 2

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

102. INTERROGATORY CR R313-25-7-102/1: SEISMIC ACTIVITY

Round 1 Interrogatory Response is satisfactory.

103. INTERROGATORY CR R313-25-7-103/2: HISTORICAL FLOODING

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

104. INTERROGATORY CR R313-25-7(2)-104/3: INFILTRATION IN THE PRESENCE OF RIP RAP OR NATURAL ROCK

A number of researchers have shown that the presence of crushed rock, gravel, or other coarse granular or blocky material (e.g., riprap) greatly reduces infiltration compared to the absence of these materials (Hadas and Hillel, 1972; Groenevelt et al., 1989; Reith and Caldwell, 1990; Kemper et al., 1994; Diaz et al., 2005; Albright et al., 2010; and Neptune and Company, 2012). Hadas and Hillel (1972) report that “soil layering reduces evaporation, especially when a coarse-textured soil overlies a fine-textured soil.” Reductions in evaporation rates of 80 to 90% for relatively thin layers of some of these materials are referenced in some of these studies. Groenevelt et al. (1989) show that the addition of larger-diameter granular inorganic material to a soil surface substantially reduced evaporation from the soil. With the use of sand, for example, cumulative evaporation from soil, after 38 days, was reduced approximately 83%. Use of scoria rock was almost as effective in reducing evaporation. Reith and Caldwell (1990) claim that a rock cover reduces evaporation from a cover system and makes more water present within the cover system. Kemper et al. (1994) show that 5 cm of gravel placed on top of soil significantly reduced evaporation and increased retention of water in the subsurface to about 80–85% of total precipitation. Diaz et al. (2005) show that reduction in evaporation was related to the thickness of volcanic tephra rock on the ground surface. A 2-cm layer, a 5-cm layer, and a 10-cm layer of tephra rock reduced soil evaporation after 31 days by 52%, 83%, and 92%, respectively. Albright et al. (2010) explain that “gravel mulches can also form a ‘reverse’ capillary barrier effect that limits surface evaporation, which may adversely affect the cover water balance....”

The DRC staff does not consider the remaining evaporation rates after coarse materials have reduced evaporation rates to be significant, at least with respect to evaporation rates in the absence of these materials. The presence of any riprap on the cover system should be accounted for in modeling by an appropriate decrease in evaporation rates, possibly even a rate of zero. ES should justify the rate chosen. ES should also explain and justify how this design will mitigate future pluvial lake flooding at Clive. We look forward to reviewing the revised report.

EnergySolutions' Response: The infiltration and evaporation impact of the 15% gravel addition to the Federal Cell's top slope cover surface layer and 50% gravel addition to the Federal Cell's side slope cover surface layer has been modeled in version 1.2 of the Model. While inapplicable to EnergySolutions' proposed Federal Cell, it is academically interesting (even absent any technical justification) that,

“the DRC staff does not consider the remaining evaporation rates after coarse materials have reduced evaporation rates to be significant, at least with respect to evaporation rates in the absence of these materials.”

However, the presence of gravel in the cover system has been accounted in the model. Furthermore, EnergySolutions reminds the Division that the gravel admixture proposed for the evapotranspirative cover surface layer is not rip-rap.

See the Round 2 Response to Interrogatory CR R313-25-7(2)-104/2: INFILTRATION IN THE PRESENCE OF RIP RAP OR NATURAL ROCK (Appendix D).

105. INTERROGATORY CR R313-25-8(4)(A)-105/3: HUMAN USE OF GROUNDWATER

Locations for groundwater wells at industrial sites are often based on considerations of property ownership and proximity to planned operations rather than on a determination of the optimal location for a well within a large basin, such as in the West Desert. ES itself at one point drilled a borehole for a water well before abandoning the project due to concerns about additional compliance requirements (i.e., the Broken Arrow Well in Section 29; see Utah Water Right 16-816). On another occasion, ES presented a proposal to drill two production wells at the site to provide groundwater for operational use (Whetstone Associates, 2005).

EnergySolutions' Response: See the Round 2 Responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS (Appendix D).

106. INTERROGATORY CR R313-25-8(4)(A)-106/3: DESALINATION POTENTIAL

As noted for other interrogatories, desalination is currently accomplished in the vicinity of Clive to produce potable water. It is expected that Utah will be someday forced to draw on water of lesser quality, such as West Desert groundwater, to service future generations. With regard to the comprehensive well completion details requested above, additional on-site and near-site information

that will be needed for investigating the hydrogeology of the deeper gravel zones of the confined aquifer will be hydraulic heads, hydraulic conductivities, hydraulic gradients, and water-quality.

EnergySolutions' Response: While the Division may find it an interesting academic exercise to speculate that Utah will

“someday be forced to draw on water of lesser quality, such as West Desert groundwater, to service future generation,”

such arbitrary supposition is contrary to NRC guidance for performance assessment. While one could speculate on the perceived inevitability of groundwater treatment in the West Desert, one could as easily speculate on the “inevitability” of overpopulation resulting in war over resources or pandemic illnesses resulting from illegal immigration or a conceivable population crash. NRC correctly cautions against such speculation. See the Round 2 Responses to Interrogatory CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS (Appendix D).

107. INTERROGATORY CR R313-25-7(1)-107/2: PREDOMINANT VEGETATION AT THE CLIVE SITE

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

108. INTERROGATORY CR R313-25-8(4)(A)-108/2: BIOINTRUSION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

109. INTERROGATORY CR R313-25-7(2)-109/2: GEOCHEMICAL DEGRADATION OF RIP RAP

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

110. INTERROGATORY CR R313-25-8(4)(A)-110/1: RADON TRANSFER FROM WATER

Round 1 Interrogatory Response is satisfactory.

111. INTERROGATORY CR R313-25-7-111/2: LIKELIHOOD OF LAVA DAM FORMATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

112. INTERROGATORY CR R313-25-8(4)(A)-112/2: HYDRAULIC CONDUCTIVITY

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

113. INTERROGATORY CR R313-25-8(5)(A)-113/2: PLACEMENT OF BULK LOW-LEVEL WASTE AMONG DU CANISTERS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

114. INTERROGATORY CR R313-25-19-114/3: ELEVATED CONCENTRATIONS OF TC-99

In Table 2 of FRV1.2, page 60, the Tc-99 concentration exceeds the 500-year GWPL at the 95th percentile, even with the ET cover. Unless ES provides information on the scenarios involving leakage of contamination into the lower aquifer and extraction of that water for beneficial uses over 10,000 years, the efficacy of the ET cover with regard to demonstrating compliance with R313-25-20 over 10,000 years cannot be determined.

EnergySolutions' Response: See the Round 2 Response to Interrogatory CR R313-25-19-114/3: ELEVATED CONCENTRATIONS OF TC-99, (Appendix D).

115. INTERROGATORY CR R315-101-5.3(6)-115/1: URANIUM TOXICITY REFERENCE DOSES

Round 1 Interrogatory Response is satisfactory.

116. INTERROGATORY CR R313-25-8(4)(A)-116/1: CS-137 DECAY

Round 1 Interrogatory Response is satisfactory.

117. INTERROGATORY CR R313-25-8(5)(A)-117/2: GROUNDWATER PROTECTION LIMIT FOR TC-99

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

118. INTERROGATORY CR R313-25-7(10)-118/1: GOLDSIM RESULTS

Round 1 Interrogatory Response is satisfactory.

119. INTERROGATORY CR R313-25-8(4)(A)-119/1: RESUSPENSION AND AIRBORNE PATHWAYS

Round 1 Interrogatory Response is satisfactory.

120. INTERROGATORY CR R313-25-8(4)(A)-120/3: GULLIES AND RADON

FRV1.2 Section 7.1, page 83, confirms that the “impact of gullies has not been fully developed in terms of their effect on biotic activity, radon transport, or infiltration.” Therefore, this interrogatory remains open until the impacts of gully formation on radon transport and infiltration have been determined.

EnergySolutions’ Response: Please see the second paragraph of the Round 3 Response for INTERROGATORY CR R313-25-7(2)-70/3: GULLY SCREENING MODEL which discusses the influence of gully formation on infiltration and radon transport:

“The influence of gully formation on infiltration and radon transport is negligible given the current below grade disposal design. In addition, analysis of the projected SIBERIA modeling results indicate that only a small fraction of the cover would have gullies extending through the surface and evaporative zone layers to the top of the frost protection layer. Figure 2 from Appendix 10 copied below is a plot of 5 realizations of the percent of the total cover area projected to 10,000 years containing gullies of a given depth. Gullies as deep as 1 cm are found on 16 percent of the cover surface on average while another 60 percent of the cover has gullies as deep as 15 cm. Gullies ranging from 15 cm to 30 cm are found on 11 percent of the cover and only 13 percent of the cover has gullies extending to or deeper than the top of the frost protection layer.”

121. INTERROGATORY CR R313-25-19-121/2: GULLIES AND RECEPTOR LOCATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

122. INTERROGATORY CR R313-25-8(4)(D)-122/1: SIZE OF PLUVIAL LAKES

Round 1 Interrogatory Response is satisfactory.

123. INTERROGATORY CR R313-25-8(4)(D)-123/2: TIMING OF LAKE CYCLES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

124. INTERROGATORY CR R313-25-8(4)(D)-124/1: MECHANISMS FOR PLUVIAL LAKE FORMATION

Round 1 Interrogatory Response is satisfactory.

125. INTERROGATORY CR R313-25-8(4)(D)-125/1: DEEP LAKE CYCLES

Round 1 Interrogatory Response is satisfactory.

126. INTERROGATORY CR R313-25-8(4)(D)-126/2: SHALLOW LAKE CYCLES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

127. INTERROGATORY CR R313-25-8(4)(D)-127/1: CARBONATE SEDIMENTATION

Round 1 Interrogatory Response is satisfactory.

128. INTERROGATORY CR R313-25-8(4)(D)-128/2: LAKE SEDIMENTATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

129. INTERROGATORY CR R313-25-8(4)(D)-129/2: LAKE EROSION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

130. INTERROGATORY CR R313-25-8(4)(D)-130/1: LAKE GEOCHEMISTRY

Round 1 Interrogatory Response is satisfactory.

131. INTERROGATORY CR R313-25-8(4)(D)-131/2: POTENTIAL WAVE ENERGY

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

132. INTERROGATORY CR R313-25-8(4)(D)-132/2: SEDIMENTATION MODEL

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

133. INTERROGATORY CR R313-25-8(4)(D)-133/1: CALCULATIONS OF RADIOACTIVITY IN WATER AND SEDIMENT

Round 1 Interrogatory Response is satisfactory.

134. INTERROGATORY CR R313-25-8(4)(D)-134/3: FUTURE LAKE LEVEL ELEVATIONS

Sections 3.3 and 3.4 of the Deep Time Assessment report (Appendix 13 to FRV1.2) have been revised to clarify the distinction between shallow and intermediate lake cycles. A statement has also been added to page 14 indicating that the deep time assessment conservatively assumes that all waste is precipitated with and incorporated into local sediments during lake recession. Therefore, this interrogatory is closed. Note, however, that there are two 1994 Oviatt references; they should be differentiated as 1994a and 1994b.

EnergySolutions' Response: The Oviatt 1994 references cited in Sections 3.3 and 3.4 of Appendix 13 of Appendix A have been differentiated.

135. INTERROGATORY CR R313-25-19-135/3: EXPOSURE TO GROUNDWATER

Groundwater from deeper portions of the confined aquifer, or other aquifers, has, after treatment, historically been used in the region for drinking. Furthermore, yields from the deeper portions of the confined aquifer may be moderately high. As previously described, ES formerly proposed to drill water wells in the deeper portions of the confined aquifer on site. Shrum (2005) refers to modeling on the site of “a production well screened from 550 to 600 feet below ground surface (bgs), pumped at 200 gallons per minute, 24 hours per day, 4 months per year....”

EnergySolutions’ Response: See the Round 2 Responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS (Appendix D).

136. INTERROGATORY CR R313-25-7(1)-136/2: IRON (HYDRO)OXIDE FORMATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

137. INTERROGATORY CR R313-25-7(1)-137/2: TOTAL DISSOLVED CARBONATE CONCENTRATIONS AND OTHER GEOCHEMICAL DATA

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

138. INTERROGATORY CR R313-25-26(1)-138/3: MONITORING WELL COMPLETION ZONES

The text was not changed in Section 2.2, page 8, of the revised Geochemical Modeling report (Appendix 6 to FRV1.2). The original wording (i.e., without the substitution of “the shallow aquifer” for “this aquifer”) remains.

EnergySolutions’ Response: The text in Appendix 6 - Geochemical Modeling of Appendix A has been corrected to the following:

“The Clive Facility has a large number of monitoring wells with completion zones in the shallow aquifer and monitoring data are currently collected from these wells on at least an annual basis.”

139. INTERROGATORY CR R313-25-7(1)-139/2: ION CHARGE BALANCE

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

140. INTERROGATORY CR R313-25-7(1)-140/2: DETERMINATION OF KD VALUES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

141. INTERROGATORY CR R313-25-7(1)-141/2: PH AND KD VALUES AND SERNE (2007)

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

142. INTERROGATORY CR R313-25-7(1)-142/2: REFERENCES FOR KD DISCUSSION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

143. INTERROGATORY CR R313-25-7(1)-143/2: NEPTUNIUM SPECIATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

144. INTERROGATORY CR R313-25-7(1)-144/2: PLUTONIUM SPECIATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

145. INTERROGATORY CR R313-25-7(1)-145/2: SORPTION REVERSIBILITY AND GLOVER ET AL. (1976) DATASET

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

146. INTERROGATORY CR R313-25-7(1)-146/2: DETERMINATION OF KD VALUES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

147. INTERROGATORY CR R313-25-7(1)-147/2: DETERMINATION OF KD VALUE FOR URANIUM

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

148. INTERROGATORY CR R313-25-7(1)-148/2: INFLUENCE OF CARBONATE ON URANIUM SPECIATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

149. INTERROGATORY CR R313-25-7(1)-149/2: AMERICIUM SORPTION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

150. INTERROGATORY CR R313-25-7(2)-150/3: PLANT GROWTH AND COVER PERFORMANCE

Deep rooting is potentially problematic at the Federal Cell. It has not been fully evaluated yet. It can be very important relative to evaluating potential radon-barrier damage, hydraulic conductivity changes, infiltration rates and contaminant transport rates. As stated in Benson (2009), “Roots seek out water in wet fine-grained soils, e.g., clay radon barriers.” Waugh and Smith (1988) indicate that at a DOE LLW site at Burrell, Pennsylvania, the hydraulic conductivity increased by two orders of magnitude at locations where roots penetrated the radon barrier.

EnergySolutions’ Response: With regard to biointrusion by plant roots, please refer to the response to Interrogatory CR R313-25-8(4)(A)-28/3: BIOTURBATION EFFECTS AND CONSEQUENCES. In particular, the following text:

“Site-specific observations of soil disturbance due to natural vegetation and demonstrated practices for minimizing disturbance were documented by SWCA (2013). Multiple soil excavations at the site demonstrated root

growth behavior indicating that roots would tend to accumulate in locations to take advantage of available water rather than penetrate the radon barrier clay. These excavations showed that greasewood tap roots and other biotic activity such as fine roots and tunnels did not extend below the compacted clay layer at 24 inches. Rather, both taproots and fine roots were found to extend laterally along the upper surface of the compacted clay layer, likely making use of any water that is perched above the clay (SWCA, 2013).”

Some of the infiltration model scenarios using HYDRUS-1D include simulations with the radon barrier having high K_s within the range recommended by Benson et al. (2011). Please refer to the response to Interrogatory CR R313-25-8(4)(A)-28/3: BIOTURBATION EFFECTS AND CONSEQUENCES for additional discussion of how infiltration model K_s values are within the ranges provided by Benson et al. (2011).

In addition, as described in the Response to Round 2 Interrogatory CR R313-25-7(2)-150/2: PLANT GROWTH AND COVER PERFORMANCE, version 1.2 of the Clive DU PA is parameterized with deep roots through the waste cover and into the above-grade waste layers. Since DU will only be buried below-grade, plant roots would have to extend more than 50 ft deep in order to penetrate the top DU waste layer. While Greasewood can be a deep-rooting plant, its tap root depths are reported to range from 5 to 20 ft (http://plants.usda.gov/plantguide/pdf/pg_save4.pdf).

Based on the observations of root growth behavior in SWCA (2013), deep taproots are not expected to penetrate the radon barriers which are comprised of compacted clay. If the radon barriers do degrade either due to biointrusion or other processes, and plant roots are able to penetrate through the radon barriers, then this scenario has been modeled in version 1.2 of the Clive DU PA Model.

Therefore, deep taproots are not a dose pathway or problematic at the Federal Cell within the regulatory period.

Furthermore, deep rooting plants within waste covers is not necessarily problematic. The following text is from SWCA (2013, p.23):

“As has been demonstrated at operational ET covers (Waugh et al. 2008), some deep-rooting plant cover is desirable because it increases water release from deep soil layers (Hauser et al. 2001; ITRC 2003). Deeply rooting vegetation stabilizes soils, reduces erosion, and increases water storage in the root zone (Hauser et al. 2001; ITRC 2003). Deep-rooting shrub species currently occupy functioning cover systems at Hanford (big

sagebrush, rabbitbrush; Gee et al. 1997, 2002) and Monticello (big sagebrush, bitterbrush, rabbitbrush; Waugh et al. 2008).”

151. INTERROGATORY CR R313-25-8(4)(A)-151/2: RADON BARRIER ATTENUATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

152. INTERROGATORY CR R313-25-8(5)(A)-152/2: GOLDSIM INPUT PARAMETERS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

153. INTERROGATORY CR R313-25-8(4)(D)-153/2: IMPACT OF PEDOGENIC PROCESS ON THE RADON BARRIER

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

154. INTERROGATORY CR R313-25-8(4)(D)-154/2: USE OF FIELD DATA TO VALIDATE DISPOSAL CELL COVER PERFORMANCE

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

155. INTERROGATORY CR R313-25-8(4)(D)-155/3: COVER PERFORMANCE FOR 10,000 YEARS

As demonstrated in Interrogatory CR R313-25-7(2)-189/3: Modeling Impacts of Changes in Federal Cell Cover-System Soil Hydraulic Conductivity and Alpha Values, the PA does not yet include modeling to show the impacts of degradation over time of the entire cover system within 10 feet of the surface. Degradation will occur within several years for all shallow cover-system soils (see Benson et al., 2011). Therefore, modeling done to date is inadequate because it does not show important changes expected to occur nearly simultaneously (relative to the overall modeling period) in hydraulic conductivity and van Genuchten alpha values for all shallow soils (i.e., those less than 10 feet deep) within the cover system. As such, as of this time the PA does not contain adequate modeling of infiltration at the Federal Cell. Therefore, claims that infiltration will not extend

(at appreciable rates) down to the depth of the radon barrier appear to be groundless. If infiltration does extend down to the radon barriers, then compromise of the radon barrier will have an impact on performance. ES should either demonstrate that these important cover-system changes will not occur (contrary to what is indicated in Benson et al., 2011), or change the model to account for these changes, with an expected consequent increase in predicted infiltration rates.

Another important factor related to cell cover system performance over the long term is freezing. Freezing can cause substantial damage to radon barriers and the soils above them, should sufficiently cold temperatures be reached in the radon barriers. The current PA does not sufficiently account for freezing. As described below, a number of reports and data show actual freezing conditions in Utah occurring, or having occurred, at greater depths than the depth currently proposed in the PA for the top of the Federal Cell upper radon barrier. The PA model needs to account for damage to the radon barriers from frost. Alternatively, the cover system should be re-designed so as to provide for thicker soil layers above the upper radon barrier.

During testing in January 2002 and January 2004, ES measured freezing or close to freezing temperatures using thermocouple temperature probes at the midpoint of the sacrificial soil in the Cover Test Cell, at a depth of about 30 inches (Edwards, 2011; Envirocare, 2005). Currently, the PA proposes the top of the radon barrier to be located at a depth of 30 inches. However, these incidents of freezing noted in the past took place during portions of winter that were not especially cold. Mean monthly low air temperatures at Dugway for January 2002 and January 2004 were, respectively, 15.45° F and 11.35° F (Western Regional Climate Center, 2014). However, in the 56 years between 1951 and 2006, inclusive, there were 13 years (i.e., 23% of the time) in which mean monthly low air temperatures for January dropped to values that were lower, and sometimes much lower, than 11.35° F, the colder of the temperatures for the two referenced reported incidents (Western Regional Climate Center, 2014).

By contrast, the coldest January on record during these 56 years of record is that of 1989, when the mean January low air temperature at Dugway was only 0.39° F. That is nearly 11 degrees colder than in January 2004, so freezing temperatures in the soil in the Cover Test Cell, had it been created and instrumented back then, would likely have gone considerably deeper than the 30 inches in the Cover Test Cell that were measured in January 2004. If so, with the cover system proposed in the PA, freezing temperatures would extend considerably deeper than the top of the upper radon barrier.

Furthermore, there are accounts of frosts of more extreme depth having occurred in Utah. For example, “JANUARY 1–9, 1979 – ‘Bitterly cold arctic air dominated

all of Utah. Due to a lack of snow cover, ground frost permeated the ground to a depth of six feet [72 inches] in many areas” (Adler, et al., 1996). Although this information comes from an almanac rather than a more scientific source, it is posted by the Utah Center for Climate and weather, which appears to be a reasonably reliable source, and it prompts some additional consideration of this issue.

In addition, significant information comes from the Federal Highway Administration (FHWA) (2008), which conducted frost penetration analysis at 41 sites nationwide for its E-FROST research analysis. FHWA used data from two Utah sites in its analysis. For one of these sites, FHWA reported a maximum (worst-case-scenario estimate) frost depth estimate of 2.019 meters (6.54 feet, or 78.5 inches). This is 350% of the value predicted by ES above.

Moreover, the frost penetration equation used for Utah by the Utah Department of Transportation (UDOT) (2012) is:

$$\text{Frost Penetration} = 1.482(\text{Freezing Index})^{0.4911}$$

This equation results in a value of 44.9 inches for 100-year frost penetration depth for Dugway, based on the National Oceanic and Atmospheric Administration (NOAA) air freezing index of 1,037 for a 100-year frost at Dugway, Utah (NOAA, 2012). This value of 44.9 inches is 200% of the value predicted by ES above. It is evident that freezing temperatures may extend deeper than 30 inches in the West Desert.

Contrary to ES calculations, a “correction factor” of 0.7 should not be used with this equation for soils. The UDOT (2012) manual itself does not appear to mention this correction factor but simply states the following:

$$\text{Frost Penetration is approximately equal to } 1.482 (\text{freezing index})^{0.4911}$$

This frost depth information should be used in the formulation of initial DARWin-ME pavement sections and selection of base and subbase materials. DARWin-ME computes the frost depth over the years of climate data available and this information may be useful in formulating a design.

However, another publication (Department of the Army, 1954) may provide insight into the use in this one example of a correction factor of 0.7. This publication states, “the surface freezing index for bituminous surfaces (kept cleared of snow) may be computed by multiplying the freezing index based on air temperatures by a correction factor of 0.7.” It is noted that this air-temp/surface-temp correction factor applies only to bituminous surfaces, such as would be

found on roads. Dark, bituminous road surfaces soak up heat from sunlight, if the surfaces are not isolated and insulated from sunlight, such as by snow. The average albedo for new asphalt is only 0.05 to 0.10, and that of aged asphalt is only 0.10 to 0.20 (American Concrete Pavement Association, 2002). Bituminous road surfaces absorb more energy from sunlight per unit area per unit time than does typical soil, which generally has an albedo in the range of 0.2 to 0.3.

By contrast, rather than tending to absorb light and heat at a higher flux than usual, a high-albedo surface, such as light-colored, mostly carbonate silty clay in the West Desert, would tend to reflect the light and heat more than usual. The average albedo of the West Desert is estimated to be in the range of 0.30 to 0.40, which is three to eight times that of bitumen asphalt, and much greater than typical soil. An air-temp/surface-temp correction factor less than unity is therefore not likely to apply to an embankment at Clive. The UDOT (2012) manual does not call for such a correction factor for soil. Therefore, the 100-year frost penetration depth for Dugway is calculated as 44.9 inches, which would bring freezing temperatures down into the currently proposed upper and lower radon barriers at Clive. It is anticipated that frost penetration depths for 500-, 1,000-, and 10,000-year return intervals would be significantly greater than the 44.9 inches estimated for a 100-year return interval. (See Budikova, 2013; Coakley, 2003; Dobos, 2003; Grace, 1998; Knorr et al., 2001; and Zhang et al., 2014.)

Given the potential for deeper frost depths as noted above, and with documented freezing-temperature depths at Clive measured as low as 30 inches during a January interval when the air temperature was not especially low, ES should plan for far more than 30 inches of frost protection on the top slope of the cover. ES should develop a more robust approach to estimating frost depth and planning for defense against the radon barrier freezing. This would involve, among other things, increasing the thickness of the cover system above the radon barriers.

With the current proposed cell design, ES' modeling should account for substantial disruption of near-surface layers above and within the radon barriers, with accompanying increases for initially low-permeability soil in both hydraulic conductivity and correlated alpha values, which should greatly affect modeled infiltration rates (see Interrogatory CR R313-25-7(2)-189/3: Modeling Impacts of Changes in Federal Cell Cover-System Soil Hydraulic Conductivity and Alpha Values). ES is required by rule to minimize infiltration (see UAC R313-25-24(3) and (4)), and it is important for ES to model infiltration under realistic assumed site conditions in order to achieve this.

EnergySolutions' Response: Version 1.2 of the Clive DU PA Model addresses changes in cover performance due to plant and burrowing animal activity by using values of hydraulic properties representing in-service conditions as described by the NRC (NUREG/CR-7028) report of Benson et al. (2011). Please see the

Round 3 Response for INTERROGATORY CR R313-25-8(4)(A)-27/3: DIFFUSION PATHWAY MODELING and Sections 12.0 and 13.0 of Appendix 5 - Unsaturated Zone Modeling for a detailed discussion.

A calculation of the frost depth for the evapotranspiration (ET) cover at the Clive site is described in Appendix E of EnergySolutions (2013). This calculation used the modified Berggren equation. This equation is used by the U.S. Department of Defense in the design and evaluation of pavement structures to incorporate soil property changes due to freezing and thawing cycles (USACE, 2012; Depths of Army and Air Force, 1988). The modified Berggren equation has a physical basis being derived from Fourier's law of heat conduction. It is the solution to the one dimensional equation of heat transfer in a homogeneous, isotopic medium (USACE, 2012). Empirical equations are available, however, comparison with analytical solutions has demonstrated that empirical equations overestimate the frost depth (USACE, 2012).

The proposed ET cover to which this analysis was applied was designed to mimic local, native ecosystems (SWCA, 2013). Beginning at the top of the cover the layers above the waste used for the ET cover design are:

- Surface layer: This layer is composed of native vegetated Unit 4 material with 15 percent gravel mixture on the top slope and 50 percent gravel mixture for the side slope. This layer is 6 inches thick.
- Evaporative Zone layer: This layer is composed of Unit 4 material. The thickness of this layer is 12 inches.
- Frost Protection Layer: This material ranges in size from 16 inches to clay size particles. This layer is 18 inches thick.
- Upper Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.
- Lower Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity.

This cover design provides 36 inches of soil from the ground surface to the top of the upper radon barrier.

In their response to the Division regarding the frost depth calculation for the ET cover, HAL (EnergySolutions, 2013) recommended that values for dry bulk density and moisture content be acquired to refine assumptions for the soil characteristics. Improved estimates of these characteristics were obtained from the infiltration modeling described in the Round 3 Response to INTERROGATORY CR R313-25-8(4)(A)-27/3: DIFFUSION PATHWAY

MODELING referred to in the first paragraph above. Frost depths for 10-year and 100-year return period were recalculated using these parameters in the modified Berggren equation and are shown in the table below and show frost depths more shallow than the top of the upper radon barrier.

	10-Year Frost Depth		100-Year Frost Depth	
	(ft)	(inches)	(ft)	(inches)
Top Slope (15% Gravel)	1.72	20.7	2.2	26.4
Side Slope (50% Gravel)	1.84	22.1	2.40	28.8

In addition to the results from the modified Berggren equation, Appendix E (EnergySolutions, 2013) also contains an estimation of frost depth calculated from an empirical equation used by the Utah Department of Transportation (UDOT, 2012). For this equation frost penetration is given as

$$\text{Frost Penetration} = 1.482 (\text{Freezing Index})^{0.4911}.$$

Neither the source of this equation nor any information regarding verification are provided in the UDOT manual (UDOT, 2012). This equation is used by UDOT in design of pavement sections and selection of base and subbase materials (UDOT, 2012). A spreadsheet is provided UDOT (2003) for calculating frost penetration using the above equation with the input of monthly maximum and minimum air temperatures from the Western Regional Climate Center. Following the instructions on pages 41 and 42 of the manual temperature data for the Dugway, Utah station for the period 9/21/1950 to 3/31/2013 were obtained and copied into the UDOT spreadsheet. The estimated frost penetration calculated by the spreadsheet was 22.8 inches, a value comparable to the modified Berggren equation results for a 10-year return period. The spreadsheet also provides a frost penetration depth which is scaled by a factor of 0.7. However, as noted by the Division, the basis for this scaling is not described in the manual (UDOT, 2012) or the spreadsheet (UDOT, 2003). In the Interrogatory Critique, a frost penetration depth of 44.9 inches was calculated using the freezing index for the 100-year return period in the UDOT equation. However, the physically based modified Berggren equation is considered to be more accurate and as discussed above empirical equations have been demonstrated to provide overestimates of frost penetration. In addition, the undocumented application of a scaling factor in the spreadsheet calculation makes the results of this approach ambiguous.

156. INTERROGATORY CR R313-25-26(2-3)-156/3: SEPARATION OF WASTES IN FEDERAL CELL

ES has not provided documentation of the necessary agreement between it and DOE. Although it is not expected that it would have any effect on the Clive DU PA, the agreement between ES and DOE must be received by DEQ before any authorization to dispose of DU could be granted.

EnergySolutions' Response: Noted without comment.

157. INTERROGATORY CR R313-25-8(5)(A)-157/2: INCLUSION OF DU AND OTHER WASTES IN PA

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

158. INTERROGATORY CR R313-15-1009(2)(B)(I)-158/2: WASTE PACKAGING

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

159. INTERROGATORY CR R313-25-8(4)(D)-159/2: EMBANKMENT DAMAGE BY LAKE FORMATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

160. INTERROGATORY CR R313-25-7(2)-160/2: COMPARISON OF CLASS A WEST AND FEDERAL CELL DESIGNS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

161. INTERROGATORY CR R313-25-7(2-3)-161/3: INCONSISTENT INFORMATION ON WASTE EMPLACEMENT

The revised Embankment Modeling report (Appendix 3 to FRV1.2) indicates that the original grade level is 4272 ft amsl and the bottom of the waste is an average of 4264.17 ft amsl. This leaves 8 feet for waste burial if the DU waste is to be at or below grade level. The revised PA does not include any of the requested information noted in the Rebuttal. We also note that Figure 9 in the revised Embankment Modeling report does not reflect the current plan to bury all of the DU waste below grade.

EnergySolutions' Response: Figure 9 in Appendix 3 - Embankment Modeling of Appendix A has been revised to show the waste layering adopted for version 1.2 of the Clive DU PA Model.

162. INTERROGATORY CR R313-25-22-162/2: DISPOSAL CELL STABILITY

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

163. INTERROGATORY CR R313-25-8(5)(A)-163/3: GROUNDWATER COMPLIANCE FOR 10,000 YEARS

Groundwater from deeper portions of the confined aquifer, or from other aquifers, has historically been used in the region for drinking and other human uses, such as washing and showering, following treatment. Therefore, the PA needs to consider a groundwater dose pathway.

EnergySolutions' Response: See the Round 2 Responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS, (Appendix D).

164. INTERROGATORY CR R313-15-1009-164/1: INCORRECT RULE CITATION

Round 1 Interrogatory Response is satisfactory.

165. INTERROGATORY CR R313-15-1009(1)(C)(I)-165/1: INCORRECT CITATION OF RA 226 LIMIT

Round 1 Interrogatory Response is satisfactory.

166. INTERROGATORY CR R313-25-22-166/2: STABILITY OF WASTE

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

167. INTERROGATORY CR R313-15-1009(2)(A)(VII)-167/2: PYROPHORICITY OF DUO2

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

168. INTERROGATORY CR R313-25-7(2)-168/2: RIP RAP SIZING

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

169. INTERROGATORY CR R313-25-7(9)-169/3: CLARIFICATION OF STATISTICAL TREATMENT OF CHEMICAL AND ISOTOPIC ASSAYS

1. In its response, ES indicated that the data used came from a Waste Profile Record file that is labeled Waste Profile Record SRS DU 9021-33_r0.pdf, as referenced in the Waste Inventory report. It is an EnergySolutions radioactive waste profile record that is signed by a DOE representative (Glenn Siry). The DOE signature is dated November, 2009. It is clear in this Waste Profile Record that the original 33 samples were used to characterize most radionuclides, and that the same (six) samples were used for the atom% data. However, it is not clear why Sample #8 is missing from the atom% table (listed as Attachment 2 in the Waste Profile Record), or why there are duplicate results presented for each of the six samples that are included.

This explanation was added as a footnote to Table 4, page 9, of the Waste Inventory report (Appendix 4 to FRV1.2).

2. In its response, ES stated that the U-233 atomic% values were treated as non-detects. Since they were reported as 0.000000at%, an assumption was made that the actual value is less than 0.0000005at%. Further explanation is being added to the report.

However, no further explanation was added to Section 3.2.2, pages 14–15, of the Waste Inventory report.

3. In its response, ES stated that the requested documents will be included with the next submittal.

However, these documents still do not appear to be available on the DRC website for the DU PA.

4. In its response, ES stated that the references will be included with the next submittal.

However, no changes appear to have been made in response to this comment. Since the SRS-2002 dataset is Beals et al. (2002), it is not clear which citations, if any, refer to SRS 2002, SRS Interoffice Memorandum 071802 Sampling Plan for DU, dated July 18, 2002, included on the reference list.

5. In its response, ES stated that the appropriate reference is:

Fussell, G.M, and D. L. McWhorter, 2002. Project Plan for the Disposition of the SRS Depleted, Natural, and Low-Enriched Uranium Materials. WSRCP-2002-00459, Washington Savannah River Site, November 21, 2002.

This citation was added to Section 2.2, page 5, of the Waste Inventory report.

6. In its response, ES stated that clarification is being included in the report, and the units are pCi/G of DU waste.

In the captions for Tables 2 (page 2), 5 (page 11), 6 (page 11), and 9 (page 18), “pCi/g” was changed to “pCi/g of DU waste.” Footnote 1 stating that “Concentration units for the data are expressed in terms of activity per gram of DU waste” was added to Table 4 on page 9. However, no such changes were made to the tables in the appendix to the Waste Inventory report.

EnergySolutions’ Response: Addressing each item in turn:

1. This issue is closed.
2. The third paragraph of Section 3.2.2 already provides the necessary information. Nevertheless, some clarification has been added.

3. The following documents:

Fussell, G.M, and D. L. McWhorter, 2002. Project Plan for the Disposition of the SRS Depleted, Natural, and Low-Enriched Uranium Materials. WSRC-RP-2002-00459, Washington Savannah River Site, November 21, 2002.

EnergySolutions. 2009b. Radioactive Waste Profile Record, EC 0230, Rev. 7, plus attachments (Form 9021 33), EnergySolutions Inc. Clive UT.

were provided as part of the original reference set (in the \GoldSim\references directory on the CD) as

Fussell and McWhorter 2002.pdf

Energy Solutions 2009b.pdf

4. The document provided as “SRS 2002.pdf” is, as indicated above, a memo documenting a DU sampling plan. This document is not referenced in Appendix 4 - Waste Inventory of Appendix A, and was included in the reference list by mistake. This has been deleted. References to data from Beals et al. (2002) are referred to as “SRS-2002” in the white paper, using a shorthand developed to identify various datasets.
5. This issue is closed.
6. The concentration units presented in the tables of Appendix 4 - Waste Inventory of Appendix A have been clarified to be per gram of DU waste.

170. INTERROGATORY CR R313-25-7-170/2: DU WASTE FORM RELEASE MECHANISMS AND RATES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

171. INTERROGATORY CR R313-25-7-171/2: ADEQUACY OF DU CELL BUFFER ZONE

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

172. INTERROGATORY CR R313-25-20-172/3: INADVERTENT INTRUDER PROTECTION

The DRC staff does not agree that mining of clay, silt, and sand could not be conducted by an inadvertent intruder, with consequent greater exposure to radioactive materials by that inadvertent intruder. Any breach of the cover system would likely result in greater exposures. Drilling of wells and use of groundwater on site, either as part of the mining and soil-treatment process or for drinking during work, could also result in greater exposures. These need to be assessed as part of the inadvertent intruder analysis.

ES also needs to explain why water ponding in open or partially open excavations will not lead to groundwater mounding that will change the course of groundwater flow under the site. This is currently happening on and near the site wherever ponding is occurring.

EnergySolutions' Response: Please see the Round 2 Responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS, CR R313-25-7(1)-101/2: NATURE OF UNITS 1 AND 2, and CR R313-25-20-172/2: INADVERTENT INTRUDER PROTECTION, (Appendix D).

173. INTERROGATORY CR R313-25-7(2)-173/2: STABILITY OF EMBANKMENT

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

174. INTERROGATORY CR R313-25-7(6)-174/1: WASTE EMPLACEMENT IN CLASS A SOUTH DISPOSAL CELL

Round 1 Interrogatory Response is satisfactory.

175. INTERROGATORY CR R313-25-7(2)-175/2: INFILTRATION RATES FOR THE FEDERAL CELL VERSUS THE CLASS A WEST CELL

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

176. INTERROGATORY CR R313-25-8(5)(A)-176/2: REPRESENTATIVE HYDRAULIC CONDUCTIVITY RATES

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

177. INTERROGATORY CR R313-25-8(5)(A)-177/2: DOSE FROM PLANT UPTAKE

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

178. INTERROGATORY CR R313-25-8(5)(A)-178/2: SURFACE WATER PATHWAY

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

179. INTERROGATORY CR R313-25-7(2)-179/2: RIP RAP

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

180. INTERROGATORY CR UGW450005 PART I.D.1-180/2: COMPLIANCE PERIOD

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

181. INTERROGATORY CR R313-25-19-181/2: GROUNDWATER MORTALITY

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

182. INTERROGATORY CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

183. INTERROGATORY CR R313-25-19-183/2: MEAT INGESTION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

184. INTERROGATORY CR R313-25-19-184/2: GOLDSIM SKIPS STABILITY CALCULATION

A response to this Interrogatory was included in the Round 2 Interrogatory Response Report of June 17, 2014. Since no new findings or critique has been included with Round 3, nothing has been added to the original Round 2 response.

185. INTERROGATORY CR R313-25-7(10)-185/3: ADD APPENDIX 18 TO LIST OF APPENDICES

Update the List of Appendices on page 91 of FRV1.2 to include the Radon Diffusion Modeling report (Appendix 18 to FRV1.2).

EnergySolutions' Response: The list of appendices within Appendix A has been revised.

186. INTERROGATORY CR R313-25-7(10)-186/3: SENSITIVITY ANALYSIS APPENDIX MIS-REFERENCED

Change references to the Sensitivity Analysis report from Appendix 19 to Appendices 15(I) and (II).

EnergySolutions' Response: The references in Appendix A to the Sensitivity Analysis have been revised.

187. INTERROGATORY CR R313-25-19-187/3: INDUSTRIAL WORKER EXPOSURES

Include in FRV1.2 a scenario description for the exposure of an industrial worker, as well as the calculated doses.

EnergySolutions' Response: The acute Inadvertent Industrial Well Driller and chronic Inadvertent Industrial Well User scenarios and projected doses are

reported in the Round 2 Response to Interrogatory CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS (which has been hereto included as Appendix D for public review).

188. INTERROGATORY CR R313-25-7(2)-188/3: MODELING GULLIES WITH SIBERIA

Provide the input and output files used to make the SIBERIA runs, as well as documentation for the input parameters selected.

EnergySolutions' Response: Appendix 10 – Erosion Modeling of Appendix A has been expanded to describe the SIBERIA parameters and scenarios. The model documentation report and a model package containing the EAMS and SIBERIA software, model input files, grids, and results are provided in an attached electronic addendum to Appendix 10.

189. INTERROGATORY CR R313-25-7(2)-189/3: MODELING IMPACTS OF CHANGES IN FEDERAL CELL COVER-SYSTEM SOIL HYDRAULIC CONDUCTIVITY AND ALPHA VALUES

Explain why the model does not consider the effects of a compromised radon barrier.

EnergySolutions' Response: In the basis this Interrogatory, the Division suggests recommendations on how the infiltration modeling should be conducted. While their suggested approach recommended is academically interesting, the model used in version 1.2 of the DU PA is a highly defensible approach for the infiltration modeling (although, slightly different). Please refer to Appendix 5 - Unsaturated Zone Modeling of Appendix A for details of the infiltration model used.

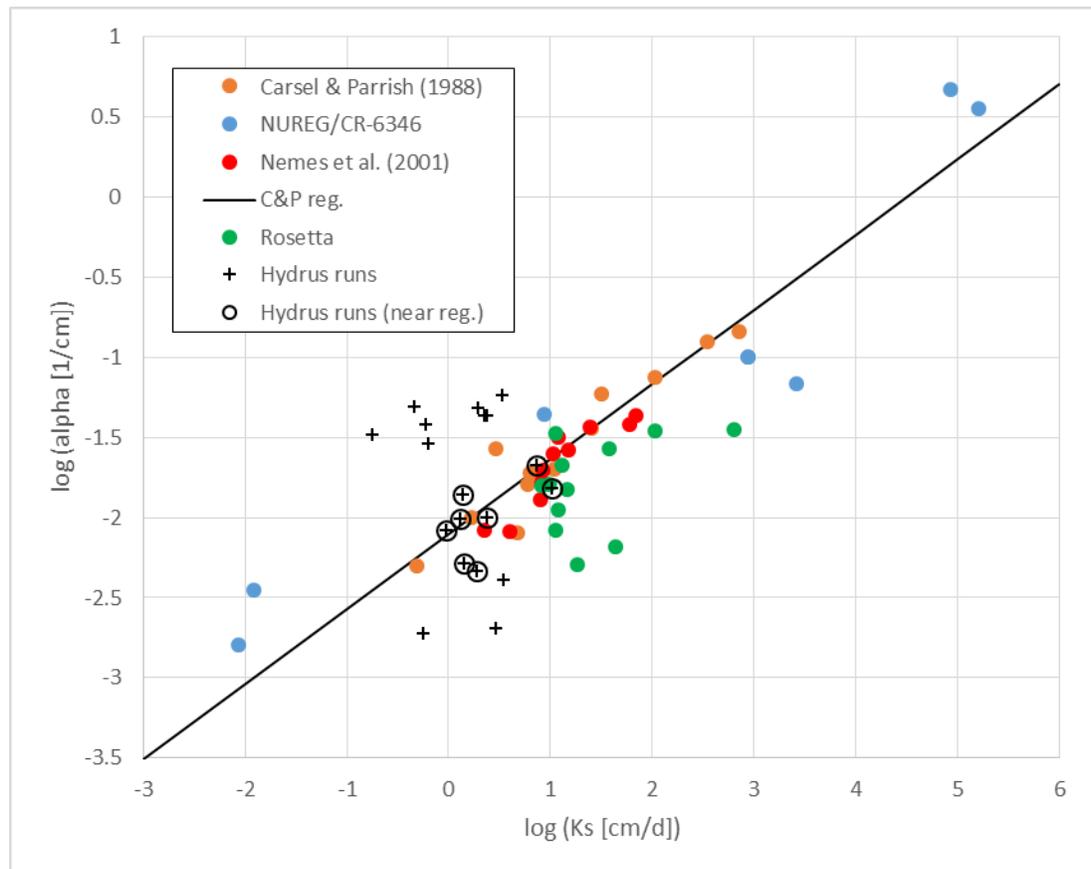
Hydraulic properties that represent the silty clay soil that comprises Unit 4 at the Clive site, as well as the compacted clay radon barriers, were taken from the Rosetta database (Schaap et al. 2001; Schaap 2002). It is recognized that there are other databases, such as Carsel and Parrish (1988) that could be used. However, Rosetta was selected because it

“implements five hierarchical pedotransfer functions (PTFs) for the estimation of water retention, and the saturated and unsaturated hydraulic conductivity. The hierarchy in PTFs allows the estimation of van Genuchten water retention parameters and the saturated hydraulic conductivity using limited (textural classes only) to more extended (texture, bulk density, and one or two water retention points) input data. Rosetta is based on neural network analyses combined with the bootstrap method, thus allowing the program to provide uncertainty estimates of the predicted hydraulic parameters” (Schaap et al., 2001).

In addition, Rosetta was developed by Dr. van Genuchten, a seminal leader in unsaturated zone modeling for whom the van Genuchten α and n parameters are named. Correlations between all hydraulic parameters in the Rosetta database were investigated, and there was no correlation between α and K_s .

The plot of $\log(\alpha)$ and $\log(K_s)$ from this Interrogatory was reproduced below. The data is sourced from Nemes et al. (2001) that appeared to be identical to the data shown as Wösten et al. (1999). The data from Rosetta for the 12 textural classes is also included in this figure where it is apparent that there is no correlation between α and K_s . This figure also includes the 20 replicates used in the infiltration modeling (plus symbols). Note that eight of the 20 replicates lie reasonably close to the Carsel and Parrish (1988) regression line (circled pluses). Therefore, these eight replicates have a correlation between α and K_s . However, there is no correlation between infiltration flux and these eight data points.

Please refer to Appendix 5 - Unsaturated Zone Modeling of Appendix A for details of the development of the hydraulic property distributions for α and K_s using the Rosetta database.



190. INTERROGATORY CR R313-25-7(2)-190/3: LIKELIHOOD OF SEISMIC ACTIVITY

Correct the statement on Section 6.0, page 9, of the revised FEP Analysis report (Appendix 1 to FRV1.2) that "...seismic activity is unlikely to impact the Clive facility."

EnergySolutions' Response: Section 6 of Appendix 1 in Appendix A has been revised.

191. INTERROGATORY CR R313-25-7(2)-191/3: EFFECT OF GULLY EROSION

Provide additional information about the ability of steep side slopes to resist gully erosion.

EnergySolutions’ Response: While EnergySolutions appreciates the visual aesthetic provided in the Division’s photo (included in their basis for this Interrogatory), it is noted that the slope depicted does not benefit from the addition of any gravel admixture. Additionally, the photo depicts an area that has been disturbed, and is non-vegetated without any apparent effort to restore the slope to natural conditions. The evapotranspirative cover that is contemplated by EnergySolutions includes such erosion control measures such as the establishment of native vegetation, gravel admixture, establishment of native soil crusts and plant litter, and appropriate compaction. As such, while visually appealing, it is not remotely representative of the performance of the Federal Cell’s evapotranspirative cover side slope (with 50% gravel admixture). Information regarding the evapotranspirative cover design’s ability to resist the gully erosion observed in the Division’s photo can be found in Appendix K of EnergySolutions (2013a) and Appendix D of EnergySolutions (2013b), wherein it is demonstrated that, “the design of the proposed evapotranspirative cover system achieves sheet, rill and gully erosion control.”

192. INTERROGATORY CR R313-25-7(2)-192/3: IMPLICATIONS OF GREAT SALT LAKE FREEZING ON FEDERAL CELL PERFORMANCE

Revisit the potential for infiltrating water in and/or above the radon barrier to freeze, given the periodic freezing of this part of the lake water in this region.

EnergySolutions’ Response: Protection of the radon barrier from the effects of freeze depth is addressed in Appendix E of EnergySolutions (2013b), which concludes,

“The frost depths calculated as part of this analysis give results that are in line with the depths of cover and frost protection proposed in the EnergySolutions ET Cover system design. The proposed radon barrier begins at depths ranging from 30-inches to 42-inches which provides frost protection for the calculated 100-year frost penetration depth of 22.4 inches to 27.8 inches for the top slope and side slope, respectively.”

193. INTERROGATORY CR R313-25-7(2)-193/3: PREDOMINANCE OF UPWARD OR DOWNWARD VERTICAL FLOW DIRECTION

Correct the assumption that ambient groundwater flow will always be vertically upward from the deep aquifer to the shallow aquifer.

EnergySolutions' Response: The predominance of an upward vertical flow direction is not an assumption, but rather a reflection of the condition observed and reported annually to the Division as part of EnergySolutions' Annual 11e.(2), LARW, Class A West, and Mixed Waste Groundwater Monitoring Reports (as exemplified by Table B-2 from the two most recent submittals EnergySolutions, 2014 and EnergySolutions, 2013c). While speculation of a range of hydrogeologic alterations that may change the direction of vertical flow may be an interesting academic exercise, NRC guidance discourages such,

“consideration given to the issue of evaluating site conditions that may arise from changes in climate . . . should be limited so as to avoid unnecessary speculation.” (NUREG-1573, pg. 3-10).

Therefore, since vertical upward flow is measurable and required to be demonstrated annual by EnergySolutions, modeling or consideration of other directional flows is not representative of current site conditions and contrary to NRC guidance.

194. INTERROGATORY CR R313-25-7(2)-194/3: POTENTIAL FOR DEVELOPMENT IN THE VICINITY AND AT THE SITE

Provide support for the assumption that the lack of potable water will limit any residential, commercial, or industrial developments.

EnergySolutions' Response: See Round 2 responses to Interrogatories CR R313-25-8(4)(B)-07/2: APPLICABILITY OF NRC HUMAN INTRUSION SCENARIOS and CR R313-25-19-182/2: GROUNDWATER EXPOSURE PATHWAYS (Appendix D).

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APPENDIX F

Clive DU PA Model GoldSim Files (version 1.2)

Electronic Copy



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