UTAH DIVISION OF RADIATION CONTROL
ENERGY*SOLUTIONS* CLIVE LLRW DISPOSAL FACILITY
LICENSE NO: UT2300249; RML #UT 2300249

CONDITION 35 COMPLIANCE REPORT; APPENDIX A: FINAL REPORT FOR THE CLIVE DU PA MODEL

SAFETY EVALUATION REPORT
VOLUME 1

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for Utah Department of Environmental Quality
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ABBREVIATIONS AND ACRONYMS

°F	degrees Fahrenheit
α	van Genuchten alpha
ACRS	Advisory Committee on Reactor Safeguards
ALARA	as low as reasonably achievable
Am	americium
amsl	above mean sea level
Bi	bismuth
Bq/L	becquerels per liter
Bq/m^3	becquerels per cubic meter
Br^-	bromide
Ca^{2+}	calcium
CAC	Class A Combined
CAS	Class A South
$CaUO_4$	calcium uranate
CAW	Class A West
CCD	complementary cumulative distribution
CFR	Code of Federal Regulations
Ci/g	curies per gram
Cl^-	chloride
CLSM	controlled low-strength material
cm	centimeter
cm^{-1}	per centimeter
cm/day	centimeters per day
$cm^2\ m^{-2}$	square centimeters per square meter
cm/s	centimeter per second
cm^2/s, cm/sec	square centimeters per second
cm/yr	centimeter per year
CO_2	carbon dioxide
CO_3^{2-}	carbonate

CQA/QC	construction quality assurance/quality control
DEQ	Utah Department of Environmental Quality
DOE	U.S. Department of Energy
DRC	Division of Radiation Control (Utah)
DTSA	Deep Time Supplemental Analysis
DU	depleted uranium
DUF_6	depleted uranium hexafluoride
DUO_3	depleted uranium trioxide
DU_3O_8	triuranium octoxide depleted in U-235
DU PA	depleted uranium performance assessment
E_H	oxidation/reduction potential
EPA	U.S. Environmental Protection Agency
ES	Energy*Solutions*, LLC
ET	evapotranspiration
F^-	fluoride
FEPs	features, events, and processes
ft	foot/feet
ft^3	cubic feet
g cm^{-3}	grams per cubic centimeter
g/L	grams per liter
GDP	gaseous diffusion plant
GTG	GoldSim Technology Group
GWPL	groundwater protection level
GWQ	Ground Water Quality Discharge
HELP	Hydrologic Evaluation of Landfill Performance
hr/yr	hours per year
HYPRES	Hydraulic Properties of European Soils
I	iodine
IAEA	International Atomic Energy Agency
IRIS	Integrated Risk Information System
K^+	potassium
Kd	absorption coefficient

kg	kilogram
km	kilometers
KOH	potassium hydroxide
kPa	kilopascal
K_{sat}	saturated hydraulic conductivity
ky	one thousand years
IAEA	International Atomic Energy Agency
L	liter
LARW	low-activity radioactive waste
LLNL	Lawrence Livermore National Laboratory
LLRW	low-level radioactive waste
LLW	low-level waste [used in some figures and quoted passages]
LN	lognormal [distribution]
m	meter
m^3/yr	cubic meters per year
MCL	maximum contaminant level
mg	milligram
Mg	megagram
Mg^{2+}	magnesium
mg/kg-day	milligrams per kilogram per day
mg/L	milligram per liter
mm	millimeter
mm/yr	millimeters per year
mol/L	moles per liter
mrem/hr	millirem per hour
mrem/yr	millirem per year
mSv	millisievert
µCi/m^3	microcuries per cubic meter
µg/L	micrograms per liter
Na^+	sodium
NCRP	National Council on Radiation Protection and Measurements
nCi/g	nanocuries per gram

NO_3^-	nitrate
NORM	naturally occurring radioactive material
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
OHV	off-highway vehicle
ORGDP	Oak Ridge Gaseous Diffusion Plant
Pa	protactinium
PAWG	Performance Assessment Working Group
Pb	lead
pCi	picocurie
pCi/g, pCi g^{-1}	picocuries per gram
pCi/L	picocuries per liter
pCi/m^2-s, pCi m^{-2} s^{-1}	picocuries per square meter per second
pCi/m^3	picocuries per cubic meter
pH	hydrogen ion concentration
Po	polonium
PORTS	Portsmouth Gaseous Diffusion Plant
ppb	parts per billion
Pu	plutonium
Ra	radium
rem/yr	rem per year
RfD	reference dose
RML	Radioactive Material License
Rn	radon
RO	reverse osmosis
s^{-1}	per second
SD	standard deviation
sec/m^3	seconds per cubic meter
SE	standard error
SER	Safety Evaluation Report
SNL	Sandia National Laboratories
SO_4^{2-}	sulfate

Sr	strontium
SRS	Savannah River Site
STPP	sodium tripolyphosphate
SWCA	SWCA Environmental Consultants
Tc	technetium
TDS	total dissolved solids
TEDE	total effective dose equivalent
Th	thorium
U	uranium
U_3O_8	triuranium octoxide
UAC	Utah Administrative Code
UF_6	uranium hexafluoride
U(IV)	tetravalent-state uranium
UO_2	uranium dioxide
$UO_2(OH)_2$	aqueous uraninite
UO_3	uranium trioxide
$U(OH)_4$	uranium hydroxide
URCB	Utah Radiation Control Board
U.S.	United States of America
UTTR	Utah Test and Training Range
U(VI)	hexavalent-state uranium
wt%	weight percent
yd^3	cubic yards
yr	year

EXECUTIVE SUMMARY

ES-1 – Purpose

The purpose of this Safety Evaluation Report (SER) is to determine the extent to which the depleted uranium performance assessment (DU PA) submitted by Energy*Solutions,* LLC (Energy*Solutions*) on June 1, 2011 (Neptune 2011), and revised on June 5, 2014 (Neptune 2014a), complies with the requirements of Utah Administrative Code (UAC) R313-25-9(5)(a) and other relevant regulations. If the DU PA is approved, amendments to Energy*Solutions*' license and groundwater permit will be required before depleted uranium (DU) may be disposed of at the facility. Those amendments would be addressed in separate licensing and permitting actions.

ES-2 – Background

Energy*Solutions* operates a low-level radioactive waste (LLRW) disposal facility west of the Cedar Mountains in Clive, Utah. The Clive Site has been used for radioactive waste management since 1985. Energy*Solutions* has been the Clive Site's Licensee since 2006. Energy*Solutions* is currently licensed to receive, store, and dispose, by land burial, the following categories of radioactive materials and waste: naturally occurring and accelerator-produced radioactive material waste, low-activity radioactive waste, Class A LLRW, special nuclear material, 11.e.(2) byproduct waste (e.g., uranium mill tailings), radioactive waste that is also determined to be hazardous (mixed waste), and naturally occurring radioactive material.

In October 2008, 5,800 drums containing DU (Class A waste) from the U.S. Department of Energy's (DOE's) Savannah River Site were sent to the Energy*Solutions* facility at Clive for disposal. Additionally, it was learned that DOE intended to dispose of a large quantity of DU [~700,000 megagrams (Mg); Neptune 2014d, Section 2.0] at the Energy*Solutions* Clive facility.

Amendments to existing Utah and federal regulations were found to be necessary to cover disposal of DU waste because DU was not considered when the U.S. Nuclear Regulatory Commission (NRC) conducted studies to determine how radioactive waste should be classified [see Title 10 of the Code of Federal Regulations (10 CFR) Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste." and associated draft and final environmental impact statements, specifically, NUREG-0782 and NUREG-0945], and because, unlike other kinds of low-level radioactive waste, DU becomes more radioactive with time, not less, because of natural decay into other radionuclides. DU waste is relatively benign initially but becomes more radioactive with time due to the in-growth of daughter products, reaching peak radioactivity more than two million years into the future. Consequently, on March 2, 2010, the Utah Department of Environmental Quality (DEQ) imposed Condition 35 on the Energy*Solutions* Radioactive Material License to cover disposal of large amounts of DU at the Clive Site. License Condition 35 consists of five parts: (a) uranium concentration and burial depth, (b) performance assessment, (c) revised disposal embankment design, (d) remediation, and (e) surety. Many of the requirements of License Condition 35 were later codified into UAC R313-25-9(5)(a).

Federal Cell Design

Energy*Solutions* plans to dispose of the DU in a proposed Federal Cell at the Clive Site. Energy*Solutions* will construct the Federal Cell embankment to the west of the existing "11e.(2)" cell, which is dedicated to the disposal of uranium-processing byproduct waste.

The proposed Federal Cell embankment is a hipped cap, with relatively steeper sloping sides nearer the edges. The upper part of the embankment, known as the "top slope," has a moderate slope (2.4 percent), while the side slope is markedly steeper (33 percent grading downward to 20 percent). Energy*Solutions* intends to dispose of DU only beneath the top slope areas of the embankment, with no DU beneath the side slopes. DU waste will be disposed of below the native grade level of the proposed Federal Cell.

An evapotranspiration (ET)[1] cover system is to be constructed above the waste in order to limit contact of water with the waste. The cover is sloped to promote runoff and designed to limit water infiltration by increasing evapotranspiration. Beginning at the top of the cover, the layers above the waste used for the ET cover design are as follows (Neptune 2014b):

- **Surface Layer:** This layer is composed of native vegetated silty clay with 15 percent gravel mixture on the top slope. The intended functions of this layer are to control runoff, minimize erosion, and maximize water loss from evapotranspiration. This layer of silty clay 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 silty clay. The purpose of this layer is to provide additional storage for precipitation and additional depth for the plant rooting zone to maximize evapotranspiration.
- **Frost Protection Layer:** This material ranges in size from 16 inches to clay-size particles. The purpose of this layer is to protect layers below from freeze/thaw cycles, wetting/drying cycles, and to inhibit plant, animal, or human intrusion.
- **Upper Radon Barrier:** This layer consists 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 compacted clay with a low hydraulic conductivity. This is a barrier layer placed directly above the waste that reduces the downward movement of water.

Directly beneath the lower radon barrier of the ET cover would be about 36 feet of non-DU material. For the purposes of the present Clive DU PA and this SER, it has been assumed that this non-DU material would be non-radioactive. However, Energy*Solutions* retains the option of using this space to dispose of ordinary, non-DU, LLRW. Should Energy*Solutions* decide to implement this option, DEQ would require Energy*Solutions* to perform an additional performance assessment, as required by UAC R313-25-9(5)(a).

The DU waste would be buried beneath the non-DU material. The DU would be placed in the Federal Cell in either cylinders or drums. The drums would be placed in a single layer on pallets, and the cylinders would be either in a single layer or stacked two layers high.

[1] Evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

The waste would be placed on a clay liner constructed of compacted local clay and be uniformly about 60 centimeters (2 feet) thick by design. The bottom of the waste cell would have a gentle slope to it.

ES-3 – Depleted Uranium

DU is a waste byproduct of the process used to enrich natural uranium for use in nuclear reactors and nuclear weapons. Natural uranium is composed primarily of two isotopes: uranium-235 (U-235) and U-238. For the types of nuclear power plants operating in the United States, the relative concentration of U-235 in the fuel material needs to be increased (or enriched), resulting in a waste product that is *depleted* in U-235.

When U-238 decays, it produces a series of products that are other uranium radionuclides or radionuclides of other elements, including thorium, protactinium, radium, radon, polonium, lead, and bismuth. In nature, U-238 is in equilibrium with its decay products, meaning that the radioactivity of the decay products is decreasing according to the half-life of U-238.

When uranium is purified in preparation for being used as nuclear reactor fuel, all of its decay products are chemically removed from the DU. Over time, the decay products will build back up in the DU and reestablish approximate secular equilibrium with U-238. The time it takes to reestablish equilibrium with U-238 is directly proportional to the decay product's half-life. Because many of DU's decay products have very long half-lives, Energy*Solutions* has calculated that equilibrium will take millions of years to achieve (ES 2014b).

The result of this buildup of decay products is that, over long time periods, DU becomes more radioactive, rather than less.

ES-4 – Clive Depleted Uranium Performance Assessment

UAC Rule R313-25-9(5)(a) requires that any facility that proposes to dispose of significant quantities of DU must submit a performance assessment demonstrating by modeling that the performance standards specified by the NRC and the State of Utah will be met for a minimum of 10,000 years and that additional simulations be performed for the period when the peak dose occurs (which will be well beyond 10,000 years), with the results of the latter simulations analyzed qualitatively. This requirement is embedded in Energy*Solutions*' Radioactive Materials License UT2300249, Amendment 14, Condition 35B (ES 2013).

In response to this requirement, Energy*Solutions* submitted its DU PA on June 1, 2011 (version 1.0, Neptune 2011), and a revised version on June 5, 2014 (Neptune 2014a, hereafter referred to as "version 1.2" or "v1.2").

ES-5 – Regulations Governing This Review of the Depleted Uranium Performance Assessment

The performance standards that a DU waste disposal site must meet are contained in the NRC's 10 CFR Part 61. As an NRC Agreement State, Utah has established its own regulations in UAC R313, "Environmental Quality, Radiation Control," which are nearly identical to the NRC's. In this SER, DEQ evaluated the Energy*Solutions* performance assessment primarily against the following applicable Federal and Utah regulations:

Table ES-1 – Regulations Governing the DU Performance Assessment

Code of Federal Regulations (CFR)	Utah Administrative Code (UAC)	Areas Covered by the Regulation
10 CFR 61.12	R313-25-8	Specific technical information
—	R313-25-9(5)(a)	Deep time analysis
10 CFR 61.41	R313-25-20	Protection of the general population from releases of radioactivity
10 CFR 61.42	R-313-25-21	Protection of individuals from inadvertent intrusion
10 CFR 61.44	R313-25-23	Stability of the disposal site after closure

Review with respect to other UAC regulations not cited in Table ES-1 was done as needed.

The DU PA prepared by Energy*Solutions* also considered topics outside the purview of these NRC and UAC regulations, including uranium oral toxicity and Utah groundwater protection levels (GWPLs).

ES-6 – DEQ's Evaluation of the Clive Depleted Uranium Performance Assessment

This SER describes in detail the analyses that DEQ and its contractor, SC&A, Inc., performed to determine whether the Energy*Solutions* performance assessment meets these Federal and Utah performance criteria. It is based on review of Versions 1.0 and 1.2 of the *Final Report for the Clive DU PA Model* (Neptune 2011, 2014a; hereafter "DU PA v1.0" and "DU PA v1.2," respectively) and its supporting appendices, the Compliance Report [Revision 0 (ES 2011), Revision 1 (ES 2013), and Revision 2 (ES 2014a)], and consideration of Energy*Solutions*' responses to 194 interrogatories submitted by DEQ (Rounds 1, 2, and 3 dated February 28, 2014, March 27, 2014, and July 1, 2014, respectively, and the supplementary interrogatories of August 11, 2014). The evaluation also included independent calculations and analyses conducted by the DEQ contractor on selected topics.

The SER evaluates the following areas:

Specific Technical Information

UAC Rule R313-25-8 requires the DU PA to include certain kinds of technical information. This SER evaluates the following technical information provided in the DU PA for facilities of this kind (DEQ's findings on these matters are located in Section 4.1 of the SER):

- Principal design features (including the ET cover, waste placement and backfill, and the clay liner) [R313-25-8(2)]
- Kind, amount, classification, and specifications of the material being disposed [R313-25-8(9)]
- Quality assurance of the GoldSim computer model used to calculate the performance of the proposed Federal Cell [R313-25-8(10)]
- Uranium solubility [R313-25-8(4)]

Protection of the General Population from Releases of Radioactivity

UAC Rule R313-25-20 specifies the maximum radiation doses that members of the public may receive from concentrations of radioactive material that are released to the general environment in groundwater, surface water, air, soil, plants, or animals. DEQ evaluated the DU PA Model's calculations of the potential doses to members of the general public at various nearby locations and through a range of possible exposures, including inhalation (wind-derived dust, mechanically-generated dust, and radon), inadvertent ingestion of surface soils, ingestion of beef, exposure to contaminated groundwater, and external irradiation (soil and immersion in air). (DEQ's findings on these matters are located in Section 4.2 of the SER.)

Protection of Individuals from Inadvertent Intrusion

UAC Rule R-313-25-21 states that the 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 (around 100 years after closure). DEQ evaluated a range of inadvertent exposure scenarios described in the DU PA for industrial workers, ranch workers, hunters, and off-highway vehicle enthusiasts. Due to the quality of the groundwater in the Clive area, Energy*Solutions* did not calculate potential doses due to groundwater ingestion. However, DEQ has examined the potential for doses to occur to inadvertent intruders via groundwater ingestion. (DEQ's findings on these matters are located in Section 4.3 of the SER.)

Stability of the Disposal Site after Closure

UAC Rule R313-25-23 states that 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. DEQ evaluated the DU PA's analysis of the following long-term influences on the stability of the site, especially its cover, including infiltration, erosion of the cover, effects of plants and animals, and frost damage. (DEQ's findings on these matters are located in Section 4.4 of the SER.)

Deep Time Analysis

UAC Rule R313-25-9(5)(a) requires that a performance assessment provide additional simulations for the time period when the peak dose occurs at the disposal site. Because DU becomes more radioactive as time passes, DEQ evaluated the DU PA's "deep time" analysis of possible environmental changes and their effects on the site up to the time when the peak dose occurs. (DEQ's findings on these matters are located in Section 5.1 of the SER.)

Uranium Oral Toxicity

Although not specifically required by UAC R313-25-9(5)(a), in the DU PA Energy*Solutions* analyzed whether ingestion of uranium could cause non-carcinogenic biological damage, such as kidney failure. DEQ evaluated this analysis in the SER. (DEQ's findings on these matters are located in Section 5.2 of the SER.)

Compliance with Utah Groundwater Protection Levels

Ground Water Quality Discharge Permit Number UGW450005 for the Clive site specifies that it meet Utah GWPLs for uranium and various radionuclides for 500 years. The Energy*Solutions*

DU PA analyzed whether the GWPLs would be met at the Clive site after DU disposal. DEQ evaluated the DU PA's assessment of this requirement. (DEQ's findings on these matters are located in Section 5.3 of the SER.)

A summary of all DEQ interrogatories to Energy*Solutions* related to these topics is included in Appendix C.

ES-7 – Summary of Conclusions

All conclusions in the SER, including determinations that issues have been resolved, conditionally resolved, or not resolved, are tentative in that they are subject to notice and comment and reconsideration by the agency in light of comments made during the public comment period and the record as a whole.[2] A final approval of the DU PA will also be subject to the specific conditions described in Section 6 of the SER.

Conclusions

Resolved: The DEQ evaluation found that for the following topics the Energy*Solutions* DU PA satisfactory met the required regulatory criteria, and these topics have been resolved:

- UAC R313-25-7(3)(c); R313-25-8(2)–(3); R313-25-9(5)(a); R313-25-19: Uranium Solubility
- UAC R313-25-20: Protection of the General Public from Releases of Radioactivity
- UAC R313-25-21: Protection of Individuals from Inadvertent Intrusion
- U.S. Environmental Protection Agency's 40 CFR 141.66: Uranium Oral Toxicity

Conditionally Resolved: The DEQ evaluation found that for the following topics the Energy*Solutions* DU PA satisfactorily met the required regulatory *criteria*, and the following topics can be resolved, based upon the demonstration that the "Additional Conditions for Approval" listed below have been met:

- UAC R313-25-8(9): Kind, Amount, Classification, and Specifications of the Material
- UAC R317-6-4; Ground Water Quality Discharge Permit UGW450005: Compliance with Groundwater Protection Levels
- UAC R313-25-8(2), (3), (5), (6), and (10); R313-25-26(4), (5), and (10): Waste Emplacement and Backfill

Not Resolved: The DEQ evaluation found that, for the following topics, the Energy*Solutions* DU PA has not satisfied all of the Department's concerns and the topics are not resolved at this time (the principal concerns are shown in parentheses):

[2] "Resolved" means that a determination has been made that there is sufficient information to demonstrate that this requirement will be met. "Conditionally resolved" means that a determination has been made that there is sufficient information to demonstrate that this requirement will be met, provided that the applicable condition is also met. "Not resolved" means that a determination has been made that sufficient information has not yet been provided to DEQ to demonstrate that this requirement will be met. "Not resolvable" means that there is sufficient information to show that this condition cannot be met.

- UAC R313-25-8(2) and (3): Evapotranspiration Cover (lack of correlation between the alpha and hydraulic conductivity values, etc.)
- UAC R313-25-8(2): Infiltration (lack of correlation between the alpha and hydraulic conductivity values, etc.)
- UAC R313-25-25: Erosion of Cover (clarification of certain issues relating to Appendix 10 to the DU PA version 1.2, June 5, 2014)
- UAC R313-25-25(3) and (4): Frost Damage (need to resolve concerns with assumed recurrence intervals, estimated frost penetration depths, and hydraulic property estimates)
- UAC R313-25-24(3) and (4): Effect of Biologicals on Radionuclide Transport (need to account for natural increases in cover permeability over time)
- UAC R313-25-8(2): Clay Liner (lack of increase in K_{sat} values over time; lack of correlation between the alpha and hydraulic conductivity values)
- UAC R313-25-8(10): GoldSim Quality Assurance [the relationship between the process level model (i.e., HYDRUS) abstractions and the primary model (i.e., GoldSim) results needs to be demonstrated]
- UAC R313-25-9(5)(a): Deep Time Analysis

Not Resolvable: The DEQ evaluation found that, at this time, no topics in the Energy*Solutions* DU PA cannot be resolved because of affirmative information that standards cannot be met.

Additional Conditions for Approval

In addition, the following are conditions that Energy*Solutions* must agree to meet before final DEQ approval can be given (see Section 6.2 of the SER for more information):

- Condition 1: Agreement with DOE.

  Prior to disposal of DU waste, Energy*Solutions* shall provide a written agreement letter between DOE and Energy*Solutions* indicating that DOE will accept title to the Federal Cell after closure.

- Condition 2: Disposal below grade.

  DU waste must be disposed of below the original-grade level of the proposed Federal Cell.

- Condition 3: Depleted uranium will continue to be Class A waste.

  Energy*Solutions* shall provide documentation that the NRC does not plan to reclassify DU.

- Condition 4: Remainder of waste will be modeled.

  Energy*Solutions* shall submit for DEQ approval a revised performance assessment that addresses the total quantities of concentrated DU and other wastes as described in UAC R313-25-9(5)(a) before any radioactive wastes other than the DU waste are emplaced in the proposed Federal Cell.

- Condition 5: Waste Acceptance Criteria.

  Prior to any land disposal of significant quantities of concentrated DU, the Licensee shall submit a written Waste Acceptance Criteria plan designed to ensure that all DU waste received by the Licensee conforms with all physical, chemical, and radiologic properties assumed in the DU PA modeling report.

- Condition 6: Prohibition of recycled uranium in DU waste.

  The Licensee is prohibited from land disposal of any quantity of DU waste that was produced at DOE facilities from uranium-bearing materials containing recycled uranium.

- Condition 7: Hydrological and hydrogeological properties of lower confined aquifer.

  The Licensee shall develop and implement a program to provide more detailed site characterization and hydrogeologic evaluation of aquifers in the area, especially the deeper confined aquifer.

ES-8 References

Division of Radiation Control (DRC), Utah Department of Environmental Quality, 2014. "License Amendment No. 16: Radioactive Material License UT 2300249," May 12. Available at http://www.deq.utah.gov/businesses/E/EnSolutions/docs/2014/05May/Amend16finalandPPS.pdf

Energy*Solutions*, LLC (ES), 2011. "Utah Low-Level Radioactive Waste Disposal License – Condition 35 (RML UT2300249) Compliance Report," June 1.

Energy*Solutions*, LLC (ES), 2013. *Utah Radioactive Material License – Condition 35 (RML UT2300249) Compliance Report (Revision 1)*, November 8.

Energy*Solutions*, LLC (ES), 2014a. "RML UT2300249 – Condition 35 Compliance Report – Revision 2," July 8.

Energy*Solutions*, LLC (ES), 2014b. "Responses to 28 February 2014 – Round 1 Interrogatories, Utah LLRW Disposal License RML UT 2300249 Condition 35 Compliance Report," March 31.

Neptune and Company, Inc., 2011. *Final Report for the Clive DU PA Model version 1.0*, June 1, 2011. (Appendix A to Energy*Solutions*, *Utah Low-Level Radioactive Waste Disposal License – Condition 53 (RML UT2300249) Compliance Report*, June 1, 2011).

Neptune and Company, Inc., 2014a. *Final Report for the Clive DU PA Model, Clive DU PA Model v1.2*, June 5.

Neptune and Company, Inc., 2014b. *Conceptual Site Model for Disposal of Depleted Uranium at the Clive Facility*, NAC-0018_R1, June 5, 2014 (Appendix 2 to Neptune 2014a).

Neptune and Company, Inc., 2014c. *Embankment Modeling for the Clive DU PA Model v1.2*, NAC-0019_R1, June 5, 2014 (Appendix 3 to Neptune 2014a).

Neptune and Company, Inc., 2014d. *Radioactive Waste Inventory for the Clive DU PA Model v1.2*, NAC-0023_R1, June 5, 2014 (Appendix 4 to Neptune 2014a).

1.0 INTRODUCTION

Utah Administrative Code (UAC) Rule R313-25-9,[3] "Technical Analyses," requires that any facility that proposes to dispose of significant quantities of depleted uranium (DU) must submit a performance assessment demonstrating that the performance standards specified by the U.S. Nuclear Regulatory Commission (NRC) in Title 10 of the Code of Federal Regulations (10 CFR) Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," and corresponding State of Utah rules will be met for a minimum of 10,000 years and that additional simulations be performed for the period when the peak dose occurs (which will be well beyond 10,000 years) and the results of the additional simulations be analyzed qualitatively. The specific language of the rule is as follows:

> *R313-25-9. Technical Analyses*
>
> *(5)(a) Notwithstanding Subsection R313-25-9(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.*

This requirement is embedded in Energy*Solutions*, LLC's (Energy*Solutions*') Radioactive Material (RML) License UT2300249 (Amendment 14, Condition 35; DRC 1989), which states that:

> *A. In accordance with UAC R313-25-8, effective June 1, 2010 the Licensee shall not dispose of significant quantities of concentrated depleted uranium prior to the approval by the Director of the performance assessment required in R313-25-8.* [Now R313-25-9].
>
> *B. 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*

[3] A new Section 6, "Director Review of Application," was added to R313-25 in April 2014. Thus all references to R313-25 Sections 6 to 28 in prior documents are now to Sections 7 to 29.

> *simulations will be performed for a minimum 1,000,000-year time frame for qualitative analysis.*
>
> *C. Revised disposal embankment design: If the performance assessment specified in paragraph 35.B indicates that changes to disposal operations and cover design are necessary to ensure compliance with the requirements of 10 CFR Part 61 or Utah Administrative Code R313, Energy*Solutions *will provide a revised design that does meet those requirements, for all wastes that have been and are reasonably anticipated to be disposed of at the facility; the revised design will be submitted within 180 days of Director approval of the performance assessment.*
>
> *D. Remediation: If following the completion of DRC's review of the performance assessment described in paragraph 35.B, the disposal of DU as performed after the date of this license condition would not have met the requirements of the performance assessment, the facility will undertake remediation to ensure that the performance standards are met, or if that is not possible, shall remove the DU and transport it off-site to a licensed facility.*
>
> *E. Surety: The Licensee shall fund the surety for the remediation, in License Condition 35.D. Within 30-days of the effective date of this license condition, the licensee shall submit for Director review and approval, the surety cost estimates for remediation of existing Savannah River DU waste disposal and planned, similar large quantity DU waste disposal.*

The purpose of this Safety Evaluation Report (SER) is to determine the extent to which the depleted uranium performance assessment (DU PA) submitted by Energy*Solutions* on June 1, 2011 (Neptune 2011b), and revised on June 5, 2014 (Neptune 2014a), complies with the requirements of UAC R313-25-9(5)(a). In particular, the DU PA evaluates disposal of DU at the Energy*Solutions* facility at Clive, Utah.

"Performance standards" is not defined in 10 CFR Part 61 or in the corresponding Utah rules. However, DEQ notes that SECY-13-0075, Enclosure 2, "Draft Regulatory Analysis for Proposed Rule: Low-Level Radioactive Waste Disposal (10 CFR Part 61)," Section 1.2, states that "*10 CFR Part 61, Subpart C, contains performance objectives, which set standards*" (NRC 2013a, page 3), so it is reasonable to assume that the "performance standards" referred to in UAC R313-25-9(5)(a) are set by the NRC's 10 CFR Part 61, Subpart C "performance objectives."

For purposes of this SER, the Utah Department of Environmental Quality (DEQ) has defined "performance standards" as those contained in the relevant portions of Subpart C, "Performance Objectives," of 10 CFR Part 61: Section 61.41, "Protection of the General Population from Releases of Radioactivity" (corresponding to UAC Rule R313-25-20); Section 61.42, "Protection of Individuals from Inadvertent Intrusion" (corresponding to UAC Rule R313-25-21); and Section 61.44, "Stability of the Disposal Site after Closure" (corresponding to UAC Rule R313-

25-23).[4] The NRC performance objective specified in 10 CFR 61.43, "Protection of Individuals during Operations [corresponding to UAC Rule R313-25-22 and also required under UAC Rule R313-25-9(4)(c)], was not addressed in depth in the DU PA. However, Energy*Solutions* discussed this performance standard in some detail in Section 3.3 of Revision 1 to its "Utah Radioactive Material License – Condition 35 (RML UT2300249) Compliance Report," dated November 8, 2013, (ES 2013b).

In addition, NRC regulations in 10 CFR 61.12, "Specific Technical Information" (corresponding to UAC Rule R313-25-8) and 10 CFR 61.13, "Technical Analyses" (corresponding to UAC Rule R313-25-9), provide supporting data necessary to demonstrate compliance with the performance standards; therefore, they are included in this SER. Sections of NRC regulation 10 CFR 61.12 judged not to be relevant to the DU PA include sub-sections 61.12(k), (l), (m), and (n). Technical information specified in these sub-sections constitutes generic requirements typically considered in disposal of any radioactive material. Hence, these issues have already been considered and approved by the Division of Radiation Control (DRC) Director (hereafter "the Director") in previous requests for license amendment. Several other NRC regulations in 10 CFR Part 61, Subpart D underlie and support the "performance standards" for low-level radioactive waste (LLRW) disposal; some of these include: 10 CFR 61.50, "Disposal Site Suitability Requirements for Land Disposal"; 10 CFR 61.51, "Disposal Site Design for Land Disposal"; and 10 CFR 61.52, "Land Disposal Facility Operation and Disposal Site Closure" [specifically, paragraph (a)]. Again, these are generic requirements that have been addressed in previous licensing actions.

Section 4.1 of this SER evaluates the DU PA in relation to 10 CFR 61.12 (and UAC Rule R313-25-8, "Specific Technical Information"); Section 4.2 evaluates it in relation to 10 CFR 61.41 (and R313-25-20, "Protection of the General Population from Releases of Radioactivity"); Section 4.3 in relation to10 CFR 61.42 (and R313-25-21); and Section 4.4 in relation to 10 CFR 61.44 (and UAC Rule R313-25-23, "Stability of the Disposal Site after Closure"). The technical analyses required under 10 CFR 61.13 (and UAC Rule R313-25-9), 10 CFR 61.50, 10 CFR 61.51, and relevant portions of 10 CFR 61.53 are discussed in detail in all of these sections; consequently, there is no need to address these separately in this SER.

For the reader's convenience, Appendix A to this SER includes the text of the key cited regulations.

Section 5.1 discusses the deep time analysis required under UAC Rule R313-25-9(5)(a); specifically, that "*Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.*"

The DU PA prepared by Energy*Solutions* also considered topics outside the purview of these NRC and UAC regulations, including uranium toxicity and Utah groundwater protection levels (GWPLs). This SER evaluates these topics in Sections 5.2 and 5.3, respectively.

[4] To be consistent with R313-25-9(5)(a), which lists "performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules," this SER lists the relevant NRC regulations first, followed by the State of Utah regulations

This SER relies on currently available information. However, the technology of in-ground waste disposal is continuously evolving. As will be subsequently discussed in this SER, several issues have been identified relating to the evapotranspiration (ET) cover to be placed on the proposed Federal Cell. These issues will need to be resolved before any license amendment related to DU waste disposal at Clive can be approved. If such approval is granted by DEQ, the approval will be based on an assessment of many uncertainties addressed in performance assessment and a determination that such uncertainties will not compromise the designed function of DU disposal embankment.

It should be noted that this SER apples only to approval/disapproval of the DU PA as required by UAC Rule R313-25-9(5)(a). That regulation does not consider "other wastes," which must be addressed in a separate performance assessment. If the DU PA performance assessment is approved, it is expected that the next step in the regulatory process would be submission of a proposed license amendment for review by DEQ.

References[5]

DRC, 1989

ES, 2013b

Neptune, 2011b; 2014a

NRC, 2013a

1.1 TIMELINE OF KEY DEQ REVIEW ACTIVITIES

The timeline of the key DEQ review activities related to the DU PA, and used to develop input to this SER, is as follows:

- June 1, 2011 – Energy*Solutions* delivers an initial version of the DU PA. The initial package consists of the Compliance Report, Appendix A to the Compliance Report [*Final Report for the Clive DU PA Model* (hereafter "DU PA Model")*, version 1.0*], and 17 appendices to the Final Report dealing with specific technical areas such as unsaturated zone modeling, geochemical modeling, conceptual site model, and others.
- August 15, 2013 – DEQ contracts with SC&A, Inc. (SC&A) to provide technical support in reviewing the DU PA (August 15, 2013).
- October 28, 2013 – DEQ provides comments based on its preliminary completeness review of the DU PA to Energy*Solutions*.
- November 8, 2103 – Energy*Solutions* submits CD13-0302. The submittal contains both Revision 1 to the Compliance Report and partial responses to the Preliminary Completeness Review (later designated Appendix B in the Energy*Solutions* July 8, 2014, submittal).

[5] All short reference lists at the ends of sections refer to the full References list in Chapter 7.

- November 13, 2013 – DEQ hosts open house meeting for public interaction on the review process.
- December 11, 2013 – DEQ provides Energy*Solutions* with feedback on Revision 1 to the Compliance Report and on its responses to the Preliminary Completeness Comments.
- February 28, 2014 – DEQ delivers Round 1 Interrogatories to Energy*Solutions*.
- March 31, 2014 – Energy*Solutions* delivers a partial response to Round 1 Interrogatories (CD14-0084). Because Energy*Solutions* determined that the initially-proposed rock armor cover for the proposed Federal Cell should be replaced by an ET cover, some interrogatories could not be addressed until a revised DU PA based on the ET cover was completed (later submitted by Energy*Solutions* on June 5, 2014).
- May 27, 2014 – DEQ provides Round 2 Interrogatories to Energy*Solutions*.
- June 5, 2014 – Energy*Solutions* delivers Version 1.2 of the Clive DU PA Model and revised supporting appendices. Version 1.2 is based on the ET cover and addresses responses to some of the prior interrogatories.
- June 17, 2014 – Energy*Solutions* delivers responses to Round 2 Interrogatories (CD14-0132).
- July 1, 2014 – DEQ provides Energy*Solutions* with Round 3 Interrogatories. The Round 3 Interrogatories focus on Version 1.2 of the Clive DU PA Model (June 5, 2014) and consider the Energy*Solutions* responses to the Round 2 Interrogatories (June 17, 2014) only to a limited extent.
- July 8, 2014 – Energy*Solutions* provides DEQ with RML UT2300249, Condition 35 Compliance Report Revision 2 and responses to DEQ Round 3 Interrogatories.
- July 14, 2014 – DEQ provides Energy*Solutions* with a White Paper on deep time analysis prepared by SC&A regarding radon emissions in the event of a return of a pluvial lake on the Clive site (and its possible effects on the DU disposal cell).
- August 5, 2014 – Energy*Solutions* submits a Deep Time Supplemental Analysis for the Clive DU PA (Clive DU PA Model vDTSA).
- August 11, 2014 – DEQ provides Energy*Solutions* with supplementary interrogatories.
- August 18, 2014 – Energy*Solutions* provides DEQ with responses to DEQ supplementary interrogatories.
- February 6, 2015 – Energy*Solutions* provides DEQ with Supplemental Responses dealing with site-specific clay studies pertinent to both the SempraSafe and DU PAs.
- March 10, 2015 – Energy*Solutions* submits revised Deep Time Supplemental Analyses for the Clive DU PA.

This SER is based on review of Versions 1.0 and 1.2 of the *Final Report for the Clive DU PA Model* (Neptune 2011b, 2014a) and its supporting appendices, the Compliance Report [Revision 0 (ES 2011b), Revision 1 (ES 2013b), and Revision 2 (ES 2014c)], and consideration of Energy*Solutions*' responses to 194 interrogatories submitted by DEQ, in documents dated

February 28, 2014, March 27, 2014, and July 1, 2014, respectively, as well as the supplementary interrogatories of August 11, 2014, which can be found in the SER Appendix B, "Supplemental Interrogatories Pertaining to the Evapotranspiration Cover"). The review also included independent calculations and analyses conducted by the DEQ contractor on selected topics. Appendix C discusses the status of resolution of all other interrogatories.

References

ES, 2011b; 2013b; 2014c

Neptune, 2011b; 2014a

1.2 FORMAT OF THE SAFETY EVALUATION REPORT

DEQ's review findings on the Clive DU PA are included in this SER. The format of the SER is as follows:

Section 1.0 Provides an introduction to the SER, including its purpose, important regulations, and the timeline for the development of the Clive DU PA.

Section 2.0 Provides an historical overview of the activities that have occurred at the site of the Clive facility since it was first used by the U.S. Department of Energy (DOE) and the State of Utah between 1984 and 1988 for the disposal of Vitro Mill tailings, and thereafter for the Envirocare period, which ran from 1988 to 2006, and finally for the Energy*Solutions* facility.

Section 3.0 Provides background information that DEQ felt would be useful to individuals who may not have it otherwise readily available. This includes a description of DU, the regulatory bases for disposing of DU at the Clive facility, an introduction to the Clive facility, and an introduction to how the Clive DU PA Model was developed.

Section 4.0 Provides DEQ findings and safety evaluations of whether or not the Clive DU PA demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules have been met, as is required by UAC R313-25-9(4) and R313-25-9(5)(a).

The subsections within Section 4 have been structured to correspond to the 10 CFR Part 61 and UAC R313-25 performance standards:

Section 4.1	10 CFR 61.12 – Specific technical information	UAC Rule R313-25-8
Section 4.2	10 CFR 61.41 – Protection of the general population from releases of radioactivity	UAC Rule R313-25-20
Section 4.3	10 CFR 61.42 – Protection of individuals from inadvertent intrusion	UAC Rule R-313-25-21
Section 4.4	10 CFR 61.44 – Stability of the disposal site after closure	UAC Rule R313-25-23

Section 5.0 Provides additional DEQ findings and safety evaluations of whether or not the

Clive DU PA demonstrates that the public's health and safety and the environment will be protected.

The criteria that have been evaluated within Section 5 are as follows:

Section 5.1	Deep Time Analysis: The deep time analysis is specifically required by UAC Rule R313-25-9(5)(a).
Section 5.2	Uranium Oral Toxicity: Because uranium is chemically as well as radiologically toxic, a uranium oral toxicity evaluation has been included pursuant to the U.S. Environmental Protection Agency's (EPA's) 40 CFR 141.66.
Section 5.3	Compliance with GWPLs: Compliance with the GWPLs is specified in the Clive facility's Ground Water Quality Discharge Permit #UGW450005 (hereafter referred to as the "GWQ Permit").

Section 6.0	Provides a summary of all of the conclusions reached in Sections 4 and 5, as well as an overall recommendation as to whether the Clive DU PA should be accepted, accepted with conditions, or denied.
Section 7.0	Provides a list of documents referred to in the SER.
Appendix A	Provides the text of relevant federal and Utah regulations for the reader's reference.
Appendix B	Provides a discussion of supplemental interrogatories pertaining to the modeling of the ET cover.
Appendix C	Provides a summary of DEQ interrogatories and their current status.
Appendix D	Provides a summary of the applicability of transuranic limitations in the Northwest Interstate Compact on Low-Level Radioactive Waste Management.
Appendix E	Describes a method for simulating the hydrology of the water balance cover.
Appendix F	Responds to Energy*Solutions*' February 2015 report on the impacts of freeze-thaw on the hydraulic conductivity of the clay barriers used on the ET cover.
Appendix G	Provides an interpretation of the Huntsman Agreement by the State of Utah Assistant Attorney General.
Appendix H	Provides a summary of historical and current understanding about the deep aquifer in the vicinity of the proposed Federal Cell.

2.0 HISTORICAL OVERVIEW

Energy*Solutions* is licensed by the State of Utah to receive, store, and dispose, by land burial, the following categories of radioactive materials and waste:

- Naturally occurring and accelerator produced radioactive material waste
- Low-activity radioactive waste (LARW)
- Class A LLRW
- Special nuclear material (in trace quantities only)
- 11.e.(2) byproduct waste (e.g., uranium mill tailings)
- Radioactive waste that is also determined to be hazardous (mixed waste)
- Naturally occurring radioactive material (NORM)

Energy*Solutions* holds the following licenses and permits:

- State of Utah Radioactive Material License UT2300249, Amendment 17 (June 4, 2014), expires January 25, 2013 (under timely renewal[6])
- State of Utah Radioactive Material License, 11(e).2 Byproduct Material License UT2300478, Amendment 10 (August 2, 2013) (under timely renewal)
- State of Utah Part B Permit, EPA Identification Number UDT982598898, expires April 4, 2013 (under timely renewal)
- State of Utah Ground Water Quality Discharge Permit Number UGW450005, (modified effective February 18, 2014), expires June 8, 2013 (currently under timely renewal)

The first activities involving radioactive waste management at Clive, Utah, were those conducted by DOE.[7] DOE removed uranium mill tailings from the inactive Vitro Mill site located near Salt Lake City, Utah, beginning in February 1985 and concluding in June 1989. Uranium mill tailings and radioactively contaminated materials that remained at the inactive Vitro site were excavated and relocated by rail and truck to the Clive site, located 85 miles west of Salt Lake City. The tailings and contaminated materials were transferred to a specially constructed embankment in Section 32, Township 1 South and Range 11 West, Salt Lake Baseline and Meridian, Tooele County, Utah. Concurrent with the Vitro relocation project, Envirocare of Utah, Inc. (Envirocare, Inc., which subsequently merged with other companies in 2006 to become Energy*Solutions,* LLC) began disposal operations at its Clive Facility in 1988 under a state radioactive materials license to dispose of NORM waste. In 1990, the Licensee submitted a license application to modify its license to allow disposal of LARW. In 1991, the Division of Radiation Control (DRC)

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[6] "Timely renewal" means that the Licensee has made a timely filing of a license renewal application and that the current license remains in effect until DRC reaches a decision on the newly submitted license renewal application.

[7] Much of the historical material cited here was extracted directly from Utah Division of Radiation Control, *Energy*Solutions *LLRW Disposal Facility Class A West Amendment Request, Safety Evaluation Report*, June 2012. (DRC 2012a).

granted the amendment request by adding LARW disposal to the facility's license. From time to time, the LARW disposal license was amended to address changes needed based on review of Licensee-furnished submittals and/or updated or new regulatory guidelines. In 1998, the DRC Director (hereafter "the Director") renewed the Licensee's license to dispose of LARW. In September 2009, Energy*Solutions* submitted a License Amendment for DU disposal (Hultquist 2010).

The ownership history of the radioactive waste disposal facilities located at South Clive, Utah, is as shown in Table 2-1.

Table 2-1 – Ownership History

Owner	Dates of Ownership
Envirocare of Utah, Inc.	February 2, 1988, through May 15, 2005
Envirocare of Utah, LLC	May 16, 2005, through March 1, 2006
Energy*Solutions*, LLC	Commencing March 2, 2006

The licensing and permitting history of the Clive, Utah, site is as follows:

- 1984–1989 – DOE Disposal of Vitro Tailings: Remedial activities began at the Salt Lake City Vitro mill site in February 1985 and were completed in June 1989. Contaminated materials that remained at the Vitro Mill site were excavated and relocated by rail and truck to a South Clive disposal cell, a new site acquired by the State of Utah and located 85 miles west of Salt Lake City.
- 1988 – Envirocare, Inc. Began Disposing of NORM: On February 28, 1988, Envirocare, Inc. received its first license from the State Bureau of Radiation Control to dispose of NORM.
- 1991 – License Amendment for LARW Disposal: On March 21, 1991, Envirocare, Inc. received an LARW license from the State Bureau of Radiation Control to accept 44 radionuclides with specified concentration limits less than Class A LLRW limits. This type of waste is termed LARW. The Utah GWQ Permit was issued this same day for the Envirocare LLRW facility.
- 1991 – Mixed Waste Permit: On November 30, 1991, Envirocare, Inc. received a Resource Conservation and Recovery Act hazardous waste permit from the State Bureau of Solid and Hazardous Waste to accept mixed waste.
- 1992 – Resolution and Order Agreement with Northwest Interstate Compact (hereafter "the Compact" or "Northwest Compact"): On May 28, 1992, Envirocare, Inc. entered into an arrangement, the "Resolution and Order" with the Compact, that allowed it to accept certain types of LLRW from outside of the Compact. Envirocare, Inc. did not receive Compact approval to receive LLRW from Northwest Compact states. However, Envirocare, Inc. was granted permission to accept mixed waste from all states. The Resolution and Order was the result of a discussion at a December 18, 1991, meeting of the Compact. The Resolution and Order has subsequently been modified and reviewed.

- 1993 – Uranium Mill Tailings [11e.(2)] Disposal License from the NRC: On November 30, 1993, Envirocare, Inc. received a license from the NRC to accept uranium mill tailings.
- 1993 – LARW License Amended: On August 27, 1993, Envirocare, Inc.'s LARW license was modified by the DRC to accept 14 additional radionuclides with specified concentration limits less than the Class A limits.
- 1994 – The Utah GWQ Permit was modified to authorize 11e.(2) waste receipt, management, and disposal in the southwest corner of Section 32 (April 29).
- 1995 – LARW License Amended: On June 20, 1995, Envirocare, Inc.'s LARW license was modified by the DRC to accept 17 additional radionuclides with specified concentration limits less than the Class A LLRW limits. It was subsequently amended on November 13, 1995, to accept eight additional radionuclides with specified concentration limits less than the Class A LLRW limits.
- 1996 – LARW Renewal Request Submitted: In August 1996, Envirocare, Inc. submitted a renewal request for the LARW license to the DRC.
- 1996 – Macro-encapsulation Approval: On October 3, 1996, Envirocare, Inc. received a Hazardous and Solid Waste Amendment permit for waste macroencapsulation from EPA Region 8.
- 1998 – Amended Resolution and Order Agreement with Northwest Compact: The Second Amended Resolution and Order of November 9, 1998, is currently in effect. With very few exceptions, Envirocare, Inc. could not accept waste from Northwest Compact states. Envirocare, Inc. could accept NORM, LLRW, and mixed waste from all other approved Compact states and non-approved states. The restrictions of the Amended Resolution and Order are presently followed by Energy*Solutions*.
- 1998 – LARW License Renewal Containing LLRW Amendment Request Approved: On October 22, 1998, Envirocare, Inc.'s LARW license was renewed and issued as a 5-year LLRW license by the Director, which included concentration limits by radionuclides less than and up to the Class A LLRW limits.
- 1999 – Class B & C LLRW License Application Submitted.
- 2000 – Full Class A Waste Disposal Cell Approved: On October 5, 2000, Envirocare, Inc. was issued a license amendment by the Director for a new Class A disposal cell that allowed it to begin disposing of Class A wastes within an approved Class A disposal embankment area.
- 2001 – Land Ownership Exemption Granted: On January 19, 2001, the Utah Radiation Control Board (URCB) granted Envirocare, Inc. an exemption to the state and federal land ownership rule based on several conditions being met.
- 2001 – Class B & C License Granted Pending Approval: On July 9, 2001, Envirocare, Inc. was issued a separate license from the DRC to accept Class B and C LLRW, pending legislature and gubernatorial approval. The license was subsequently appealed to the URCB.

- 2001 – Class A LLRW Cask Amendment Granted: On October 19, 2001, Envirocare, Inc. was issued an approval for a license amendment to receive and dispose of full-concentration Class A LLRW in casks.
- 2002 – Resolution and Order Agreement with Northwest Compact Reviewed: The Second Amended Resolution and Order of November 9, 1998, was most recently reviewed at the June 5, 2002, meeting of the Compact and no changes were made. Therefore, Energy*Solutions* is presently required to follow the 1998 Resolution and Order Agreement that was made with the Compact.
- February 2003 – Final Agency Action on Class B & C Waste: On February 10, 2003, Envirocare, Inc. was granted final agency action by the URCB on the Class B and C LLRW license, pending legislative and gubernatorial approval.
- March 2003 – NRC Uranium Mill Tailings License Amendment Request: On March 27, 2003, Envirocare, Inc. submitted a request to the NRC to amend its NRC uranium mill tailings license to accept tailings with radium-226 (Ra-226) concentrations up to 100,000 picocuries per gram (pCi/g). This was to allow it to accept the DOE Fernald Site Closure Project (Fernald) waste if it were classified as 11e(2) byproduct material.
- May 2003 – NRC Uranium Mill Tailings Disposal License Renewal Request: On May 27, 2003, Envirocare, Inc. submitted a license renewal application to the NRC for the uranium mill tailings disposal cell. Envirocare, Inc. was granted timely renewal (current license remaining in effect until a decision is reached on the license renewal application).
- July 2003 – Class A LLRW License Renewal Request: On July 2, 2003, Envirocare, Inc. submitted a license renewal application to the Division for its LLRW license. Envirocare, Inc. was granted timely renewal.
- November 2003 – Withdrawal of 2003 NRC Uranium Mill Tailings License Amendment Request: On November 19, 2003, Envirocare, Inc. withdrew its request for a license amendment from the NRC to accept waste from the DOE Fernald site.
- 2004 – Mixed Waste License Public Comment Period: On May 4, 2004, a 30-day public comment period commenced on an amendment to the LLRW license for Envirocare, Inc. to accept mixed waste up to Class A limits.
- January 2005 – Class A LLRW North Embankment Amendment Request: On January 17, 2005, Envirocare, Inc. submitted a request for a license amendment to the LLRW license to allow disposal of Class A materials in the northern area previously approved for Class A, B, and C waste disposal.
- February 2005 – Withdrawal of Class B and C Waste License Request: In February 2005, Envirocare, Inc. withdrew a request for a Class B and C waste disposal license.
- May 2005 – Name Change: On May 16, 2005, the name on the licenses and permits was changed from Envirocare of Utah, Inc. to Envirocare of Utah, LLC.

- May 2005 – Submission of the Class A Combined (CAC) Amendment Request: On May 27, 2005, Envirocare, LLC submitted a license amendment request to the LLRW license to create a CAC cell.
- June 2005 – Submittal of License Renewal Application: On June 20, 2005, Envirocare, LLC submitted an application to renew its LLRW disposal license.
- 2006 – Transfer of Licenses and Permits: On March 2, 2006, the licenses and permits were transferred from Envirocare of Utah, LLC to Energy*Solutions*.
- 2007 – Agreement with Governor Huntsman: On March 15, 2007, Energy*Solutions* entered into an agreement with Governor Huntsman to withdraw the amendment request for a CAC cell.
- 2011 – Submission of the Class A West (CAW) Embankment License Amendment Request: On May 2, 2011, Energy*Solutions* submitted a request to amend the LLRW license and permit to create the proposed CAW disposal embankment and to formally retract a previous request for a CAC disposal cell.
- 2012 – Submission of Radioactive Material License No. UT2300249 Renewal Application: On October 25, 2012, Energy*Solutions* submitted a request to renew License UT 2300249. The application specified use of an ET cover on the CAW cell.
- 2014 – DRC Issuance of LLRW License Amendment: On May 12, 2014, DRC issued a LLRW License Amendment, No. 16, approving the May 2, 2011, Energy*Solutions* request for redesign of the CAW Embankment. This design included a rock armor/radon barrier cover system.

References

DRC, 2012a

Hultquist, 2010

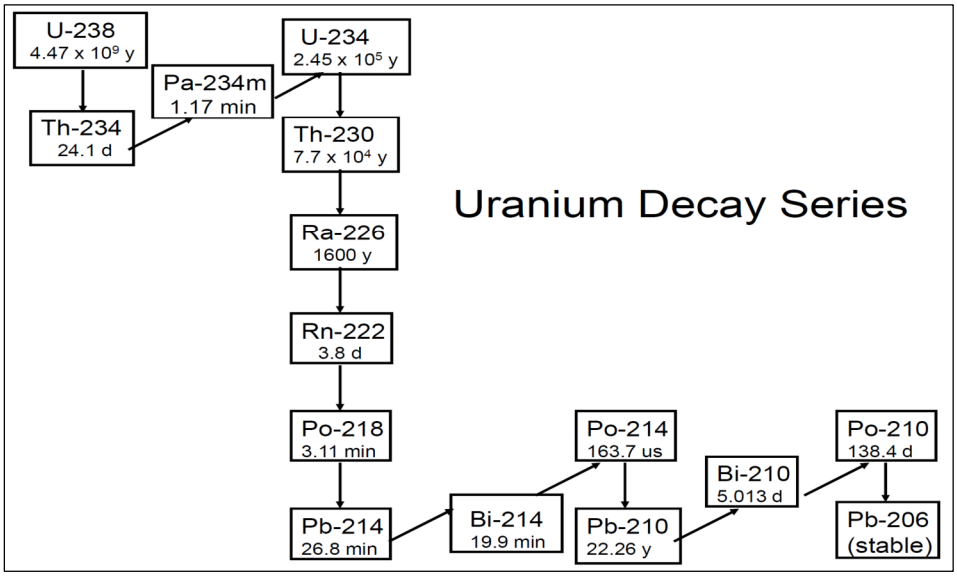
3.0 CLIVE DEPLETED URANIUM PERFORMANCE ASSESSMENT: BASIS AND DESCRIPTION

3.1 DEPLETED URANIUM

DU waste is a product of the process used to enrich natural uranium for use in nuclear reactors and in nuclear weapons. Natural uranium is composed primarily of two isotopes; uranium-235 (U-235) (0.7 percent by weight [wt%] of natural uranium), and U-238 (99.3 wt%). U-235 is the readily fissionable isotope of uranium; for the types of nuclear power plants operating in the United States, the concentration of U-235 needs to be increased (or enriched) to between 3 and 5 wt% for use as a nuclear fuel. The enrichment process concentrates the U-235 isotope in the fuel product material, resulting in a waste that is *depleted* in U-235. Uranium with a concentration of U-235 below that of natural uranium (0.7 wt%) is called "depleted uranium" (DU). For example, if an enrichment facility processes 1,000 kilograms (kg) of natural uranium to raise the U-235 concentration from 0.7 wt% to 5 wt%, the facility would produce 85 kg of enriched uranium and 915 kg of DU.

DU retains a smaller percentage of U-235 and a slightly greater percentage of U-238 (99.8 wt% instead of 99.3 wt%). Because of the shorter half-life of U-235 compared to U-238, the radioactivity associated with newly formed DU is, at that time, approximately 40 percent less than that of natural uranium.

When U-238 decays, it produces a series of decay products, as shown in Figure 3-1. In nature, U-238 is in equilibrium with its decay products, meaning that the activity of the decay products is decreasing according to the half-life of U-238.



Source: NRC (2011).

Figure 3-1 – The uranium series

However, when uranium is purified in preparation for being used as nuclear reactor fuel, all of its decay products are chemically removed. Over time, the decay products will build back up and reestablish equilibrium with the parent radionuclide, U-238. The time it takes to reestablish

equilibrium with U-238 is directly proportional to the decay product's half-life; for example, thorium-234 (Th-234) and protactinium-234 (Pa-234m), which have short half-lives, will reestablish equilibrium with U-238 in a matter of months. Because of its 2.45×10^5-year half-life (see Figure 3-1), U-234 will not reestablish equilibrium with U-238 for several hundreds of thousands of years. The decay products after U-234 (e.g., Th-230, Ra-226, etc., see Figure 3-1) will initially establish equilibrium with U-234 and build with U-234 toward reestablishing equilibrium with U-238. For the Clive DU PA Model, EnergySolutions has calculated that, at 2.1 million years, lead-210 (Pb-210) (the last radionuclide in the series modeled) has reestablished equilibrium with U-238 to within less than one half of one percent (ES 2014d). While Ra-226 also reaches its peak activity in this same time frame, the majority of its equilibrium activity (>95 percent) is accomplished in approximately 1 million years.

References

ES, 2014d

NRC, 2011

3.2 LICENSE CONDITION 35

The framework for the technical analysis of the disposal of radioactive waste was developed in the 1980s with the NRC's issuance of Title 10 of the Code of Federal Regulations (10 CFR) Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste." Part 61 established a waste classification scheme based on the role that the radionuclide concentration and waste form play in the long-term performance of disposal facilities. The final Part 61 analyses did not consider large quantities of DU waste because, at that time, there were no commercial facilities producing large quantities of DU, and DU produced at Federal facilities was not regulated by the NRC; instead, it was controlled and managed by DOE as a possible future resource. Because Utah is an Agreement State, the Utah regulations for the issuance of licenses for the land disposal of radioactive wastes, as discussed within UAC R313-25, closely follow the NRC's Part 61 regulations.

In October 2008, 5,800 drums containing the DU from DOE's Savannah River Site (SRS) were sent to the Energy*Solutions* facility at Clive for disposal. Later, DEQ was informed by Energy*Solutions* that the SRS inventory included about 33,000 drums of DU waste needing disposition. Additionally, it was learned that DOE intended to dispose of a large quantity of DU [~700,000 megagrams (Mg) or 700,000 metric tons; Neptune 2014i, Section 2.0] at the Energy*Solutions* Clive facility.

Because the DU disposal issue was of more immediate concern in Utah than in the United States generally, DEQ took more timely action than did the NRC to develop a solution.

Beginning in the fall of 2009, the URCB received public comments and held discussions regarding proposed DU disposal at Energy*Solutions* facilities. These discussions led to a formal rulemaking effort by the URCB to amend UAC R313-25, as discussed below.

While this rulemaking was underway, DEQ, on March 2, 2010, imposed Condition 35 on the Energy*Solutions* RML UT2300249 to address DU and other concerns. License Condition 35 consists of five parts: (a) uranium concentration, (b) performance assessment, (c) revised

disposal embankment design, (d) remediation, and (e) surety. The first three parts of Condition 35 are directly related to this SER:

A. *In accordance with UAC R313-25-8, effective June 1, 2010 the Licensee shall not dispose of significant quantities of concentrated depleted uranium prior to the approval by the Director of the performance assessment required in R313-25-8* [note: the relevant rule at that time was R313-25-8; it is now R313-25-9].

B. *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.*

C. *Revised disposal embankment design: If the performance assessment specified in paragraph 35.B indicates that changes to disposal operations and cover design are necessary to ensure compliance with the requirements of 10 CFR Part 61 or Utah Administrative Code R313, Energy*Solutions *will provide a revised design that does meet those requirements, for all wastes that have been and are reasonably anticipated to be disposed of at the facility within 180 days of Director approval of the performance assessment.*

References

Neptune, 2014i

3.3 UAC RULES R313-28-9(4) AND R313-25-9(5)(a)

In the January 1, 2010, issue (Vol. 2010, No. 1) of the *Utah State Bulletin*, DEQ published a notice of proposed rule UAC R313-25-8, with an effective date of June 2, 2010 (DRC 2010). At that time, UAC R313-25-8 consisted of two provisions: (1) identification of five analyses needed to demonstrate that the performance objectives will be met and (2) performance assessment requirements for any facility that proposes to dispose of large quantities of DU. Since then, three more provisions have been added to R313-25-8 to better define which licensees and applicants need to conduct a site-specific performance assessment, and the rule has been re-numbered to UAC R313-25-9 (as of May 2014). The portions of R313-25-9 that are most relevant to this SER are Sections (4)(a)–(d) and (5)(a), which are reproduced here:

(4) The licensee or applicant shall also include in the specific technical information the following analyses needed to demonstrate that the performance objectives of Rule R313-25 will be met:

(a) 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 Section R313-25-20.

(b) Analyses of the protection of inadvertent intruders shall demonstrate a reasonable assurance that the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided.

(c) 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 Rule R313-15.

(d) Analyses of the long-term stability of the disposal site shall be based upon analyses of active natural processes including erosion, mass wasting, slope failure, settlement of wastes and backfill, infiltration through covers over disposal areas and adjacent soils, surface drainage of the disposal site, and the effects of changing lake levels. The analyses shall provide reasonable assurance that there will not be a need for ongoing active maintenance of the disposal site following closure.

(5)(a) Notwithstanding Subsection R313-25-9(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.

It is worth noting that the performance assessment requirements for the disposal of large quantities of DU contained within R313-25-9(5)(a) are essentially the same as those required in License Condition 35B—one difference being the duration of the "qualitative analysis" period. Condition 35B specified that the qualitative analysis period be 1 million years, while UAC R313-25-9(5)(a) specifies "the period where peak dose occurs." Currently, License Condition 35 continues to identify the qualitative analysis period as a minimum of 1 million years.

Consistent with License Condition 35B, DEQ understands that, sometime in the future, it may need to revise R313-25-9(5)(a) once the NRC issues its own requirements for the disposal of large quantities of DU.

References

DRC, 2010

3.4 PROPOSED FEDERAL CELL DESIGN

Energy*Solutions* operates an LLRW disposal facility west of the Cedar Mountains in Clive, Utah. Clive is located along Interstate-80, approximately 5 kilometers (km) (3 miles) south of the highway, in Tooele County. The facility is approximately 80 km (50 miles) east of Wendover, Utah, and approximately 100 km (60 miles) west of Salt Lake City, Utah. The facility sits at an elevation of approximately 1,302 meters (4,275 feet) above mean sea level (amsl) and is accessed by both road and rail transportation.

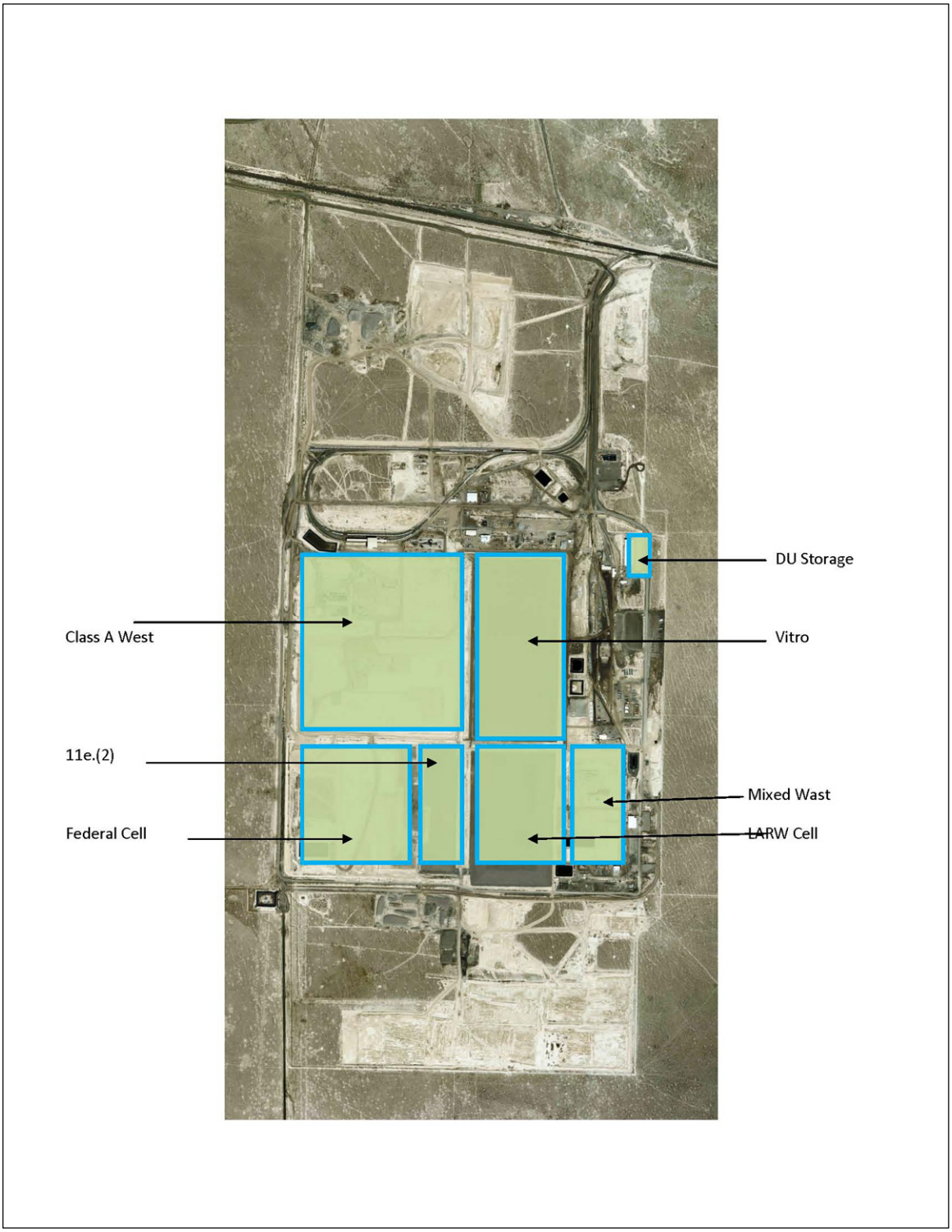
The disposal cell in the southwestern-most part of Section 32 has been defined as the "11e.(2) Cell," which was initially authorized by the NRC in 1995, before Utah became an Agreement State.[8] The currently approved 11e.(2) Cell occupies a footprint of about 2,254 feet (751 yards) by 1,767 feet (589 yards), which is about 3.98 million square feet (about 442,339 square yards) (ES 2002), and is licensed with a waste disposal capacity of about 5.04 million cubic yards (ES 2007).

On January 4, 2008, Energy*Solutions* requested a design change to the 11e.(2) Cell that would allow LLRW to be disposed of in the western portion of the 11e.(2) Cell, which was and still is unused. That configuration was known as the Class A South (CAS) Cell proposal. This LLRW disposal area was to be 1,472 feet by 1,860 feet in size (ES 2008a), with a geometry similar to that proposed today; for details, see Figure 3-3 and Table 3-2. As part of the DRC review process, a November 26, 2008, Completeness Review was issued (DRC 2008). Later, in an Energy*Solutions* letter of May 2, 2011, the company withdrew its request for the CAS Cell (ES 2011a).

In the initial DU PA, Energy*Solutions* had proposed a Federal DU embankment inside the western fraction of the Federal Cell (Figure 3-2). As before, the eastern section was to be occupied by the 11e.(2) Cell, which is dedicated to the disposal of uranium processing byproduct waste but is not considered in this analysis. Subsequently, Energy*Solutions* decided that the Federal Cell and the 11e.(2) Cell would be physically separate and informally provided drawings of the revised Federal Cell on November 14, 2014 (Rogers 2014b). A stylized drawing of the proposed Federal Cell and its relationship to the 11e.(2) Cell is shown in Figure 3-3; Federal Cell dimensions are given in Table 3-2.

The DU disposal zone inside the Federal Cell embankment is proposed to be located at the bottom of the cell, below native grade under the top slope area. Dimensions for the DU disposal zone are approximately 7.4 feet thick by 968 feet wide (east–west) by 1,425 feet long (north–south) [ES Drawing No. 14004 L1A (1)]. This equates to a design capacity for DU disposal of about 10.2 million cubic feet (about 378,000 cubic yards), all below native grade.

[8] 11e.(2) waste is the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. State regulation of the Energy*Solutions* 11e.(2) waste cell for engineering design and groundwater protection began with issuance of a GWQ Permit modification in April 1994.



Source: Energy*Solutions*.

Figure 3-2 – The Clive facility, showing the location of the proposed Federal Cell embankment and other embankments. This orthophotograph is roughly 1 mile across, and north is up.

The general aspect of the proposed Federal Cell embankment is that of a hipped cap, with relatively steeper sloping sides nearer the edges. The upper part of the embankment, known as the top slope, has a moderate slope, while the side slope is markedly steeper (33 percent transitioning to 20 percent as opposed to 2.4 percent). Energy*Solutions* intends to dispose of DU only beneath the top slope areas of the embankment, with no DU beneath the side slopes. All DU waste will be disposed below current grade level.

Table 3-1 lists the amount of DU potentially available from DOE's SRS and three gaseous diffusion plants (GDPs) at Paducah, KY, Portsmouth, OH, and the former K-25 site in Oak Ridge, TN (Neptune 2014i, Table 1).

Table 3-1 – Amounts of DOE Depleted Uranium Potentially Available for Disposal

Source	Form	Mass	Containers
SRS	DUO_3	3,577 Mg	5,408 Drums[b]
Paducah GDP	DUF_6	436,400 Mg	36,191 Cylinders
Portsmouth GDP	DUF_6	195,800 Mg	16,109 Cylinders
Former K-25 GDP[a]	DUF_6	54,300 Mg	4,822 Cylinders

[a] In 2004, DOE decided to relocate the DU from K-25 to Portsmouth (69 *Federal Register* 44649; July 27, 2004), and shipment was completed in FY 2007 (DOE 2014).
[b] Drums in storage at Clive.
Source: Neptune (2014i), Table 1.

Table 3-2 – Dimensions of the Proposed Federal Cell Embankment

Waste bottom	4,264 ft-amsl	Length overall	1,317.8 ft	Width overall	1,775.0 ft
Original grade	4,272 ft-amsl	Length to break	175 ft	Width to break	175 ft
Break to ridge	521 ft	Length within break	968 ft	Width within break	1,425.0 ft
Ridge length	383 ft				

Source: Neptune (2014f), Section 3.1.1, and ES Drawing No. 14004-V1A(1).

A cover system is proposed to be constructed above the waste. A primary objective of the cover system is to limit contact of water with the waste. Another objective of the cover system is to limit potential flux of radon outside of the embankment. The cover as proposed is sloped to promote runoff and designed to limit water flow by increasing ET. Figure 3-4 shows the arrangement of the layers used for the ET cover design. Beginning at the top of the cover, the layers above the waste used for the ET cover design are as follows (Neptune 2014f):

- **Surface Layer**: This layer is composed of native vegetated Unit 4 material[9] with 15 percent gravel mixture on the top slope and 50 percent gravel mixture for the side slope. This layer is 6 inches thick. The functions of this layer are to control runoff, minimize erosion, and maximize water loss from ET. This layer of silty clay provides

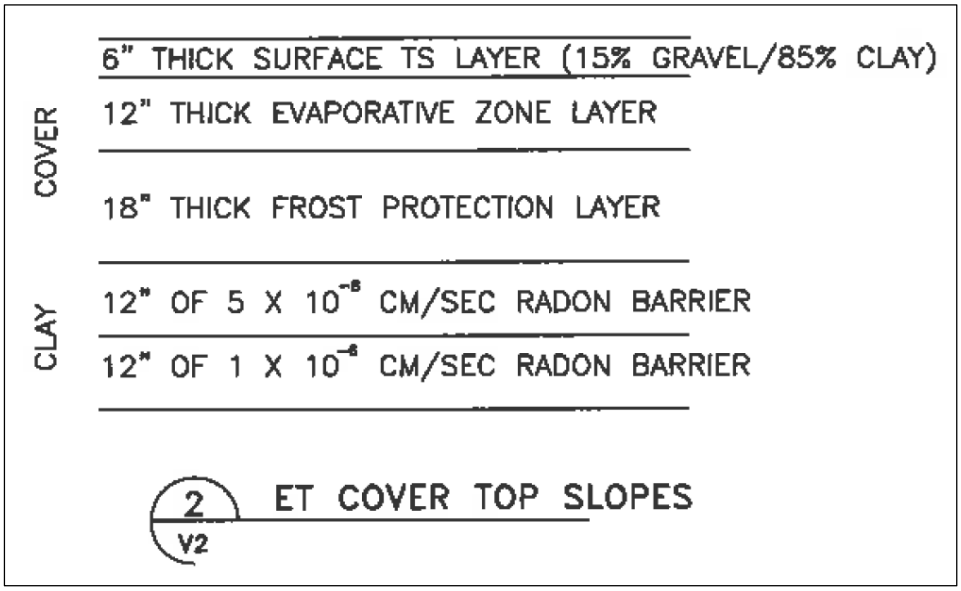
[9] Unit 4 material is a silty clay found at the surface at and near the facility and is included in the Surface Layer, Evaporative Zone Layer, and Upper and Lower Radon Barriers, as well as the Clay Liner beneath the DU.

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 12 inches. The purpose of this layer to provide additional storage for precipitation and additional depth for plant rooting zone to maximize ET.
- **Frost Protection Layer**: This material has particle sizes that range 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 and wetting/drying cycles, and to 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. However, this very low hydraulic conductivity is the result not only of compaction, but also of treatment of the clay with an application of sodium tripolyphosphate (STPP), or the equivalent, to deflocculate clays present and reduce hydraulic conductivity. Discussion of its intended use at Clive is found on page 23 of the August 7, 2014, Attachment II-9 to Energy*Solutions*' Construction Quality Assurance/Quality Control (CQA/QC) Manual (ES 2012b). It is unknown how long treatment by STPP will maintain a condition of low hydraulic conductivity in the Unit 4 clays. STPP is highly soluble, and it tends to be progressively hydrolyzed in natural waters (HERA 2003). When hydrolyzed, STPP can be assimilated by microorganisms. STPP treatment is more effective in some soils than in others. Yiasoumi (2004) indicates that STPP is ineffective in sandy soils or soils high in calcium carbonate. Clive Unit 4 silty clay contains about 65 percent calcium carbonate.

  This barrier layer reduces the downward movement of water to the waste and the upward movement of gas out of the disposal cell. The saturated hydraulic conductivity (K_{sat}) values for the radon barriers were sampled from a distribution developed from a minimum value of 4×10^{-3} centimeters per day (cm/day) corresponding to the proposed as-built design specification for the upper radon barrier (Whetstone 2007, Table 8), and 50th and 99th percentile values of 0.7 cm/day and 52 cm/day, respectively, which are from a range of in-service ("naturalized") clay barrier K_{sat} values described by C. H. Benson et al. (2011, Section 6.4, p. 6-12). A lognormal distribution was fit to the 50th and 99th percentiles, and the minimum value of 4×10^{-3} cm/day was used as a shift.

  Lower Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This lower radon barrier reduces the downward movement of water and upward migration of radon. For all HYDRUS simulations, although various K_{sat} values for the radon barriers were employed between runs, in each run the same K_{sat} value was applied to both the upper and lower radon barriers.



Source: ES (2014d), Drawing No. 14004, V7.

Figure 3-3 – Proposed Federal Cell evapotranspiration cover design

Directly beneath the lower radon barrier of the cover would be about 36 feet of non-DU material. For the purposes of the present Clive DU PA Model and this SER, Energy*Solutions* assumes that this non-DU material would be nonradioactive. However, Energy*Solutions* retains the option of using this space to dispose of ordinary, non-DU, LLRW. Beneath the non-DU material is the disposed-of DU waste. The DU would be placed in the proposed Federal Cell in either cylinders or drums. There would be a single layer of drums, and the cylinders would be in a single layer in the western area of the disposal zone, or stacked two layers high in the eastern portion of the disposal zone. Table 3-3 summarizes the estimated number of cylinders and drums of DU and their arrangement within the proposed Federal Cell.

Table 3-3 – Proposed Federal Cell: Estimated Number of Depleted Uranium Containers

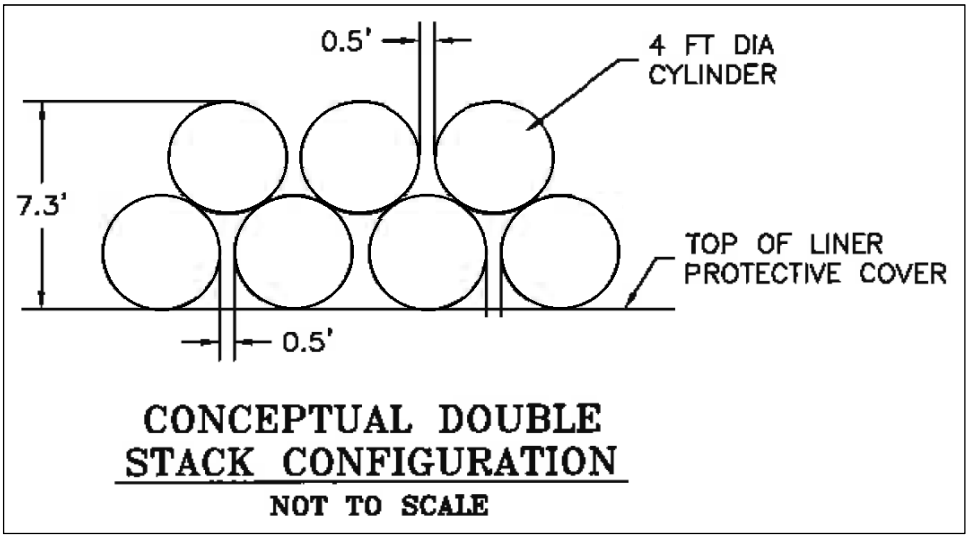
Container Type	Layers	Width (ft)	Length (ft)	Area (ft^2)	Number
Cylinders	Double	205	1,425	29,213	10,500
Cylinders	Single	763	1,425	1,087,275	20,300
Drums on pallets	Single	37	615	22,755	5,408
Drums on side[a]	Single	763	1,425	1,087,275	170,800

[a] Possible.
Source: ES Drawing No. 14002-L1A(1).

As per ES Drawing No. 14004, L1A(1), the Table 3-3 container number estimate was based on the following assumptions: (1) all cylinders were assumed to be 12 feet long by 4 feet in diameter; (2) single-layer cylinders were assumed to be spaced 0.2 feet end-to-end and side-to-side; (3) double-layer cylinders were assumed to be spaced 0.2 feet end-to-end and

0.5 feet side-to-side for both layers; (4) drums were assumed to be placed on 4 feet-by-4-feet pallets, spaced 0.1 foot apart; and (5) additional 55-gallon drums could be laid on their sides and placed in a single layer on top of the single-layer cylinders.

Figure 3-5 shows an example of the double stacking of the DU cylinders, which is to be limited to the eastern portion of the DU disposal zone. In the western area of this zone, only one layer of DU cylinders is to be disposed.



Source: ES (2014d), Drawing No. 14004, L1.

Figure 3-4 – Double-layer placement of DU canisters

Because of the unique characteristics that disposal of the triuranium octoxide depleted in U-235 (DU_3O_8) cylinders pose for the facility, the need to ensure a stable embankment and meet the waste backfill-related requirements in UAC R313-25-8(2) and R313-25-9(4)(d), and the quality assurance requirements in R313-25-8(10), revisions to the CQA/QC manual may be required. In addition, a revised Waste Acceptance Plan will be required to ensure that all DU waste containers and shipments received by the Licensee are equivalent to and in conformance with all physical, chemical, and radiologic properties assumed in the Director-approved DU PA modeling report. This Waste Acceptance Plan must be approved by the Director before land disposal of any DU waste. Additionally, since there is no written description of the newly proposed Federal Cell, the Licensee must provide such a description and indicate how such factors as steeper side slopes, changes in disposal area and volume, and inclusion of additional waste drums (beyond those currently in storage) will affect the DU PA. Finally, the Licensee must provide additional information regarding the 1-foot-thick protective liner that is placed over the bottom clay liner including the following:

- Function of the protective liner
- Material specifications for the liner
- How evaluated in performance assessment

References

C. H. Benson et al., 2011

DOE, 2014

DRC, 2008

ES, 2002; 2007; 2008a; 2011a; 2012b; 2014d; 2014f

HERA, 2003

Neptune, 2014f; 2014i

Rogers, 2014b

Whetstone, 2007

Yiasoumi, 2004

3.4.1 Proposed Federal Cell Compliance with Existing License Condition 9.E and the March 15, 2007, Governor Huntsman–Energy*Solutions* Agreement

License Condition 9.E was incorporated into the Energy*Solutions* LLRW License with issuance of License Amendment 14 for the CAW Cell on November 26, 2012. Background information on License Condition 9.E is found in the DRC's November 14, 2012, Public Participation Summary, pages 6–7 (DRC 2012b), as follows:

> ***(2) License Amendment and the Huntsman Agreement***
>
> *On March 15, 2007, Governor John Huntsman for the State of Utah and CEO Steve Creamer for Energy*Solutions *entered into an agreement (Appendix E) that committed Energy*Solutions *to limit its disposal to "the currently-licensed low-level radioactive waste cell volumes," including the volume of waste that the agreement anticipated as a result of converting Energy*Solutions'*11e.(2) cell into a Class A waste cell. The Division and Energy*Solutions *have agreed that this total approved volume is 10,357,412 million cubic yards (Class A= 3,778,896 million yd^3; Class A North= 1,722,509 million yd^3; Class A South= 3,501,915 million yd^3; Mixed Waste= 1,354,092 million yd^3 for a total of 10,357,412 million yd^3). Energy*Solutions *had originally anticipated that this disposal would occur in three already-licensed low-level radioactive waste cells (Class A, Class A North and Mixed Waste cells) and in the 11e.(2) cell that it expected to convert to a Class A cell. The Licensee has now chosen instead to develop this allowable capacity in two cells, the existing Mixed Waste Cell, and a new combined Class A and Class A North cell (now proposed as the Class A West cell). The Mixed Waste and Class A West cells will have a combined capacity of 10,078,189 cubic yards. This leaves a capacity of 279,223 cubic yards that Energy*Solutions *can still develop under the Huntsman Agreement.*
>
> *Additional amendments to Energy*Solutions' *License to conform to the Huntsman agreement are not necessary because this License covers all areas where Class A waste can be disposed. The only other area that is licensed to take radioactive*

> *waste is the 11e.(2) cell. Class A waste cannot be disposed of in that cell, and only Class A waste is subject to the Huntsman Agreement. Because there is no other area that may accept Class A waste, there is no possibility that the Agreement will be violated under currently applicable licenses. Additional requirements would be redundant and unnecessary.*
>
> *A modification to License Condition 9.E of the revised RML UT 2300249 will be made to address a correction in the calculations:*
>
> > *"The Licensee may dispose of a volume of Class A Low-Level Radioactive Waste (LLRW) and Naturally Occurring and Accelerator Produced Radioactive Materials (NARM) in the Class A West disposal cell described in License Condition 40 not exceeding ~~8,742,097~~ 8,724,097 cubic yards, and in the Mixed Waste Landfill Cell not exceeding ~~1,353 ,004~~ 1,354,092 cubic yards. Together the total aggregate volume of waste disposed of in the Class A West disposal Cell and the Mixed Waste Landfill Cell shall not exceed 10.08 million cubic yards. Class A waste LLRW is defined in Utah Radiation Control Rule R313-15-1009 and NARM at R313-12-3."*

As described in the Public Participation Summary statement quoted above (DRC 2012b), the Huntsman–Energy*Solutions* Agreement allows the company to expand its LLRW disposal capacity by 279,223 cubic yards above that already approved for the CAW Cell under License Amendment 14.

The volume limitations derived from the Huntsman Agreement and incorporated into License Condition 9.E will remain in effect unless the Licensee proposes a license amendment regarding alternative waste volumes for disposal in Section 32 and the proposed amendment is approved by the State of Utah. See Appendix G for additional details.

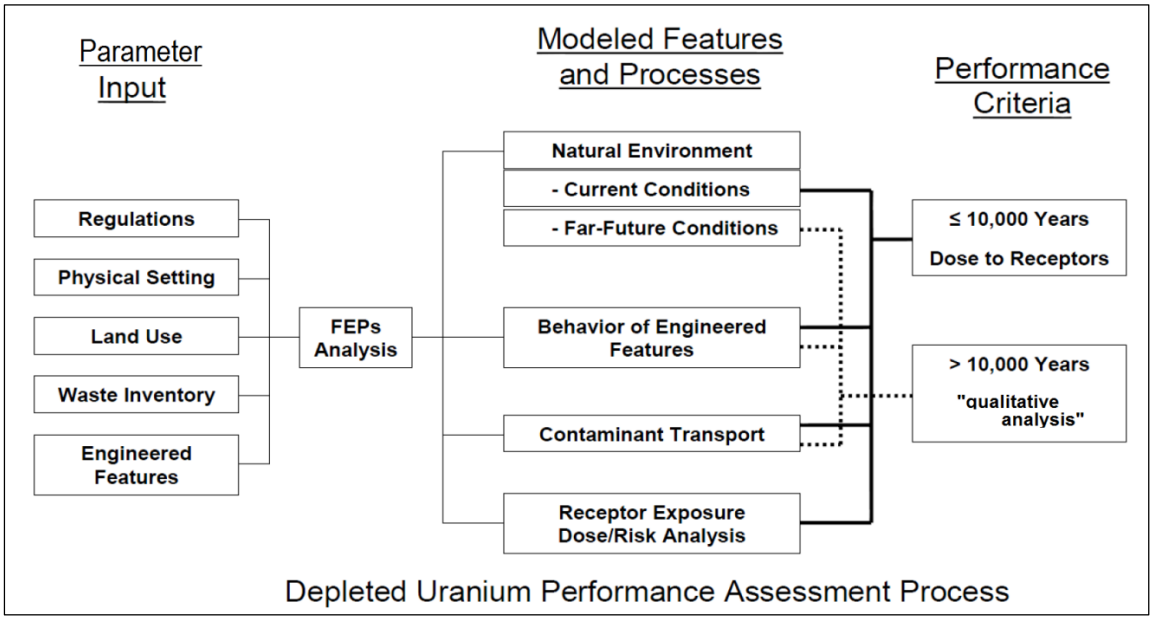
References

DRC, 2012b

3.5 CLIVE DEPLETED URANIUM PERFORMANCE ASSESSMENT DESCRIPTION AND RESULTS

The overall scope of the Clive DU PA is to evaluate the long-term siting and performance integrity of the portion of the proposed Federal Cell at Energy*Solutions*' Clive facility for the proposed disposal of DU. The need for the Clive DU PA is driven by both State of Utah and proposed Federal regulations, which require an evaluation of the potential human radiation doses and consequences from the disposal of DU.

In general, the performance assessment process consists of three stages: (1) Parameter Input, (2) Modeled Features and Processes, and (3) Performance Criteria, as illustrated in Figure 3-5.



Source: Modified from Neptune (2014d), Figure 1.

Figure 3-5 – Conceptual diagram of the performance assessment process

The Parameter Input stage includes the State of Utah and Federal regulations that must be met [e.g., UAC R313-25-9(4) and (5)(a)]; the physical characteristics of the Clive site (e.g., meteorology, hydrology, geology); land use at Clive, which currently is mostly industrial; the expected amount and characteristics of DU to be disposed of in the proposed Federal Cell; and any features of the cell (e.g., the ET cover, the clay liner) designed to mitigate the potential impacts of the waste disposal.

"FEPs Analysis" is the process of identifying those features, events, and processes (FEPs) that form the basis for scenarios that are evaluated to assess site performance and that, therefore, must be accounted for in the performance assessment model. For the Clive DU PA Model, FEPs were developed in the following eleven broad areas:

- Meteorology (e.g., precipitation, atmospheric dispersion, resuspension)
- Climate change (e.g., the appearance/disappearance of large lakes)
- Hydrology (e.g., groundwater transport, in both the unsaturated and saturated zones)
- Geochemical (e.g., chemical sorption and partitioning between phases, aqueous solubility, leaching of radionuclides from the waste form)
- Engineered Features (e.g., cell design, material properties)
- Containerization (e.g., the Clive DU PA did not take any credit for the DU being containerized)
- Waste (e.g., inventory of radionuclides, physical and chemical waste forms)
- Source Release (e.g., leaching, radon emanation, plant uptake, and translocation by burrowing animals)

- Contaminant Migration (e.g., diffusion, dilution, advection-dispersion, re-suspension, atmospheric dispersion, biotically induced transport)
- Human Processes (e.g., human behaviors and activities, resource use, unintentional intrusion)
- Exposure (e.g., dosimetry, ingestion pathways, inhalation pathways)

The example FEPs given for each broad area are representative of the FEPs developed but are by no means a complete list of all the Clive DU PA Model FEPs. Neptune (2014g) should be consulted for more information on FEPs and how they were developed for the Clive DU PA Model.

In the Modeled Features and Processes stage of the Clive DU PA, the FEPs are converted into mathematical models that can then be applied using computer software. As Figure 3-5 shows, the Modeled Features and Processes stage is divided into Natural Environment, Behavior of Engineered Features, Contaminant Transport, and Receptor Exposure Dose/Risk Analysis. Figure 3-6 shows the interconnections between all of the modeled features and processes. An examination of Figure 3-6 reveals that many of the features and processes within the Clive DU PA Model can be linked back to the FEPs. Many of the FEPs are included in the Clive DU PA Model as distribution functions, e.g., a normal or lognormal distribution, with a specified mean and standard deviation.

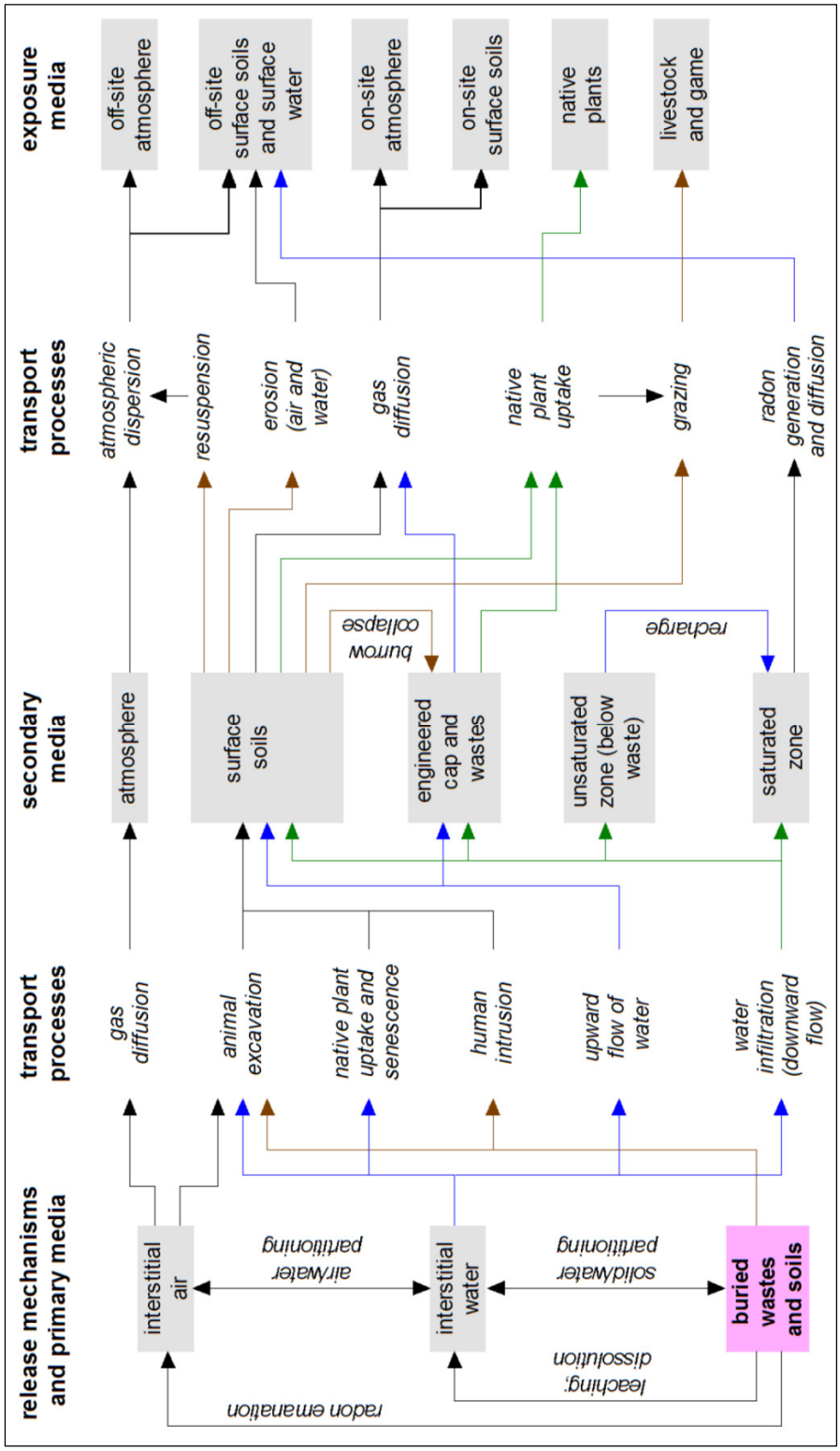
The Clive DU PA Model was developed using computer software called GoldSim (GTG 2013a, 2013b). GoldSim is a highly graphical, Windows-based program for carrying out dynamic, Monte Carlo simulations of complex systems to support management and decision-making. The GoldSim visual interface allows exploration of the model implementation. This interface facilitates traceability of codes developed with the GoldSim platform. The Monte Carlo functionality of GoldSim allows the Clive DU PA Model to be a probabilistic simulation, as opposed to a deterministic simulation.

The final stage in the performance assessment process, Performance Criteria, is to run the Clive DU PA Model and compare the results to the performance criteria contained in State and Federal regulations. GoldSim solves the Clive DU PA Model multiple times (i.e., multiple realizations), each time randomly selecting a different value for each parameter's distribution. When all of the realizations have been completed and compiled, the results (e.g., dose to the general public, dose to an inadvertent intruder, sediment concentration) can be taken as the mean, median, 95th percentile, or some other percentile from the entire distribution of results.

References

GTG, 2013a; 2013b

Neptune, 2014d; 2014g



Source: Neptune (2014d), Figure 11.

Figure 3-6 – Clive DU PA modeled features and processes. This figure describes those features and processes modeled by Neptune in the DU PA.

4.0 PERFORMANCE OBJECTIVES

4.1 10 CFR 61.12 – SPECIFIC TECHNICAL INFORMATION (UAC RULE R313-25-8)

During the course if its review of the DU PA, DEQ developed 73 interrogatories related to requests for additional specific technical information: 20 in the area of natural and demographic disposal site characteristics [under UAC Rule R313-25-8(1)]; 19 related to design features of the land disposal facility [under UAC Rule R313-25-8(2)]; 2 related to construction and operation [under UAC Rule R313-25-8(6)]; 14 related to kind, amount, classification, and specifications of the material [under UAC Rule R313-25-8(9)]; 8 related to quality assurance programs; and 10 related to multiple subsections or not assigned to any subsection of UAC Rule R313-25-8, "Specific Technical Information."

4.1.1 Principal Design Features: Descriptions and Justification

UAC Rule R313-25-8 requires descriptions of the design features of the near-surface disposal cell, including those features related to infiltration of water; integrity of covers; structural stability of backfill, wastes, and covers; contact of wastes with standing water; disposal site drainage; disposal site closure and stabilization; elimination, to the extent practicable, of long-term disposal site maintenance; inadvertent intrusion; occupational exposures; disposal site monitoring; and the adequacy of the size of the buffer zone for monitoring. The DU PA technical review involves some aspects of UAC Rule R313-25-8, while other aspects of R313-25-8 are not specifically pertinent to the DU PA review. For example, disposal site monitoring and the adequacy of the size of the buffer zone are not directly relevant to evaluating the actual system performance; instead, they focus on the facility's ability to measure and confirm system performance, and perform remediation if necessary. Site monitoring issues are established in any licensing action and are not part of this DU PA review. Certain modifications to current monitoring procedures may be required for the area between the proposed Federal Cell and the existing 11.e(2) Cell.

The requirements contained in UAC R313-25-8(2) and (3) addressing the design features of the facility as they relate to the performance objectives established for those design features apply in different ways and to different extents to the various principal design features incorporated into the proposed Federal Cell for the disposal of DU waste. The principal design features of the proposed Federal Cell addressed in this section of the SER are the following:

- ET cover
- Waste placement and backfill
- Clay liner

Evaluation of each of these principal design features with respect to the DU PA is addressed in separate sections below. Note that regulatory requirements that DEQ judged not to impact performance are not addressed.[10]

[10] These include UAC Rule R313-25-8(7), (10), (11), (12), (13), and (14).

The provisions of UAC Rule R313-25-8(2) identify the following 11 required functions that the principal design features must perform:

- Minimize infiltration of water.
- Ensure integrity of covers for disposal units.
- Ensure structural stability of backfill, wastes, and covers.
- Minimize contact of wastes with standing water.
- Provide disposal site drainage.
- Ensure disposal site closure and stabilization.
- Eliminate to the extent practicable long-term disposal site maintenance.
- Protect against inadvertent intrusion.
- Limit occupational exposures.
- Allow for and provide disposal site monitoring.
- Provide a buffer zone for monitoring and allow for implementation of potential mitigative measures, if required.

Energy*Solutions* describes the ET cover, waste emplacement, and backfill and clay liner in Appendix 5, *Unsaturated Zone Modeling for the Clive DU PA Model v1.2*, dated June 12, 2014 (Neptune 2014k).

References

Neptune, 2014k

4.1.1.1 Evapotranspiration Cover

Disposal involves placing DU waste on a protective cover over a prepared clay liner that is approximately 8 feet below the ground surface. For the proposed Federal Cell design, the depth of the waste below the top slope is a maximum of 53 feet (16 meters), leaving as much as 45 feet of non-DU waste above natural grade. A cover system is constructed above the waste. The primary objective of the cover system is to limit contact of water with the waste. The cover is sloped to promote runoff and designed to limit water in-flow by increasing ET. The cover system also inhibits release of radon gas from the subsurface. Beginning at the top of the cover, the layers above the waste used for the ET cover design are as follows (see Section 3.4 for a full description):

- Surface Layer (6 inches)
- Evaporative Zone Layer (12 inches)
- Frost Protection Layer (18 inches)
- Upper Radon Barrier (12 inches)
- Lower Radon Barrier (12 inches)

As part of the review and response preparation for the Round 1 Interrogatories, Energy*Solutions* revised the proposed design of the Federal Cell from a rock armor cover to an ET cover similar to that currently under review by DRC for construction on the CAW Embankment. The DRC review (DRC 2015) should be consulted to assess interrogatories regarding apparent deficiencies of that cover system, especially when bulk waste is proposed for disposal directly beneath the cover system. DEQ'S review of Energy*Solutions*' Round 1 responses resulted in a second round of interrogatories, which Energy*Solutions* responded to on June 17, 2014 (DRC 2014b; ES 2014h). Following delivery of the Round 2 interrogatories to Energy*Solutions*, DEQ proceeded to review version1.2 of the Clive DU PA modeling report (Neptune 2014a; hereafter "the DU PA Model v1.2"), which documented the performance of the proposed Federal Cell with ET cover, and to generate Round 3 interrogatories specifically targeting the revised model. Energy*Solutions* provided DRC with responses to the Round 3 revised model interrogatories on July 8, 2014 (ES 2014b). The current status of each interrogatory [i.e. whether it was satisfactorily resolved ("closed")] is found in Appendix C to this SER. Subsequent to the three rounds of interrogatories and responses, DEQ and Energy*Solutions* participated in several phone conferences. As result of these meetings, on August 11, 2014, DEQ requested 10 additional clarifications and proposed additional HYDRUS simulations with specific combinations of input parameters (DEQ 2014). Energy*Solutions* responded to the DEQ request on August 18, 2014 (ES 2014g). The 10 additional clarification comments, a summary of the Energy*Solutions* responses, and subsequent DEQ findings are provided in Appendix B to this SER.

In response to DEQ's request for the additional HYDRUS simulations, the Energy*Solutions* response states, in part, the following:

> *In general, Energy*Solutions *strongly disagrees with the request of running highly speculative, unsupported, one-off cases suggested in the subject request. This is not consistent with the intent of the Utah regulation nor the meaning or application of a "sensitivity analysis." In practice, an appropriate sensitivity analysis would consider only combinations of input values that are plausibly visible at the site under study. Whereas the concept of plausibility in this context is applied based on available data and professional judgment, the values that are suggested in the subject document (and repeated above) are not plausible for this site.*

and

> *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. Any more comprehensive sensitivity analysis for the infiltration modeling should not be based on selective, unrepresentative, and non-systematic changes in physical properties of cover materials. Moving beyond the current model in order to further refine the analysis requires more detailed site-specific data collection. However, the value of any such data collection is highly questionable, since all of the PA model endpoints <u>are insensitive to changes in any of the hydraulic input parameters.</u>*

DEQ agrees that one-off bounding analyses are not ideal for predicting representative overall system performance. However, this approach was proposed primarily because there are still a number of unresolved concerns related to HYDRUS and GoldSim. For example, in the 20 HYDRUS simulations, it appears that the tails of the distributions describing the hydraulic properties are poorly sampled, and more extreme cases may be inadequately represented. Furthermore, for the hydraulic properties that compose the surface and evaporative zone layers of the ET cover, the van Genuchten alpha (or "α") and *n* values were taken from the distributions (mean and standard deviation) for each parameter from the Rosetta database of hydraulic parameters for the textural class of silty clay (Schaap 2002). The parameters α, n, and K_{sat} values obtained from the Rosetta database are said by the Licensee not to be correlated. Evaluation of data from Carsel and Parrish (1988), however, demonstrates that there is a strong correlation (R^2=0.9) between log(α) and log(K_{sat}) based on regression analyses of average parameter values for 12 National Resource Conservation Service soil textural classes based on 5,097 samples for which K_{sat} data exist. Another large database exhibiting similar correlation between log(α) and log(K_{sat}) is that of Wösten et al. (1999). Theoretical research also shows similar relationships. Additional information regarding the correlation between the log(α) and log(K_{sat}) parameters is provided in Section 4.4.1 and DEQ's Interrogatory CR R313-25-7(2)-189/3 (DRC 2014c). The lack of sensitivity of the performance assessment inputs to any of the hydraulic parameters remains a concern in that the modeled hydraulic properties of the cover system soils may be leading to unrealistically low infiltration rates.

DEQ's proposed deterministic approach was also seen as a means to provide additional insight and defensibility in the GoldSim results. Based on the modeling results that have been provided so far, it appears that the infiltration rates could be considerably higher than those predicted by HYDRUS but still low enough to comply with the Utah regulations. However, the infiltration analysis needs to be more transparent and technically defensible in order to withstand additional scrutiny from the public and provide a measure of credibility to the entire performance assessment.

Conclusion: There are still a number of unresolved issues with respect to the selection of parameter ranges, distributions, and correlations, as well as the modeling approach and predicted sensitivities. These concerns are detailed in Appendix B. Further, because the model-predicted infiltration rates may be sensitive to the hydraulic properties assigned to each ET layer, the α and K_{sat} values assumed for modeling moisture in each soil layer within the cover system must be correlated based on experimental data. Also, additional justification is required for the soil property values used in the model by Energy*Solutions*. Therefore, DEQ does not consider this portion of the performance assessment resolved.

References

Carsel and Parrish, 1988

DEQ, 2014

DRC, 2014b; 2014c; 2015

ES, 2014b; 2014g; 2014h

Schaap, 2002

Wösten et al., 1999

4.1.1.2 Waste Emplacement and Backfill

The DU PA considers the emplacement of DU waste both in standard 55-gallon drums and in much-larger 10- and 14-ton steel cylinders. There are 5,408 55-gallon drums currently in a storage building at the Clive site containing depleted uranium trioxide (UO_3) from SRS that is contaminated with small amounts of activation and fission products. In addition, it is estimated that 57,122 steel cylinders will be filled with DU_3O_8 produced from the deconversion of depleted uranium hexafluoride (DUF_6) generated at three DOE GDPs (Neptune 2014i). After the deconversion process, the DU_3O_8 is being loaded back into the same cylinders in which the DUF_6 was originally stored. Most of the storage cylinders are approximately 12 feet long and 4 feet in diameter. It is estimated by Energy*Solutions* that about 10 percent of the cylinders will contain small amounts of fission and activation products (Henson 2006). Because these fission and activation products are predominantly found highly concentrated in localized heels, rather than generally distributed through the DU_3O_8, and because these heels, if analyzed separately, could constitute transuranic waste (Hightower et al. 2000), they are of special concern to DEQ.

Energy*Solutions* is committed to emplace all of the DU waste below grade and, as a corollary to that commitment, to emplace only that amount of DU waste that will fit into the available below-grade volume of the proposed Federal Cell. Further, as discussed in Section 3.4.1, the disposal volume at Clive of all wastes is constrained by the Huntsman Agreement.

The average original grade elevation is 4,272 feet amsl (ft-amsl) and the average elevation of the bottom of the waste is 4,264.17 ft-amsl, which leaves a height of under 8 feet in which the DU waste can be emplaced. (Neptune 2014f, Table 1). Energy*Solutions* estimated that about 44,712 cylinders and 5,408 drums could be emplaced within the available cell volume (in *Utah Radioactive Material License – Condition 35 (RML UT2300249) Compliance Report (Revision 1)*, November 8, 2013, CD13-0302, hereafter "Revision 1 of the Compliance Report" [ES 2013b]). Based on this preliminary estimate, only about 78 percent of the anticipated number of DOE DU cylinders could be emplaced below grade. However, as discussed in Section 3.4 above, Energy*Solutions* has now decided to physically separate the proposed Federal Cell from the 11e.(2) cell. This change has reduced the cell volume available for DU disposal. According to the Licensee, this volume will support disposal of 30,800 cylinders (see Table 3-3).

To ensure stability, Energy*Solutions* plans to place backfill between the cylinders and drums. According to Revision 1 of the Compliance Report, Section 3.4, p. 3-14 (ES 2013b):

> *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.*

DEQ requested additional information regarding backfill procedures under Interrogatory CR R313-25-22-166/2: Stability of Waste (DRC 2014c), including:

- Details on how headspace will be eliminated from the DU cylinders after arrival at Clive, including methods and equipment necessary for detecting

headspace, access of the container to insert controlled low-strength material (CLSM) fill, and re-sealing or closure of the waste container

- Discussion of potential interactions between CLSM and DU waste materials, including any possible effects on the ability of the CLSM to harden sufficiently to sustain needed stresses without deformation of the cover system
- Waste container spacing and geometry on a waste lift and details about any co-location of DU waste cylinders with DU waste drums
- Placement of fill material between individual containers on a waste lift

Energy*Solutions*, in its Round 2 Interrogatory responses (ES 2014a), stated that:

> *No revisions will be needed to the LLRW and 11e.(2) Construction Quality Assurance/Quality Control Manual. DUF_6 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 DUF_6 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.*

As discussed in Section 3.4 of this SER, DEQ believes that it is likely that revisions to the CQA/QC Manual (ES 2012b) will be necessary. Energy*Solutions* must demonstrate, based on prior experience, that configurations sufficiently similar to the DUF_6 cylinders and containing similar waste products can be fully filled with CLSM. In addition, Energy*Solutions* must provide evidence that the interstices between arrays of cylinders with 6-inch longitudinal spacing and 2.5-inch end-on-end spacing can be adequately backfilled. Absent such a demonstration, implementation of a test pad may be required. If so, appropriate conditions can be added to any license amendment.

In the initial version of the Compliance Report, dated June 1, 2011 (ES 2011b), Energy*Solutions* noted that a principal design criterion for waste emplacement and backfill is that the embankment settlement be limited to 0.02 feet/feet or 1 foot over a 50-foot horizontal distance. Energy*Solutions* stated that compliance with this criterion was met by the conditions of License Condition 53 (RML UT2300249). In the 2008 license renewal, DRC certified that the Licensee was in compliance with all applicable regulatory requirements (ES 2008b).

Conclusion: Based on prior approvals, use of qualified procedures in the CQA/QC Manual, clarifications provided through interrogatories, and possible new license conditions, DEQ believes that the requirements of UAC Rule R313-25-8 are satisfied with regard to waste emplacement and backfill and has conditionally resolved issues relating to this portion of the performance assessment.

References

DRC, 2014c

ES, 2008b; 2011b; 2012b; 2013b; 2014a

Henson, 2006

Hightower et al., 2000

Neptune, 2014f; 2014i

4.1.1.3 Clay Liner

The waste would be placed on a protective liner covering the clay liner that is approximately 8 feet below the current, preconstruction ground surface. The clay liner is to be constructed of compacted local clay. The clay liner is uniformly about 60 centimeters (cm) (2 feet) thick by design, though the bottom of the waste cell has a gentle slope to it.

Energy*Solutions* developed the distribution for saturated hydraulic conductivity for the clay liner using the design value from Table 8 of Whetstone (2007) for the clay liner of 1×10^{-6} centimeter per second (cm/s) as the geometric mean of a lognormal distribution. A geometric standard deviation of 1.2 was chosen to provide an approximate order of magnitude variation above and below the geometric mean.

DEQ staff note that Energy*Solutions* does not account for deterioration over time of the clay liner, with resulting higher values of hydraulic conductivity that should be modeled as such. As shown in a U.S. Army Corps of Engineers assessment (Berney et al. 2008), degradation of liners over time (e.g., within 10 years) is a nearly universal occurrence. The assessment states, "*A literature review found that, in all documented in-place clay liner studies, cracking occurred in the clay liner within 10 years, leading to failure of the liner system*." Berney et al. (2008) summarize the results of a study in this area of interest by Albrecht and Benson (2001), who state, "*the resultant cracking caused increases in hydraulic conductivity by as much as 500 times*." Energy*Solutions* does not account for this magnitude of increase in liner K_{sat} in its modeling. Therefore, the conclusions developed in the DU PA Model v1.2 are unsupported and will continue to be unsupported until this shortcoming in modeling assumptions is resolved.

In a report dated February 6, 2015, Energy*Solutions* evaluated data and drew conclusions regarding the potential impacts of freezing and thawing on the hydraulic conductivity of clay barriers used in the final covers at the Energy*Solutions* LLRW disposal facility in Clive, Utah (ES 2015a).

In this report, Energy*Solutions* concludes that hydraulic properties of site-specific data do not mirror the impact of the freeze/thaw on hydraulic conductivity predicted in C. H. Benson et al. (2011) and, therefore, Clive's site-specific observations should be preferentially weighted over Benson et al.'s national ranges. However, this conclusion is based on comparisons of hydraulic conductivity measurements made during construction of the clay barriers and made after the barriers had been exposed to winter weather. Energy*Solutions* also made comparisons between dry densities measured during construction and those measured after exposure to winter weather. Based on these comparisons, Energy*Solutions* concluded that the hydraulic conductivity decreased after exposure to winter weather, and the dry density increased after exposure to

winter weather. In Appendix F to this SER, Dr. Craig H. Benson raises a number of concerns with this approach, which include:

- Insufficient information on freezing and thawing
- Inconsistency with existing knowledge base
- Field-testing methodology
- Changes in dry density
- Other pedogenic processes

See Appendix F for a detailed discussion of these concerns.

Conclusion: As with the ET cover, there is still an unresolved concern that K_{sat} values will increase greatly over time, and that the α and K_{sat} values assumed for modeling flow through the liner must either be correlated or a sensitivity analysis be conducted to demonstrate that the lack of correlation assumed does not adversely affect the modeling results. In addition, there are problems with assumed liner hydraulic conductivity values. The DU PA Model v1.2 does not account for liner degradation over time. These concerns need to be resolved.

References

Albrecht and Benson, 2001

C. H. Benson et al., 2011

Berney et al., 2008

ES, 2015a

Whetstone, 2007

4.1.2 Kind, Amount, Classification, and Specifications of DU Waste Material

UAC R313-25-8(9) requires the application to include the following:

> *Descriptions of the kind, amount, classification and specifications of the radioactive material proposed to be received, possessed, and disposed of at the land disposal facility.*

DEQ posed 14 interrogatories to Energy*Solutions* related to this category of specific technical information. All of the interrogatories were satisfactorily resolved except Interrogatory CR R313-25-7(9)-89/3: Contamination Levels in DUF_6 (DRC 2014c). As discussed in more detail in Section 5.3 of this SER, DEQ believes that there is significant uncertainty in technetium-99 (Tc-99) concentrations that is not fully captured in the DU PA. This can not only affect compliance with the GWPLs at 500 years but also the ability of the facility to protect the groundwater in the confined aquifer underlying the Clive site from degradation over 10,000 years. A related issue is the fact that contaminants in the DU cylinders are concentrated in the cylinder heels. Heels are the residual materials remaining in the cylinders after the gaseous uranium hexafluoride (UF_6) is removed. Contaminants include technetium, neptunium (Np), and plutonium (Pu) with bounding concentrations in the heels estimated to be as follows (Hightower et al. 2000):

- Pu-238 – 5 parts per billion (ppb)

- Pu-239 – 1,600 ppb
- Np-237 – 54,000 ppb
- Tc-99 – 5,700,000 ppb

During the deconversion process, the DUF_6 cylinders are rinsed with a neutralizing solution of potassium hydroxide (KOH) before being refilled with DU oxide. It is unlikely that the neutralization process will remove significant amounts of the contaminants in the heels.

The concentration of transuranic elements (such as Pu-238, Pu-239 and Np-237) is limited to a total of 10 nanocuries per gram (nCi/g) under the terms of the Northwest Interstate Compact on Low-Level Radioactive Waste Management. It has been established by the 10th Circuit Court that the Northwest Compact has authority over disposal at Energy*Solutions*. Details are included in Appendix G). Thus, the presence the contaminants from recycled uranium in the DU waste can increase groundwater contamination and may result in quantities of transuranics that exceed limits established by the Northwest Compact.

Not all cylinders contain heels contaminated with technetium, neptunium, and plutonium. It has been estimated that only about 15 percent of the cylinders are contaminated (Henson 2006). This emphasizes the importance of an appropriate Waste Acceptance Plan to ensure that cylinders containing recycled uranium are not shipped to Clive.

Conclusion: As discussed above, DEQ has resolved issues related to this portion of the DU PA based on the assumption that new license conditions regarding the CQA/QC Manual and a revised Waste Acceptance Plan will be added to any revised license. This issue resolution is further predicated upon adding one additional condition: that disposal of DU waste contaminated with the activation and fission products in recycled uranium not be permitted.

References

DRC, 2014c

Henson, 2006

Hightower et al., 2000

4.1.3 GoldSim Quality Assurance

UAC R313-25-8(10) requires the application to include the following:

> *Descriptions of quality assurance programs, tailored to low-level waste disposal, including audit and managerial controls, for the determination of natural disposal site characteristics and for quality control during the design, construction, operation, and closure of the land disposal facility and the receipt, handling, and emplacement of waste.*

Several DEQ interrogatories have questioned various aspects of the quality assurance program for the Clive DU PA Model v1.2 (Neptune 2014a). Two important examples of these are Interrogatories R313-25-7(10)-78/1: GoldSim Model Calibration (DRC 2014a) and R313-25-7(10)-80/1: Testing of GoldSim Abstractions (DRC 2014a).

Interrogatory R313-25-7(10)-78/1: GoldSim Model Calibration (DRC 2014a) asked Energy*Solutions* to "*Describe the role of model calibration in substantiating that GoldSim*

adequately simulates the physical, chemical, and biological processes at the Clive site." Energy*Solutions* begins its response by indicating that, because of the nature of the problem being modeled (i.e., the behavior of the proposed Federal Cell far into the future), it would be difficult to impossible to calibrate the results to actual measured data (ES 2014d). DEQ recognizes this and is asking for something more basic: DEQ wants to be sure that the results from the DU PA Model v1.2 GoldSim calculation match (within reasonable expectations) the results that would be expected from the underlying models that form the basis of the GoldSim model. For example, DEQ is trying to better understand the fact that the infiltration rates modeled with HYDRUS do not match the GoldSim-calculated infiltration rates very closely. (See Appendix B for additional discussion.)

A related concern is how infiltration through the ET cover has been abstracted into the DU PA Model v1.2 GoldSim model. Appendix 5, Section 12.8 (Neptune 2014k) to the DU PA indicates that 20 HYDRUS runs were made for various sets of van Genuchten α and n and saturated hydraulic conductivities (K_{sat}) (see Appendix 5, Table 9). However, the varied α parameter values were only for the Surface Layer or the Evaporative Zone, whereas the varied K_{sat} parameter values were only for the radon barrier soils. No changes were made in K_{sat} for the Surface Layer or Evaporative Zone (assumed in the runs to be at constant values), and no changes were made in α for the radon barriers. Thus, a reasonably thorough sensitivity analysis, or a subset thereof, was not conducted by Energy*Solutions*. In Section 12.9, Table 10 (Neptune 2014k), regression coefficients are presented that relate the van Genuchten α and n and K_{sat} to the water content of the various cover layers (i.e., surface, evaporative, frost, and upper and lower radon barriers) and to the infiltration rate. On the other hand, while K_{sat} values for the Upper and Lower Radon Barrier were varied in the HYDRUS and GoldSim models, there was no correlated change made in α values. The value of α was held constant at 0.003 cm^{-1}, even though K_{sat} values were varied by orders of magnitude. There is little information provided about how Energy*Solutions* got from the HYDRUS input parameters to the regression coefficients, or on how well the regression analysis results match the HYDRUS results. For example, Section 12.9, Table 10 (Neptune 2014k) states that, "*For the net infiltration flux regressions, K_s [saturated hydraulic conductivity] was dropped as a predictor due to poor fit of the models*." No further explanation is provided, and Energy*Solutions* seems to expect DEQ to accept this at face value. Energy*Solutions* has included additional information pertaining to the derivation of the GoldSim infiltration rates from the HYDRUS results in its responses to additional interrogatories (ES 2014d). As discussed in Appendix B, however, there are a number of questions that remain open.

In some cases, it is unclear whether unexpected GoldSim results are due to the mathematical model formulations of the code itself or to assumptions with respect to the model input parameters. For example, it is DEQ's understanding that the intent of the model abstraction approach and linkage of process model output to the GoldSim input is that the fundamental relationships can be "abstracted" from more complex models that are time consuming to run and can be effectively maintained within the GoldSim framework in order to perform probabilistic analyses within a reasonable time frame. Therefore, as discussed in the example below and in Appendix B, the complete absence of correlation between the infiltration rates predicted by HYDRUS and those calculated by GoldSim creates a dilemma, in that the predicted infiltration rates are the foundation for many other contaminant fate and transport and dose predictions.

In response to Supplemental Interrogatory 1, Energy*Solutions* indicates that the distributions for van Genuchten's α and *n* were scaled in the Clive DU PA v1.2 GoldSim model to reflect the more coarse nature of the GoldSim cell structure (ES 2014d). The scaling approach that Energy*Solutions* describes can be used to characterize uncertainty in the mean, but the spatial variability within the hydraulic data is not represented properly. Scaling to address spatial averaging should address variance reduction using a variance function, which is defined based on the spatial correlation structure of the hydraulic properties (Vanmarcke 2010). As a result, the tails of the distributions are not represented properly, which will affect a stochastic or uncertainty analysis. It is unknown whether the spatial discretization is hardwired into GoldSim and whether any grid convergence studies were ever performed to ascertain the adequacy of the discretization.

Appendix 5, Section 12.9, to the DU PA Model report (Neptune 2014k) indicates that the HYDRUS-calculated infiltration rate into the waste zone ranged from 0.0007 to 0.29 centimeter per year (cm/yr), with an average of 0.042 cm/yr. However, when DEQ made a 1,000-realization run with the DU PA Model v1.2 file, the GoldSim-calculated infiltration rate only ranged from 0.024 to 0.047 cm/yr, with a mean of 0.034 cm/yr. These results are summarized in Table 4-1. It appears that somewhere in the GoldSim abstraction process the full range of the HYDRUS-calculated infiltration rates has been truncated, but without additional justification for the HYDRUS abstraction into GoldSim, DEQ is unable to verify the Energy*Solutions* approach or conclusions. This must be thoroughly explained by Energy*Solutions*.

Table 4-1 – Comparison of GoldSim- and HYDRUS-Calculated Infiltration Rates

	Infiltration Rate (cm/yr)	
	GoldSim v1.2, 1,000 realizations	**Appendix 5, Section 12.9[a]**
Minimum	0.024	0.0007
Mean	0.034	0.042
Maximum	0.047	0.29

[a] Neptune (2014k).

Moreover, until other factors, such as model inputs and correlations between these inputs, are accounted for, infiltration results from either HYDRUS or GoldSim will not necessarily provide representative infiltration values.

Energy*Solutions*' response to Interrogatory R313-25-7(10)-78/1 (ES 2014d) includes the statement, "*The Clive DU PA Model is a highly-integrated system model, with many interrelated processes*." DEQ understands that the Clive DU PA Model is very complex. This is precisely the reason that, as much as feasible, DEQ must be able to trace back all parameters used or calculated by the DU PA v1.2 GoldSim model to their original underlying models. Unless Energy*Solutions* provides the necessary descriptions and data in the final report, DEQ will not be able to complete this portion of the Clive DU PA Model v1.2 verification and benchmarking.

Conclusion: Specific instances where additional information and data are needed from Energy*Solutions* in order to allow DEQ to perform the necessary verification of Clive DU PA Model v1.2 have been identified in Appendix B and other sections of the SER (e.g., Section 4.4.1 for infiltration). Once all of those additional requests have been satisfactorily completed,

reviewed, and determined to show that the regulatory requirements have been met, DEQ will consider this concern to be resolved.

References

DRC, 2014a

ES, 2014d

Neptune, 2014a; 2014k

Vanmarcke, 2010

4.1.4 Uranium Solubility

The solubility values assumed in the DU PA are based on studies conducted by Sandia National Laboratories (SNL 2007) on the solubility of americium (Am), neptunium, protactinium, plutonium, thorium, and uranium. Some of the solubility values presented in SNL 2007 are tables with pH and partial pressure of carbon dioxide (CO_2) as variables. These studies assume 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 [i.e., aqueous uraninite ($UO_2(OH)_2$)].

As part of the performance assessment review, DEQ's contractor generated the phase diagrams in Figure 4-1, Figure 4-2, and Figure 4-3 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 8 and 12 in the geochemical modeling report (Appendix 6 to the DU PA, Neptune 2014m), with and without carbonate included and with the pH fixed at 7. The oxidation/reduction potential (E_H) 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 tetravalent-state uranium [U(IV)] minerals limits the solubility of uranium through formation of an insoluble uraninite mineral phase. As can be seen in Figures 4-1 through 4-3 below, increased concentration of carbonate in an oxidizing groundwater environment encourages the dissolution of uranium due to formation of soluble uranyl carbonate complexes. This phenomenon has a bearing on performance assessment model assumptions for uranium fate and transport in the subsurface environment (the vadose and saturated zones).

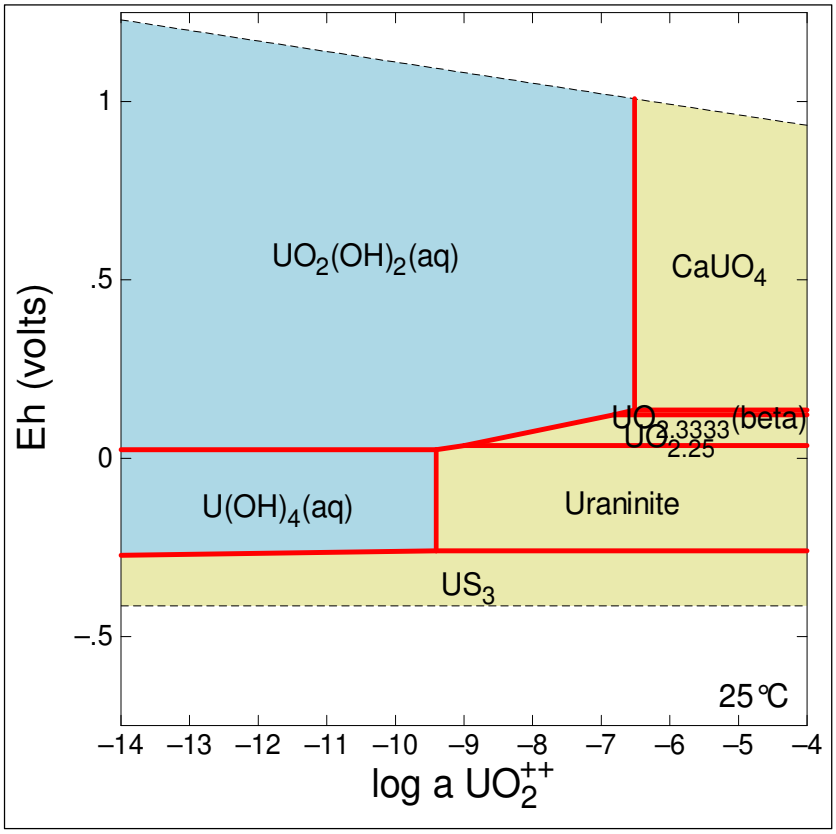


Figure 4-1 – Eh-activity diagram demonstrating uranium speciation and solubility in the absence of carbonate. Note that yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

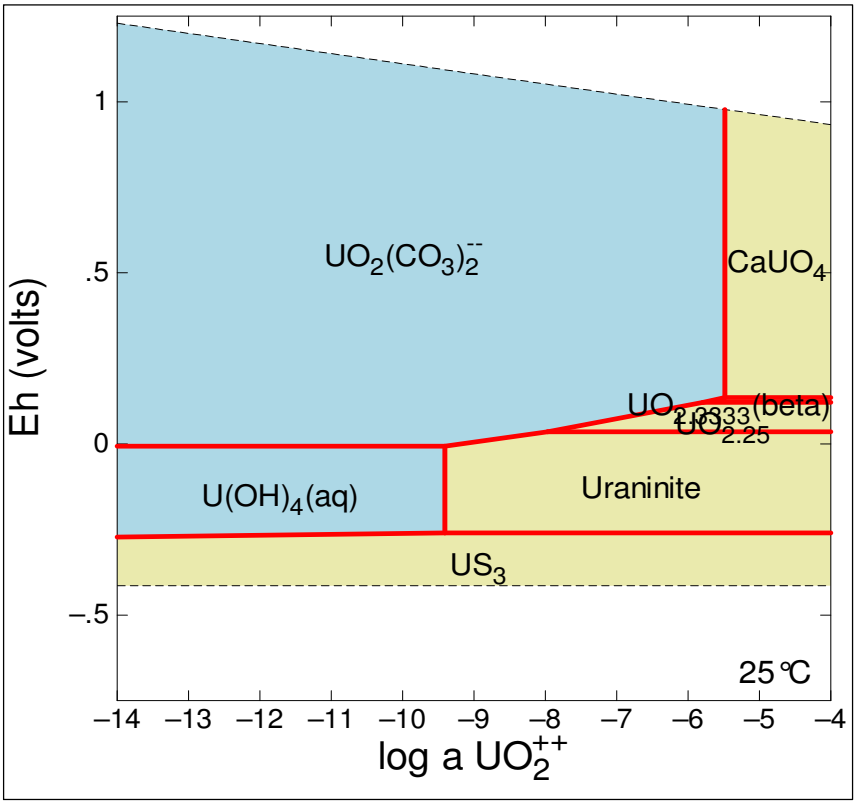


Figure 4-2 – Eh-activity diagram demonstrating uranium speciation and solubility in the presence of approximately 100 mg/L carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

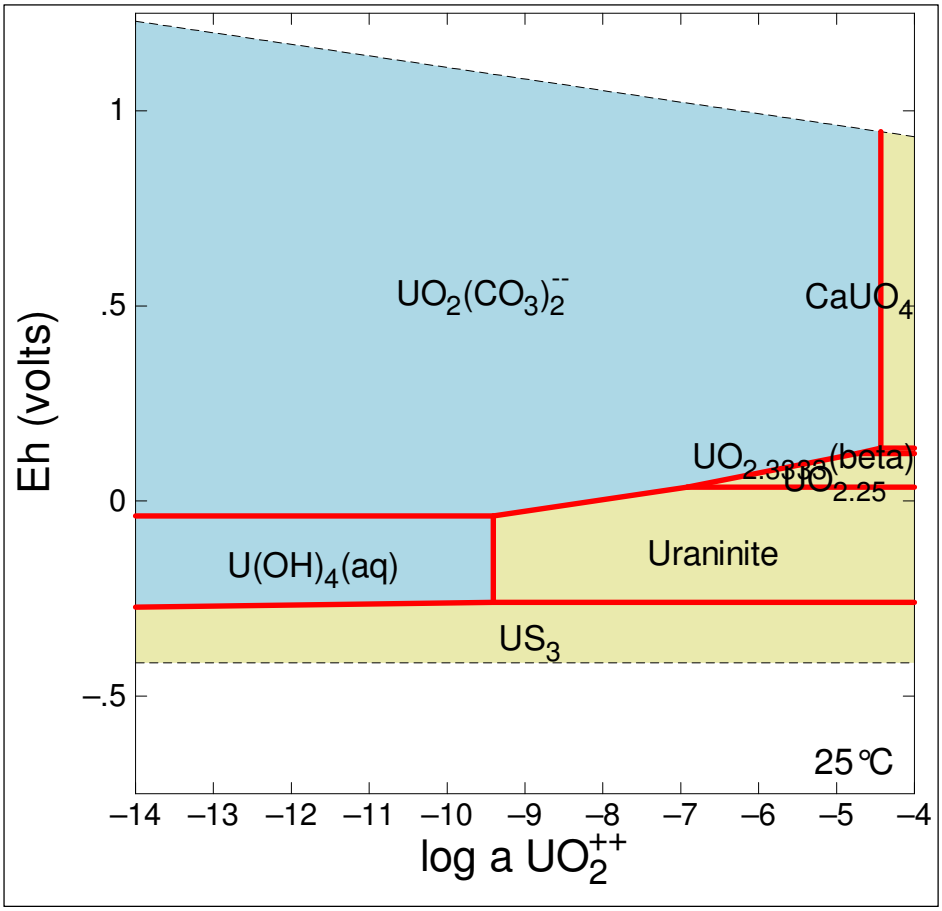


Figure 4-3 – Eh-activity diagram demonstrating uranium speciation and solubility in the presence of approximately 350 mg/L carbonate. Note yellow regions indicate formation of a solid phase. Model generated using Geochemist Workbench and LLNL v8r6+ database.

In Energy*Solutions*' response to Round 1 interrogatories (ES 2014d), the last line of Table 2-64/1 presents uranium solubility data from SNL 2007. The uranium concentrations reported in Energy*Solutions*' Table 2-64/1 seem to only include the solubility of hexavalent-state uranium [U(VI)] and mixed U(IV/VI) phases and do not consider the potential formation of U(IV) phases [i.e., aqueous $U(IV)(OH)_x^{4-x}$ species and U(IV) minerals such as uraninite]. Formation of uraninite will significantly decrease overall uranium solubility in groundwater. As noted in the Round 2 Interrogatory CR R313-25-8(4)(a)-64/2 (DRC 2014b), the DU PA needed to clarify whether the geochemical model considers the potential formation of uraninite or other U(IV) phases and the expected redox conditions of the waste in the landfill, because not considering the U(IV) phases if they are indeed forming will result in an overly conservatively high estimate of aqueous uranium concentrations, due to failure to consider aqueous uranium hydroxide [$U(OH)_4$].

Also relevant to the overall prediction of the solubility of uranium is that the solubilities listed in Table 12 of the geochemical modeling report (Neptune 2014m) represent the output of a Visual MINTEQ model of triuranium octoxide (U_3O_8) solubility. Given the low solubilities of uranium reported in Table 12, 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[11] and U_3O_8 solubility in Tables 9 through 12 of the geochemical modeling report (Neptune 2014m) was to give the boundaries of uranium solubility. However, it is unrealistic to run a model with a relatively high E_H/pH condition (such as pH 8, E_H 200 millivolts in Table 10) and not allow for the oxidation of reduced species. Therefore, the Round 2 Interrogatory CR R313-25-8(4)(a)-64/2 expressed a concern about whether the reported low-solubility values in Energy*Solutions* Table 12 are reliable for use as the source term in reactive transport models. Figure 4-4 and Table 4-2 show the reported values from Energy*Solutions* Table 12 as well as two columns of output from additional DEQ Visual MINTEQ runs. As part of the DU PA review, DEQ used the average ion concentrations in the last row of Table 8 in conjunction with the data in Table 12 of the geochemical modeling report (Neptune 2014m) in an attempt to reproduce the reported total dissolved uranium concentrations shown in Table 12. 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 12. However, the final column in Table 4-2 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. Because the redox chemistry of the waste disposal site in this work is variable, DEQ recommended in the Round 2 interrogatory CR R313-25-8(4)(a)-64/2 (DRC 2014b) that redox-coupled solubility calculations be used when defining the source concentrations in reactive transport models. The specific E_H and pH ranges expected under the various geologic conditions considered in the reactive transport models must be used in this source term analysis.

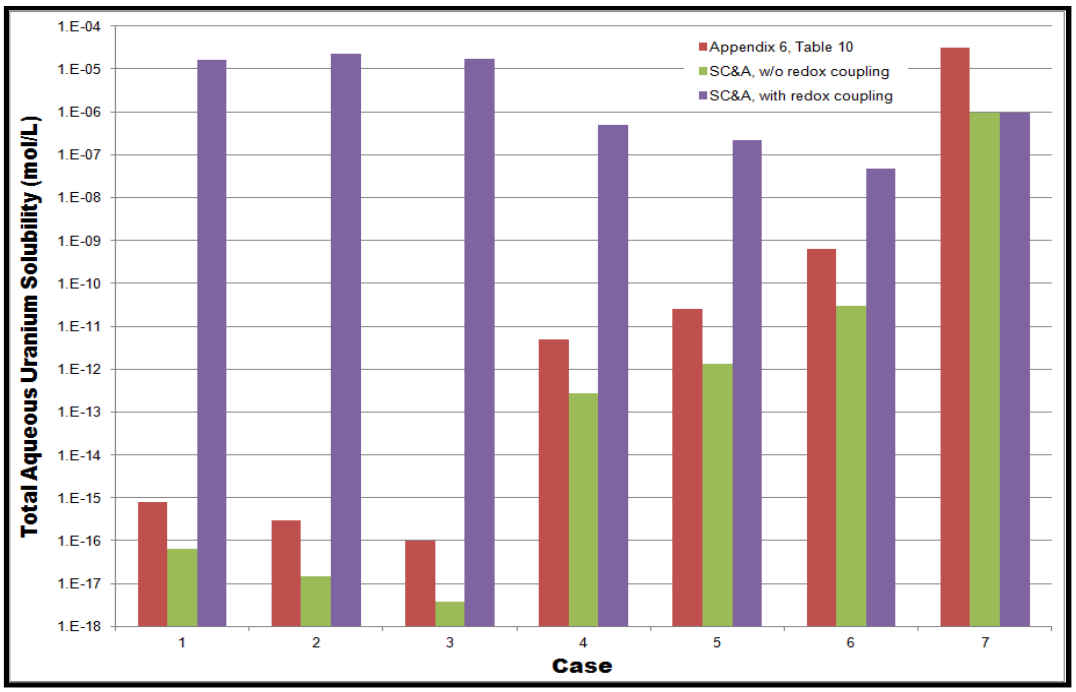


Figure 4-4 – Comparison of redox coupled and uncoupled solubility models

[11] Schoepite is an oxidized alteration product of uraninite, where uranium occurs as U(VI).

Table 4-2 – Ion Concentrations, pH, and Eh Values for Various Uranium Solubility Models Using Visual MINTEQ

Condition	pH[a]	Eh[a]	Total CO_3^{2-} [a]	Br^- (mg/L)[b]	F^- (mg/L)[b]	Cl^- (mg/L)[b]	NO_3^- (mg/L)[b]	SO_4^{2-} (mg/L)[b]	Ca^{2+} (mg/L)[b]	Mg^{2+} (mg/L)[b]	K^+ (mg/L)[b]	Na^+ (mg/L)[b]	Neptune-Reported Total Uranium Solubility Based on U_3O_8 (mol/L)[a]	DEQ-Calculated Total Uranium Solubility without Redox Coupling (mol/L)	DEQ-Calculated Total Uranium Solubility with Uranium Redox Coupling (mol/L)	Neptune-Reported Total Uranium Solubility Based on UO_3 (mol/L)[c]
1	6.5	200	190	20	4.2	24094	1.5	3079	552	793	509	15162	7.85E-16	6.49E-17	1.62E-05	1.18E-04
2	7	200	190	20	4.2	24094	1.5	3079	552	793	509	15162	3.00E-16	1.51E-17	2.23E-05	9.72E-06
3	8	200	300	20	4.2	24094	1.5	3079	552	793	509	15162	1.00E-16	3.76E-18	1.68E-05	1.80E-03
4	7.3	-10	190	20	4.2	24094	1.5	3079	552	793	509	15162	4.98E-12	2.74E-13	4.84E-07	–
5	7.3	-40	190	20	4.2	24094	1.5	3079	552	793	509	15162	2.52E-11	1.30E-12	2.24E-07	–
6	7.3	-100	190	20	4.2	24094	1.5	3079	552	793	509	15162	6.45E-10	2.93E-11	4.74E-08	–
7	7.3	-300	190	20	4.2	24094	1.5	3079	552	793	509	15162	3.18E-05	9.44E-07	9.44E-07	–

Note: Reported values from the geochemical modeling report (Neptune 2014m) are provided. Models with and without redox coupling were performed using the reported pH, Eh, and ion concentrations shown with each condition.
[a] From Neptune (2014m), Table 12.
[b] From Neptune (2014m), Table 8.
[c] From Neptune (2014m), Table 9.

In its Round 2 response to Interrogatory CR R313-25-8(4)(a)-64/2 (ES 2014a), Energy*Solutions* stated that:

> *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 shoepite 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 U_3O_8 solubility does not make a difference in the 10,000-year quantitative model. For the 10,000-year model, only UO_3 is considered as a solid phase. U_3O_8 solubility is used in the Deep Time portion of version 1.2 of the Model. Therefore, the U_3O_8 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 U_3O_8 solubility distribution will not make a noticeable difference, if that model conservatism is removed.*

In the Round 3 Interrogatory CR R313-25-8(4)(a)-64/2 (DRC 2014c), DEQ requested additional clarification of the data presented in Table 2, page 2, of the revised geochemical modeling report (Neptune 2014m). In that table, U_3O_8 was listed with an expected low solubility, and Energy*Solutions* was asked to indicate whether U_3O_8 was allowed to oxidize to schoepite or some other oxidized phase within this model. If U_3O_8 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.

In the Round 3 Interrogatory CR R313-25-8(4)(a)-64/2 (DRC 2014c), DEQ also raised questions regarding the means by which the solubility of uranium is simulated in the GoldSim model, specifically:

> *Section 5.1.14.1, page 24, states that: "The solubility of U_3O_8 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 UO_3 and U_3O_8. The text implies, but does not clearly state, that U_3O_8 was ignored (since UO_3 is the primary control of solubility). If this is indeed the case, then all of the discussion of U_3O_8 is superfluous. The section could be shortened to one statement that the solubility of U_3O_8 is orders of magnitude lower than UO_3 (with proper references), so UO_3 is considered the dominant phase.*

In response to the concerns raised pertaining to exactly how GoldSim models uranium solubility, Energy*Solutions* stated the following in its Round 3 response to Interrogatory CR R313-25-8(4)(a)-64/3 (ES 2014b):

> *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 UO_3. Since UO_3 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 U_3O_8 for the first 10,000 yr instead, as a way of evaluating sensitivity to this parameter.) U_3O_8 solubility is used to control uranium solubility in the Deep Time model (over 10,000 yr). If the UO_3 solubility were used in the Deep Time model, or if the U_3O_8 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.*

Conclusion: The uranium solubilities used in the Clive DU PA v1.2 ranged from 3.58E-6 to 2.79E-3 moles per liter (mol/L) (Neptune 2014c, Appendix 16, Table 22). These solubilities were based on UO_3. As described in Table 4-2, the uranium solubilities based on redox coupling ranged from 4.74E-08 to 2.23E-05 mol/L for comparable ranges of pH and Eh. Thus, the use of UO_3 is conservative (i.e., results in higher uranium solubility).

References

DRC, 2014b; 2014c

ES, 2014a; 2014b; 2014d

Neptune, 2014c; 2014m

SNL, 2007

Sparks, 1998

4.2 10 CFR 61.41 – PROTECTION OF THE GENERAL POPULATION FROM RELEASES OF RADIOACTIVITY (UAC RULE R313-25-20)

UAC Rule R313-25-20 states:

> *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 0.25 mSv (0.025 rem) to the whole body, 0.75 mSv (0.075 rem) to the thyroid, and 0.25 mSv (0.025 rem) to any other organ of any member of the public. 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. Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.*

UAC Rule 213-25-4(a) requires:

> *(4) The licensee or applicant shall also include in the specific technical information the following analyses needed to demonstrate that the performance objectives of Rule R313-25 will be met:*
>
> *(a) 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 Section R313-25-20.*

From the requirements of UAC R313-25-9(4)(a), it is clear that in the process of evaluation of compliance with UAC R313-25-20 (10 CFR 61.41), the Director must consider:

1) Analysis of Multiple Exposure Pathways – In order to determine future dose to a member of the public that might arise from the proposed DU waste disposal, the Director must examine five different routes of human exposure, including air, soil, groundwater, surface water, and plant uptake.

2) Annual Limit for Dose from Ground Water – The reference to UAC R313-25-20 presents a more rigorous degree of protection of public health and the environment (than 10 CFR 61.41), in that it requires that groundwater pollution caused by the proposed Federal Cell not cause human exposures greater than 4 millirem per year (mrem/yr). This 4-millirem dose would be a component of the total dose limit set in UAC R313-25-20 (and 10 CFR 61.41), i.e., the 25/75/25 mrem/yr maximum dose to whole body, thyroid, and any other organ, respectively. At the Clive facility, this maximum groundwater dose limit has been implemented under Energy*Solutions* GWQ Permit No. UGW45005, Part I.C and Table 1A.

3) Effects of Burrowing Animals – This mandate is found in both the DEQ and NRC regulations (e.g., UAC R313-25).

4) Differentiate Mechanisms Controlling Waste Isolation – The Director must consider natural phenomena and characteristics of the disposal site, and man-made or engineered features at the facility that contribute to isolation and sequestration of LLRW contaminants.

Section 5.1.6 of the DU PA Model v1.2 (Neptune 2014a) defines potentially exposed members of the general public as those "*who perform activities in the vicinity of the Clive facility*." For purposes of DEQ, these persons are those who conduct activities outside the 90-foot buffer zone surrounding each disposal cell.[12] Energy*Solutions* has calculated the potential dose to the following members of the general public at these locations:

- Nearby highway (Interstate-80) – 4 km, north
- The Knolls Off-Highway Vehicle (OHV) Recreation Area (Knolls) - 12 km, west
- The nearby railroad (Railroad) - 2 km, north
- The Grassy Mountain Rest Area on I-80 (Rest Area) - 12 km, northeast
- The Utah Test and Training Range (UTTR) access road – immediately, west

Unlike inadvertent intruders who might be exposed by a variety of pathways the site (see Section 4.3), these listed offsite receptors were assumed by Energy*Solutions* to be exposed primarily to wind-dispersed contamination of radon and progeny, for which the inhalation exposure pathway dominates. DEQ notes that a person receiving exposure just inside the buffer zone would be an inadvertent intruder while a person performing the same actions just outside the buffer zone would be a member of the public, but their exposures would be essentially the same. As such, while exposure scenarios may be similar, specific regulatory protections and dose limits are different. It should also be noted that while Energy*Solutions* did not include the groundwater pathway in its calculation of doses to the general public, DEQ did perform such analyses and the results are discussed in Section 4.2.2.

Table 4-3 summarizes results from these five Energy*Solutions* scenarios, based on modeling exposures over 10,000 years.

[12] This 90-foot buffer zone is defined by Part X of the Utah Ground Water Quality Discharge Permit. During active waste disposal operations, members of the general public are those who do not receive an occupational dose (see UAC R313-12-3).

Table 4-3 – Annual Mean Peak Doses (TEDE) for Exposure to the General Population

Receptor	Mean Peak TEDE (mrem/yr)
Nearby Highway (Interstate-80)	4.87E-07
Knolls OHV Recreation Area	4.36E-06
Nearby Railroad	7.65E-07
Grassy Mountain Rest Area on I-80	1.02E-05
UTTR access road	2.47E-04

Source: Neptune (2014a), Table 4.

Energy*Solutions* also calculated potential doses to industrial workers, ranch workers, hunters, and OHV enthusiasts, but because their potential exposures were assumed to occur on site, Energy*Solutions* considered them to be inadvertent intruders and not members of the general public [see the DU PA Model v1.2, Section 5.1.7 (Neptune 2014a)]. See Section 4.3 for a discussion of these and other inadvertent intruders.

It has been suggested that other scenarios involving exposures of the general public from future industrial land development outside the disposal site boundary are possible. For example, it has been postulated that existing buildings owned by Energy*Solutions*, but currently not included in the LLRW surety, could be left standing after facility closure, encouraging future industrial use. It is not obvious what sort of scenario would produce greater exposures than the chronic inadvertent intruder industrial scenario developed in response to Interrogatory CR R313-25-19-182/2: Groundwater Exposure Pathways. In that scenario, a worker is exposed to ground surface contaminated with water extracted from the lower confined aquifer for 2,000 hours per year, receiving doses from both ground shine and inhalation (ES 2014e). Total doses to an industrial worker from the chronic inadvertent intruder industrial scenario are minimal—on the order of 6E-05 mrem/yr (see Section 4.3).

The Clive DU PA Model developed by Energy*Solutions* included the evaluation of various potential exposure pathways, including inhalation (wind-derived dust, mechanically-generated dust, and radon), inadvertent ingestion of surface soils, ingestion of beef, and external irradiation (soil and immersion in air).

References

ES, 2014e

Neptune, 2014a

4.2.1 Review of the Radon Pathway

Energy*Solutions* plans to dispose of the DU below grade and then place an embankment, topped with an engineered cover to minimize infiltration, over the DU. The embankment, designated the proposed Federal Cell, is planned to be approximately 36 feet 4 inches (11 meters) thick and

consist of clean soil or non-DU material. For the purposes of the present Clive DU PA Model and this SER, it has been assumed that this non-DU material would be nonradioactive (see Section 3.4). The engineered cover is planned to consist of surface, evaporative, frost protection, and radon barrier layers, with a total thickness of about 5 feet (1.5 meters). Thus, the disposed layers of DU waste would be over 41 feet (12.5 meters) beneath the top surface of the proposed Federal Cell.

With the DU this deep below the surface, it is unlikely that much, if any, radioactivity from the DU other than radon would find its way to the surface soil or dust during the entire 10,000-year Compliance Period. The sensitivity analysis presented in DU PA Model v1.2, Section 6.2.2 (Neptune 2014a) shows that the radon escape-to-production ratio (which defines the amount of radon leaving the waste matrix and entering the air-filled porosity of the waste material) is the most significant predictor of dose and has the highest sensitivity index[13] for dose of all of the various input parameters. Thus, the general population dose during the Compliance Period from the disposal of DU at the Clive site is very dependent upon the radon flux at the ground surface of the embankment.

For the calculation of radon flux at the ground surface from the decay of Ra-226 in the ground, the NRC in Regulatory Guide 3.64 (NRC 1989) provided the following equation:

$$J_w = 10^4 R\,\rho\,E\,\sqrt{\lambda\,D}\,\tanh\left(t\,\sqrt{\lambda/D}\right) \quad (1)$$

where:
- J_w = Radon-222 flux on the waste surface (pCi m^{-2} s^{-1})
- 10^4 = Units conversion (cm^2 m^{-2})
- R = Radium-226 concentration (pCi g^{-1})
- ρ = Bulk density (g cm^{-3})
- E = Radon emanation factor (dimensionless)
- λ = Radon decay constant (s^{-1})
  - = 2.1×10^{-6} (s^{-1})
- D = Radon diffusion coefficient (cm^2/s)
- t = Thickness of the source (cm)

In Equation (1), the hyperbolic tangent term $\left(\tanh\left(t\,\sqrt{\lambda/D}\right)\right)$ accounts for the finite thickness of the Ra-226 source; that is, as the thickness of the source material approaches infinity, this term approaches unity. For the Clive DU PA Model v1.2, the Ra-226 source would be the DU and the thickness would be the lower ~8 feet of the proposed Federal Cell that contains the disposed-of DU.

Furthermore, the International Atomic Energy Agency (IAEA) (2013) states that the flux from a covered radon source may be approximated by Equation (2):

[13] The sensitivity index represents the portion of total statistical variance in the output (i.e., dose) that is attributed to each input parameter.

$$F_C = F_S \exp(-t / D_L) \quad (2)$$

where:
F_C = Radon flux on top of the cover (pCi/m^2-s)
F_S = Radon flux on top of the source (pCi/m^2-s)
t = Cover thickness (cm)
D_L = Radon diffusion length (cm)
$= \sqrt{\frac{D}{\lambda}}$
D = Radon diffusion coefficient (cm^2/s)
λ = Radon decay constant (s^{-1})
$= 2.1\times10^{-6}$ (s^{-1})

As explained in the DU PA radon diffusion modeling report (Neptune 2014j), the radon flux at the ground surface of the embankment was not calculated from Equations (1) and (2), above. Rather, it was calculated using the GoldSim internal diffusion process routines. Nevertheless, DEQ has used Equations (1) and (2) to perform a confirmatory analysis of the DU PA Model v1.2 reported radon flux on the ground surface of the embankment.

In order to utilize Equations (1) and (2), it is necessary to know the radon diffusion coefficient within the waste and cover layers of the embankment. DEQ took three different approaches to estimate the diffusion coefficients. For the first approach, in 2002 Tye Rogers presented a paper that discussed diffusion coefficients specific to the Clive facility (Rogers 2002). This paper gave the waste and the cover the diffusion coefficients as 0.031 and 0.00064 square centimeters per second (cm^2/s), respectively.

For the second approach, DEQ used the work of V.C. Rogers and K.K. Nielson (1991), who developed the empirical expression shown in Equation (3) for the radon diffusion coefficient based on 1,073 diffusion coefficient measurements on natural soils:

$$D = D_0 \Phi \exp[-6\, m\, \Phi - 6\, m^{14\,\Phi}] \quad (3)$$

where:
D = Radon diffusion coefficient (cm^2/s)
D_0 = Radon diffusion coefficient in air (0.11 cm^2/s)
Φ = Total porosity (dimensionless)
m = Moisture saturation fraction (dimensionless)
$= \frac{M}{\Phi}$
M = Moisture content, dry basis (dimensionless)

The diffusion coefficients in each layer of the waste and cover were determined by DEQ for this SER using Equation (3).

For the third approach, in its response to Interrogatory CR R313-25-7(2)-05/2: Radon Barrier, Energy*Solutions* stated that the "*diffusion coefficient is calculated as the product of the diffusion coefficient in free air and the tortuosity*," and that the air phase tortuosity is simply the air-filled

porosity divided by the total porosity raised to the two-thirds power (ES 2014a). Expressed mathematically, this is:

$$\begin{aligned} D &= D_0\,\tau\,C_f \\ &= D_0\,\frac{\Phi - M}{\Phi^{2/3}}\,C_f \end{aligned} \qquad (4)$$

where:
- D = Radon diffusion coefficient (cm^2/s)
- D_0 = Radon diffusion coefficient in air (0.11 cm^2/sec)
- τ = Tortuosity in air (dimensionless) = $\frac{\theta_a}{\Phi^{2/3}}$
- θ_a = Air-filled porosity (dimensionless) = $\Phi - M$
- Φ = Total porosity (dimensionless)
- M = Moisture content (dimensionless)
- Cf = Correction factor (dimensionless)

As described in Neptune (2014j), spatially-discretized models (such as the Clive DU PA Model) tend to overestimate diffusive flux. This was accounted for by applying a correction, or calibration, factor, as shown in Equation (4). Actually, Neptune determined and applied three correction factors: 0.394 for the waste layers (i.e., below the radon barriers), 0.894 for the radon barrier layers, and 0.974 for the upper cover layers, as documented inside the DU PA GoldSim model itself.

Figure 4-5 presents the radon fluxes at 10,000 years calculated via the Clive DU PA Model v1.2 GoldSim file (hereafter "GoldSim v1.2") and via the three alternative DEQ approaches described above:

- **GoldSim v1.2** (blue solid curve in Figure 4-5) – The Clive DU PA Model v1.2 GoldSim file that was provided to DEQ by Energy*Solutions* was used. DEQ modified the file in order to save the radon flux results at the top of each waste and cover layer throughout the embankment, so that they could be viewed, but no changes were made that would affect the calculated radon flux.
- **Air Tortuosity** (starred, thin blue curve) – Equations (1) and (2), with the diffusion coefficients calculated via Equation (4). This approach attempts to match the Clive DU PA Model v1.2 results to determine whether the GoldSim diffusion routine is performing as claimed in Neptune (2014j).
- **IAEA Equation** (purple curve) – Equations (1) and (2), with the diffusion coefficients calculated via Equation (3).
- **Rogers 2002** (orange curve) – Equations (1) and (2), with the diffusion coefficients from Rogers (2002).

For each waste and cover layer of the embankment, the values for the bulk density, total porosity, and moisture content for the IAEA Equation and Air Tortuosity approaches were taken

from the Energy*Solutions* GoldSim results. DEQ modified the Clive DU PA Model v1.2 GoldSim file that was provided by Energy*Solutions* so that these parameter values were saved and could be displayed.

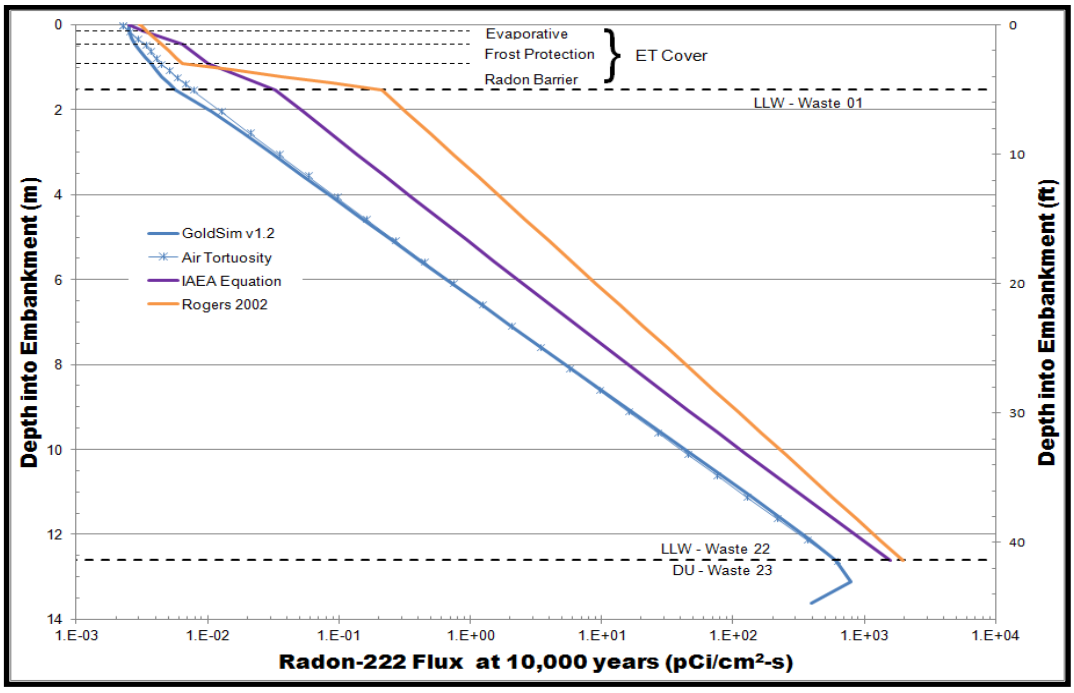


Figure 4-5 – Mean radon flux in the embankment

The first thing to notice about Figure 4-5 is that all of the calculated ground surface fluxes are about the same, as shown in Table 4-4 (column 2).

Table 4-4 – Summary of Radon Flux Analyses

Case	Calculated Radon Flux (pCi/m^2-s)			ET Cover Attenuation
	At Ground Surface	On Top of Other Waste	On Top of DU	
GoldSim v1.2	0.0025	0.0057	605	2.3
Air Tortuosity	0.0022	0.0076	605	3.4
IAEA Equation	0.0025	0.033	1,570	13.0
Rogers 2002	0.0031	0.21	1,960	70.0

Second, there is a large difference between the GoldSim v1.2 radon attenuation in the ET cover and the ET cover attenuation calculated by either the IAEA Equation or Rogers 2002. For both the IAEA Equation and Rogers 2002, the attenuation provided by the radon barrier layers is clearly shown in Figure 4-5, but for the GoldSim v1.2 there is virtually no attenuation by the radon barrier layers [Table 4-4 shows only an attenuation of 2.3 (i.e., 0.0057 picocuries per

square meter per second [pCi/m^2-s] ÷ 0.0025 pCi/m^2-s) for GoldSim v1.2]. In fact, close examination of the Figure 4-5 GoldSim v1.2 curve shows that there is less attenuation per unit thickness in the radon layers than there is in the waste layers. This is due to the different correction factors that Energy*Solutions*/Neptune calculated and applied (i.e., 0.394 for the waste layers and 0.894 for the radon barrier layers) and Equation (4)'s linear relationship between moisture content and diffusion coefficient. In other words, the increase in the correction factor more than compensated for the increase in the moisture content.

Third, because the IAEA Equation curve is based on calculated diffusion coefficients using Equation (3) and the diffusion coefficient for the Rogers 2002 curve is simply a fixed value, DEQ believes that the IAEA Equation radon flux is more representative of the conditions at the proposed Federal Cell.

The Air Tortuosity curve in Figure 4-5 agrees well with the GoldSim v1.2 radon flux, indicating that GoldSim v1.2 is performing the calculations as described in the Clive DU PA Model v1.2 documentation (Neptune 2014j).

As discussed elsewhere in this SER (e.g., Section 4.1), there remains considerable uncertainty regarding the functionality of the ET cover. As shown in Table 4-4, in the GoldSim v1.2 and IAEA Equation cases, the ET cover radon attenuation factors were calculated to be 2.3 and 13, respectively. If it is assumed that the ET cover is removed in its entirety, then the ground surface radon fluxes would increase by a factor of 2.3 or 13. Since the general population doses reported in Table 4-3 are all several orders of magnitude below the 25 mrem/yr limit, completely removing the ET cover would not affect the site's ability to meet the UAC R313-25-20 (10 CFR 61.41) criteria, and this conclusion remains valid regardless of the ET cover's functionality, or lack thereof. Additionally, if the ET cover were to be removed or were to prove ineffective at minimizing infiltration, this would result in higher moisture levels within the material placed over the DU waste (shown as "LLW" in Figure 4-5), which in turn would act to reduce the ground surface radon flux.

References

ES, 2014a

IAEA, 2013

Neptune, 2014a; 2014j

NRC, 1989

Rogers, 2002

Rogers and Nielson, 1991

4.2.2 Groundwater Pathway

Energy*Solutions* did not evaluate any exposures pathways for the general public involving groundwater ingestion. The groundwater from both the upper and lower aquifers beneath the site contains very high levels of total dissolved solids (TDS); i.e., the upper, unconfined aquifer TDS concentration ranges from 32,000 milligrams per liter (mg/L) to 74,000 mg/L, while the lower,

confined aquifer TDS concentration is typically above 20,000 mg/L (ES 2012a). Thus, Energy*Solutions* concludes that groundwater around the site is not potable and, therefore, the groundwater ingestion exposure pathway does not need to be evaluated. DEQ has questioned this conclusion and points to the fact that public water supply systems are currently registered with the Utah Division of Drinking Water, including four facilities in Tooele County, near Clive, which already rely on reverse osmosis (RO) treatment to supply industrial or commercial water from the groundwater (Edwards 2014). At least two of these facilities have used the treated groundwater for culinary purposes and drinking. Consequently, DEQ evaluated exposures to the general public from the groundwater pathway.

As noted previously, the second requirement of UAC R313-25-20 is 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*." DEQ evaluated both the shallow and deep aquifers, and found that the yield of the shallow aquifer is so limited, due to its low permeability, that a private homeowner or a public drinking water system would not be able to pump enough shallow groundwater to supply its daily needs. As a result, DEQ has decided to evaluate the deep aquifer for 10,000 years to determine whether that exposure pathway is in compliance with the 4 mrem/yr dose limit in UAC R313-25-20 as it applies to a general member of the public. An individual member of the general public could be exposed to DU-contaminated groundwater at Clive from a well located outside the buffer zone, or beyond 90 feet. These calculations are described below.

To examine the importance of the groundwater pathway, DEQ preformed a simple deterministic calculation of the dose that an individual would receive who consumed treated groundwater from a well located 90 feet (27 meters) from the toe of the Federal Cell.[14] The well was assumed to be drilled through the upper, unconfined aquifer and into the lower, confined aquifer, but some leakage along the borehole casing from the upper aquifer was assumed to contaminate the lower aquifer during pumping episodes. As explained in Energy*Solutions* (2014e), the amount of leakage was calculated using the Dupuit-Thiem equation. For the ingestion pathway, DEQ assumed that the water would be treated by RO to reduce TDS to potable levels as is currently done at several nearby sites. It was assumed that during removal of the dissolved solids to achieve levels acceptable for potability, the decontamination factor for dissolved radionuclides was 10. EPA studied the efficacy of point-of-use RO units for households and determined that radium and uranium are effectively removed by RO (EPA 2005). For example, Clifford (2004) reported >99 percent removal of radium and uranium. In another study, Lewis et al. (2006) reported removal of uranium to <0.1 microgram per liter (µg/L). While the RO process is effective at removing some types of radionuclide (e.g., particulates), it is ineffective at removing gases, such as radon. However, since radon does not contribute significantly to the water ingestion exposure pathway, this is not a concern for this calculation.

[14] At this location, the individual could be either an inadvertent intruder or a member of the public.

In February 2014, the NRC approved publication of an NRC staff alternative to modify 10 CFR Part 61 specifically to address the disposal of long-lived radionuclides, such as DU. Unlike the two-tier approach of UAC R313-25-9(5)(a), the approved draft Part 61 alternative is based upon a three-tiered approach: (1) Compliance Period, lasting 1,000 years, with a general population dose limit of 25 mrem/yr; (2) Protective Assurance Period, from 1,000 to 10,000 years, with a 500 mrem/yr general population dose limit; and (3) Performance Period, for time greater than 10,000 years, requiring a qualitative analysis, but no dose limit (NRC 2014b, 2014c, 2014d).

In anticipation of the modified 10 CFR Part 61, doses were evaluated for three periods: 0–500 years, 0–1000 years, and 0–10,000 years, for both DU containing contaminants associated with recycled uranium and DU with no such contaminants. DEQ considered two scenarios for this treated groundwater from the lower aquifer: one where a member of the public consumes 3 liters (L) per day,[15] and one where a maintenance worker handles the brine reject stream from the RO unit. The results are summarized in Table 4-5.

Table 4-5 – Calculated Doses Due to the Lower Aquifer Groundwater Pathway

Time Period:	Peak Dose – Based on Mean Groundwater Concentration (mrem/yr)					
	0–500 years		0–1,000 years		0–10,000 years	
Exposure / DU:	All DU	No Recycle	All DU	No Recycle	All DU	No Recycle
Acute Exposure of Well Driller	8.9E-09	9.0E-21	1.8E-07	4.0E-15	1.7E-06	6.6E-08
Chronic Industrial Worker Exposure	4.3E-07	4.3E-19	8.8E-06	1.9E-13	8.4E-05	3.1E-06
Chronic Ingestion of Groundwater	7.3E-04	1.1E-15	1.5E-02	5.1E-10	1.4E-01	4.7E-03
Chronic Exposure to RO Brine	8.2E-07	8.2E-19	1.7E-05	3.7E-13	1.6E-04	5.9E-06

In the case of the 0–500 year and the 0–1,000 year results, the peak dose occurred at the end of the period. For the 0–10,000 year period, the "All DU" dose occurred at about 3,500 years and at 10,000 years for the "No Recycle" dose. The highest calculated dose was 0.14 mrem/yr for a person consuming the treated well water. It should be noted that the All DU dose at 3,500 years is about 30 times greater than the No Recycle dose at 10,000 years. This emphasizes the importance for keeping doses as low as reasonable achievable (ALARA) of not accepting DU with contaminants from recycled uranium. As discussed elsewhere in this SER, there remains much uncertainty regarding the performance of the ET cover to reduce infiltration into the embankment. Should the resolution of these uncertainties result in a revised embankment infiltration rate, the Table 4-5 doses would change. The impact of the infiltration rate on the Table 4-5 ingestion dose is presented below in the discussion of Figure 4-7.

Figure 4-6 shows the behavior of significant groundwater contaminants over 10,000 years.

[15] EPA has proposed in the Draft 2014 Update of Human Health Ambient Water Quality Criteria (EPA-820-F-14-003) that the default drinking water intake rate be increased to 3 L/day (EPA 2014a).

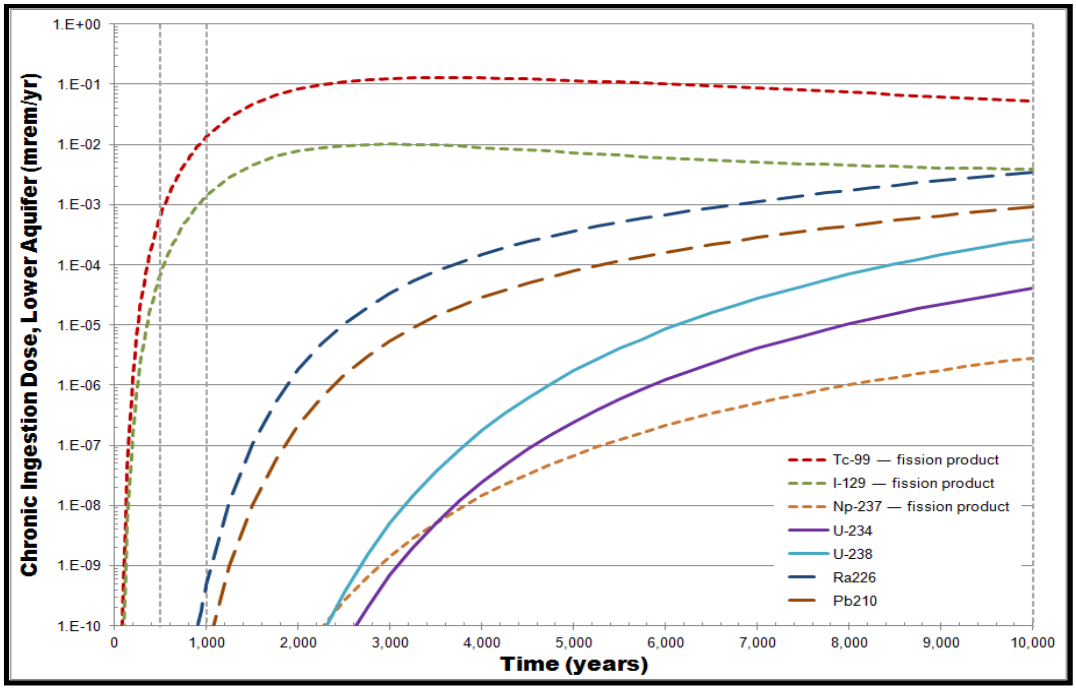


Figure 4-6 – Time-dependent lower aquifer groundwater ingestion dose

At 10,000 years, Tc-99 is still the dominant contributor to dose.

Based on this model and assuming standard annual water consumption levels, ingestion doses are well within the general population limit of 4 mrem/yr specified for the groundwater pathway in UAC Rule R313-25-20. It is recognized that this individual is located at the edge of the site, close to the embankment, and not at any of the five specified offsite locations considered by Energy*Solutions*; however, due to dispersion within the groundwater, the groundwater ingestion dose at any more distant offsite location would be less than this very small boundary dose estimate. It is also recognized that a characterization program needs to be established to gain a better understanding of the spatial and temporal characteristics of the hydrogeologic system. A summary of DEQ's current understanding of the deep hydrogeology is presented in Appendix H.

One could argue that this calculation understates the risks from groundwater ingestion because there could be multiple wells or aquitard discontinuities that could increase the contaminant concentration in the lower aquifer. However, the limiting contaminant concentration in the lower aquifer is the concentration in the upper aquifer. DEQ examined this limiting case in a White Paper, "Groundwater Pathway Doses, Part 2, Revision 1" (Marschke 2015). Section 3.0 of that paper states:

> *Obviously, the lower aquifer water cannot be more contaminated than the upper aquifer water. Table 3 presents the doses to a hypothetical upper aquifer groundwater user for each of the four exposure scenarios in Table 2, three time periods, and two source terms.*

> *Again it is stressed that the upper aquifer does not produce sufficient water to be a productive source of water, and that the doses reported in Table 3 are extreme upper bound estimates. However, it is instructive to notice that even though the Table 3 doses are upper bound estimates, they are all (with one exception) below the R313-25-19 dose from groundwater limit of 4 mrem/yr. The All DU doses exceed the limit for the Chronic Ingestion of Groundwater pathway for the 0-1,000 years and 0–10,000 years time periods….*
>
> *Because the upper aquifer cannot support a production well, in order for the well to produce sufficient water some quantity of lower aquifer water would need to be added to the upper aquifer water. This addition of lower (i.e., clean) aquifer water would dilute the radionuclide concentration in the well water below the upper aquifer concentration, with a corresponding decrease in the doses received.*

To provide additional perspective on the significance of the groundwater ingestion pathway, DEQ performed a bounding calculation in which it was assumed that the yield from the upper aquifer was sufficient to provide enough water to support a household. As discussed above, this scenario is bounding because the yield from the upper aquifer is not sufficient to support such a scenario. This calculation, which is summarized in Table 3 of Marschke (2015), shows that for time periods up to 10,000 years, a 1:11 dilution of upper to lower aquifer water is necessary to reduce the calculated dose to below the UAC R313-25-19 dose-from-groundwater limit of 4 mrem/yr. However, if disposal of DU-containing recycled uranium is not permitted as proposed in this SER, then the bounding undiluted upper aquifer groundwater ingestion dose is 1.4 mrem/yr, which is below the UAC limit.

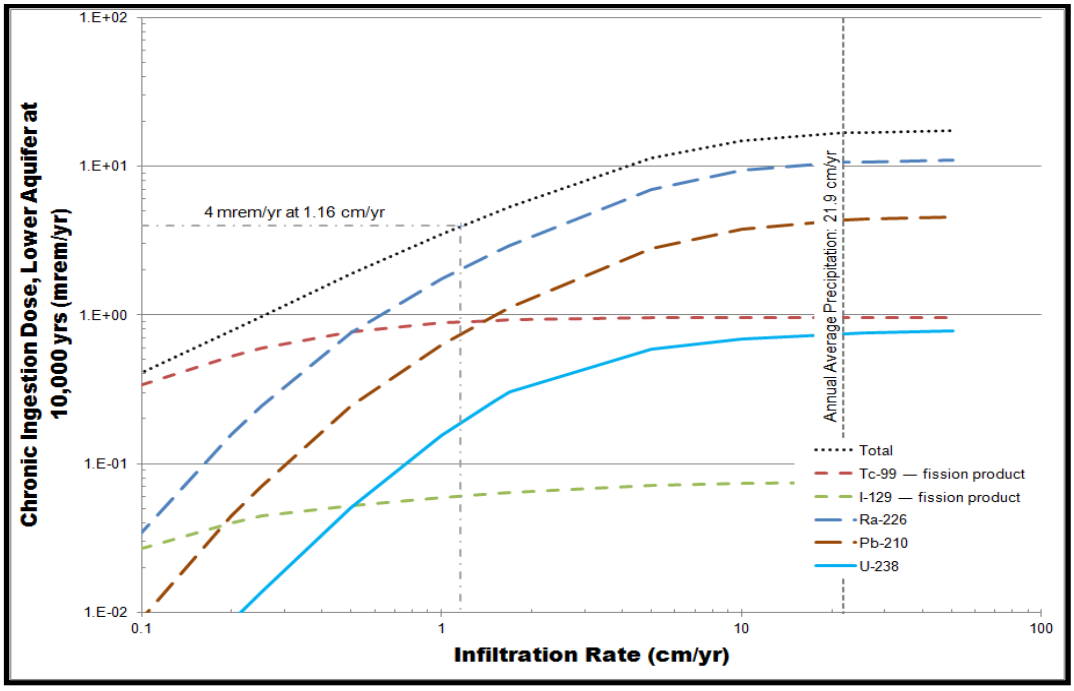


Figure 4-7 – Ingestion dose at 10,000 years versus infiltration rate

As discussed below in Section 4.4.1, there is much uncertainty regarding the infiltration rate that was utilized in DU PA v1.2. Figure 4-7 shows how the calculated chronic groundwater ingestion dose would vary as a function of the infiltration rate, with all other parameters remaining the same as for the Table 4-5 and Figure 4-6 doses. When viewing Figure 4-7, keep in mind that the mean infiltration rate used in DU PA v1.2 was 0.0344 cm/yr (see Section B.7, page B-11). Figure 4-7 shows that, if the infiltration rate exceeds 1.16 cm/yr, the chronic groundwater ingestion dose from this exposure pathway would exceed the UAC R313-25-19 groundwater exposure dose limit of 4 mrem/yr.

DRC has approved a rock armor cover for the CAW Cell at Clive (ES 2013b):

> *the proposed CAW embankment cover is a multi-layer system consisting from bottom to top of a two-component compacted clay radon barrier, a lower granular filter zone ("Type B" Filter Zone), a sacrificial soil layer, an upper granular filter zone ("Type A" Filter Zone), and an erosion (rock riprap) barrier layer.* (URS 2012)

The average infiltration rate through the top slope of the approved CAW rock armor cover is 0.09 cm/yr, while through the side slopes the rate is 0.168 cm/yr (URS 2012, Table 4-9). These infiltration rates were based on studies reported in Whetstone Associates (2011).

It is recognized that, although the rock armor cover has been approved for the CAW Cell, Energy*Solutions* and DRC are evaluating an alternative ET cover for the CAW Cell with expected improved performance. Nevertheless, the infiltration rates for the DRC-approved CAW rock armor cover should provide a reasonable upper bound for the ET cover proposed for the Federal Cell, and Figure 4-7 shows that the CAW rock armor infiltration rate would result in groundwater ingestion doses that are below the UAC R313-25-19 dose limit.

The final requirement of UAC R313-25-20 is that "*Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable*." For the ALARA objective, the DU PA Model v1.2 evaluated the estimated dose to the entire population of ranch workers, hunters, and OHV enthusiasts over the 10,000-year Compliance Period. There is a bit of a disconnect between the ALARA evaluation and the general population dose, because for the ALARA evaluation, ranch workers, hunters, and OHV enthusiasts are included, but for the general population dose, they are considered to be inadvertent intruders rather than part of the general population. Nonetheless, ranch workers, hunters, and OHV enthusiasts are likely to be the individuals who would receive the largest exposure; therefore this disconnect results in a conservative ALARA evaluation. Over the entire 10,000-year Compliance Period, the mean population dose was reported in the DU PA Model v1.2, Table 8 to be 1.56 person-rem.

DEQ recognizes that this 10,000-year population dose estimate is very small. However, the remoteness of the site was one of the reasons for locating the disposal facility there in the first place; i.e., most of the immediate area is uninhabited. At the time of the 2010 Census, the closest resident lives roughly seven miles to the northeast of the site and acts as a caretaker for the rest stop just off I-80. The largest group of people lives 48 to 80 miles to the east and southeast of the site in the Tooele-Grantsville area. Furthermore, the Tooele County Commission has designated the area around the Clive site as a hazardous industries zone. This designation prohibits all

residential housing in the vicinity of the Clive site, although it cannot be relied upon to limit the population past the 100-year institutional care period. For all of these reasons, the DU PA Model v1.2 population dose estimate is acceptable.

In the DU PA Model v1.2 ALARA evaluation (Neptune 2014a), a monetary value of $1,000 per person-rem without discounting was utilized. This value is not consistent with NRC policy. As stated in NUREG-1530 (NRC 1995) and included in revisions of NUREG/BR-0058 (NRC 2004), the NRC's policy is to use a value of $2,000 per person-rem for ALARA determinations. In addition, NUREG/BR-0058, Revision 4, requires that when intergenerational consequences are involved, lower discount rates (including potentially no present worth, or zero percent) should be used. DEQ believes that Energy*Solutions* should have utilized the $2,000 per person-rem without discounting—the latest guidance from the NRC. Additionally, the DU PA Model v1.2 ALARA analysis did not include doses to Industrial Workers, who were introduced by Energy*Solutions* (2013b, Section 2.6.3). Since the Industrial Worker dose is based on the Ranch Worker dose, which contributes less than 25 percent to the population dose, it is not expected that the Industrial Worker would contribute more than 25 percent to the total population dose. Nevertheless, because the calculated population exposure is so small, doubling it to account for $2,000 per person-rem and increasing it to account for Industrial Workers would make no difference in the conclusion that the radioactivity effluents are ALARA.

Conclusion: As discussed elsewhere in this SER, there remains much uncertainty regarding the performance of the ET cover to reduce infiltration into the embankment. Nonetheless, based on the DU PA and DEQ contractor calculations summarized in this SER, DEQ concludes that the design of the proposed Federal Cell provides adequate protection of the general population from releases of radioactivity from disposed DU waste as required by UAC R313-25-20. This conclusion is contingent upon the belief that, although the infiltration rate may increase once all of the ET cover concerns have been resolved, it is unlikely that the increase will be significant enough to cause the doses reported in this section to exceed the UAC R313-25-20 limits. However, should the resolution of the ET cover concerns result in an infiltration rate of 1 cm/yr, or greater, then this conclusion will need to be revisited. Furthermore, a characterization program needs to be established to gain a better understanding of the spatial and temporal characteristics of the hydrogeologic system, specifically the lower confined aquifer.

References

Clifford, 2004

Edwards, 2014

EPA, 2005

ES, 2012a; 2013b; 2014e

Lewis et al., 2006

Marschke, 2015

Neptune, 2014a

NRC, 1995; 2004; 2014b; 2014c; 2014d

URS, 2012

Whetstone Associates, 2011

4.3 10 CFR 61.42 – PROTECTION OF INDIVIDUALS FROM INADVERTENT INTRUSION (UAC RULE R313-25-21)

UAC Rule R-313-25-21, "Protection of Individuals from Inadvertent Intrusion," states:

> *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 Rule 213-25-4(b) also requires:

> *(b) Analyses of the protection of inadvertent intruders shall demonstrate a reasonable assurance that the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided.*

UAC Rule R313-25-2, "Definitions," defines an "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.*" In 10 CFR 61.2, "Definitions," the NRC defines an inadvertent intruder as "*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*" (emphasis added). Although the definitions are similar, there are subtle differences. For DEQ's purposes, the inadvertent intruder will be considered to be one who occupies the site and is unknowingly exposed. DEQ believes that this assumption is more conservative, resulting in higher exposures to radiation. Because of the site's semi-arid and remote nature and designation as a hazardous industries zone, occupying the site will be limited to industrial activities and not full-time residency or agricultural use of nearby lands.

It should be noted that inadvertent intrusion occurs only within the disposal site. UAC R313-25-2 provides the following definitions:

> "*Buffer zone" means a portion of the disposal site that is controlled by the licensee and that lies under the disposal units and between the disposal units and the boundary of the site.*
>
> "*Disposal site" means that portion of a land disposal facility which is used for disposal of waste. It consists of disposal units and a buffer zone.*

Thus, the disposal site does not include the entirety of a land disposal facility but rather only the disposal units and their buffer zones. Also, "boundary of the site" for the Clive site has been defined pursuant to the Radiation Control Act [Utah Code Annotated (UCA) 19-3-105] and

previous gubernatorial and legislative approval as Section 32. Inside Section 32, the buffer zones for each disposal cell are defined by the GWQ Permit; see Part I.D, Tables 2A, 2B, and 2C.[16] Under these DEQ-approved Energy*Solutions* engineering drawings, a 90-foot buffer zone is defined for each disposal cell at Clive. Between the disposal cells, the individual 90-foot buffers are contiguous, leaving a 180-foot separation internally. For the proposed Federal Cell, this 180-foot separation will exist on the north margin between the Federal Cell and the CAW Cell. However, on the east margin, this separation distance between the waste in the Federal Cell and the waste in the 11e.(2) Cell would be 50 feet [ES Drawing No. 14003-V3A(1)].

For purposes of DEQ's DU PA review, any future industrial-related human activity within the confines of the proposed Federal Cell and its buffer zone will be considered as site intrusion. Conversely, future activities on other parts of the Energy*Solutions* land disposal facility do not constitute human intrusion for DEQ's DU PA model review but instead are to be considered as sources of possible releases to the general population under UAC R313-25-20 (see Section 4.2). Under this requirement, dose limits to an individual member of the public are 25 mrem/yr (whole body), 75 mrem/yr (thyroid), and 25 mrem/yr (any organ), with a no more than 4 mrem/yr dose from groundwater sources. This is also true for all land outside of Section 32.

Because a large number of inadvertent intruder scenarios can be envisioned, the NRC has provided guidance to limit speculation. As stated by the Performance Assessment Working Group (PAWG) in NUREG-1573 (NRC 2000, p. 3-10 and 11):

> *The overall intent 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. In developing this "reference natural setting," changes in vegetation, cycles of drought and precipitation, and erosional and depositional processes should be considered; future events should include those that are known to occur periodically at the site (e.g., storms, floods, and earthquakes). It must be emphasized that the goal of the analysis is not to accurately predict the future, but to test the robustness of the disposal facility against a reasonable range of potential outcomes. The parameter ranges and model assumptions selected for the LLW [low-level waste] performance assessment should be sufficient to capture the variability in natural conditions, processes, and events.*
>
> *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…. 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*

[16] Related Permit requirements are also found in Parts I.F.1(f and g), Table 7, I.D.5, and Table 3.

> *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. Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity off-site.*

As reported by Energy*Solutions* in its response to Round 1 Interrogatory CR R313-25-8(4)(b)-07/1 (ES 2014d):

> *Archeological surveys of the Clive area performed in 1981. …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 (*[ES 2013a]*). 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 2001studies. 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).*

A 500-mrem/yr inadvertent intruder dose standard has been proposed by NRC staff in a July 18, 2013, recommendation to the Commission (NRC SECY-13-0075, pp. 4–6; NRC 2013b). In a February 12, 2014, order to the NRC staff, the Commission approved this approach; among other issues (SECY-13-0075/RIN3150-A192; NRC 2014b). Consequently, DEQ has determined that the compliance threshold for inadvertent intruder exposure will be 500 mrem/yr or less. This approach is also consistent with the inadvertent intruder dose limit in the 1981 NRC *Draft Environmental Impact Statement on 10 CFR Part 61 Licensing Requirements for Land Disposal of Radioactive Waste*, NUREG-0782 (NRC 1981; see Vol. 2, Section 4.5.1, pp. 4-54 through 4-56).

Based on the above NRC guidance, current local land-use practices, and recent Energy*Solutions* archeological survey work, DEQ has determined that for the first 10,000 years after site closure, the DU PA Model will be limited to examination of the following inadvertent intruder scenarios/conditions:

1) **Excavations on the Disposal Cell** – The Federal Cell that Energy*Solutions* proposes to use for disposal of DU waste is designed to have an ET cover that includes five layers (see Section 3.4 for a full description of the layers) (Neptune 2014k).

   DU waste in the proposed Federal Cell will be located at or below the level of the original grade at about 4,270 ft-amsl. Under the ET cover, the DU waste will be covered by other LLRW or other materials varying in thickness from 45 feet at the ridgeline of the cell to 27 feet at the shoulder point where the top slope breaks to the steeper side slope (Neptune 2014f). Thus, an inadvertent intruder would need to penetrate 5 feet of ET cover and from 27 to 45 feet of other materials before reaching the DU waste. Consequently, temporary shallow intrusion excavations (e.g., excavation of a building basement) would not

penetrate to the DU waste.[17] DEQ considers this scenario, which is equivalent to the NRC intruder discovery scenario, to be insignificant, in that the dose to the inadvertent intruder would be low. As shown in Table 4-6, the dose to an industrial worker on the site is 2.4E-02 mrem/yr. If the excavation removed the ET cover, locally the radon flux (and hence the exposure) would increase by a factor of 13 based on the IAEA approach presented in Table 4-4 to a level of 0.3 mrem/yr. If the depth of the temporary excavation was 20 feet, it can be deduced from Figure 4-5 that the dose at the bottom of the excavation would be about 18 mrem/yr [based on an annual exposure of 2.000 hours per year (hr/yr), which is unrealistically long for an intruder-discovery scenario].

2) **Sand, and Clay Mining on the Disposal Cell** – Similarly, if an inadvertent intruder were exploring for sand and clay by trenching into the disposal cell cover, he would soon realize that economic quantities of sand and clay were not present and cease his activities. Under such a scenario, he could receive a limited inadvertent exposure. Quantification of this exposure would be necessary if Energy*Solutions* decides to bury "other waste" above the DU waste as discussed in Section 3.4 of this SER. Sand and clay would be present in portions of the cover system, where they could be harvested easily and economically by individuals unaware of resulting potential impacts on radiological dose, but an intruder at that location would receive an exposure that is only a fraction of the 500-mrem limit (see Section 4.2 and Table 4-4). Shallow intrusions could have secondary consequences, such as locally increasing the water infiltration rate into the waste or increasing the radon flux at the surface in areas where the cover was disturbed by the intruder.

3) **Dwelling Construction and Full-time Occupation on the Disposal Cell** – Dwelling construction on the disposal cell and full-time occupation were not considered in the DEQ review of the DU PA Model v1.2 due to the lack of past human habitation at Clive, as demonstrated by recent Energy*Solutions* archeological studies. In addition, as noted in the passage from NUREG-1573 quoted above, "*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"* (NRC 2000). Since the area around Clive is defined as a hazardous industries zone where residential dwellings are not permitted, the NUREG-1573 guidance provides another argument for excluding dwelling-related scenarios.

4) **Industrial Building Construction on the Disposal Cell** – Under this scenario, which was introduced by Energy*Solutions* (2013b, Section 2.6.3), a building is constructed on the disposal cell for an industrial purpose, and workers occupy it for as many as 8 hours a day or about 2,000 hr/yr. Typical industrial building construction involves erecting a structure on a concrete pad. As such, the upper and lower radon barriers would not be disrupted, and exposure from penetrating radiation would be negligible due to the large amount of material

[17] As mentioned above, dwelling construction and full-time occupation were not considered in the DEQ review of the DU PA Model v1.2.

between the bottom of the concrete pad and the top of the DU waste. The pad itself would provide additional shielding.

5) **Exposure Under Nearby Drilling-Related Conditions** – The radiation dose consequences of deeper inadvertent intrusions have been modeled as part of the DU PA evaluation process (Rogers 2014). Energy*Solutions* considered two exposure scenarios (acute and chronic) related to drilling for water into the lower confined aquifer (to a depth of 171 meters or about 561 feet) over times up to 10,000 years after closure as follows:

   A) **Intruder – Deep Well Scenario** – The lower aquifer was assumed to become contaminated by leakage from the DU waste through the upper aquifer that allowed contamination to move downward through improperly sealed boreholes, deteriorated well casings, or flaws in the underlying strata. The modeled well was located at the edge of the proposed Federal Cell site and within the buffer zone. This virtual well was located 27 meters (90 feet) from the outermost edge of the waste embankment (approximately 240 feet from the edge of the DU waste). The chronic exposure scenario assumed that the lower aquifer was contaminated by leakage from the upper, unconfined aquifer and that the contaminated water was pumped to the surface and used for dust suppression. As described by Rogers (2014), contamination transport from the shallow aquifer to the lower confined aquifer was calculated using Dupuit-Theim's method (Freeze and Cherry 1979). The volume of water produced from the shallow aquifer is based on steady-state pumping to achieve a specified cone of depression. A dilution factor was obtained by dividing this flow rate by the flow rate from the well drilled into the lower aquifer that serves as the conduit to transport contamination to the surface. Exposure pathways included external exposure from contaminated surfaces and inhalation of radionuclides suspended in the air. In the chronic exposure scenario, the industrial worker is exposed for about 2,000 hr/yr.

   B) **Intruder – Driller Scenario** – Under this scenario, a borehole is drilled inadvertently through the proposed Federal Cell, and drill cuttings are brought to the surface to expose drill-rig workers. In the acute exposure scenario, the well-driller is exposed to external radiation from the drill cuttings and inhalation of contamination from airborne cuttings during the drilling process.

   For both scenarios, the annual doses were very low (i.e., less than 10^{-6} mrem/yr), as compared to an NRC-proposed limit of 500 mrem/yr for inadvertent intrusion. Details are provided in Table 4-6.

6) **Ingestion of Groundwater** – The groundwater from neither the upper nor lower aquifers is potable without treatment because of very high levels of TDS. The TDS for the upper aquifer is about 40,500 mg/L,[18] while the lower aquifer contains greater than 20,000 mg/L[19] (ES

[18] Section 3.4.2.2, page 11, of the Conceptual Site Model report (May 28, 2011) (Neptune 2011a) states that Brodeur (2006) reports that groundwater beneath the Clive site has a TDS content of 40,500 mg/L. This is fairly

2012a). It is possible that the water could be rendered potable by treatments such as RO. Energy*Solutions* argues that a person who treats raw water to achieve potability is not an inadvertent intruder. Because the intruder understands the use of sophisticated technology to treat the water, she would also be aware that the water contained radionuclides. Energy*Solutions* argues that, therefore, intrusion into the waste to obtain water for treatment is advertent. However, this line of reasoning ignores the fact that knowledge of water treatment to reduce TDS does not necessarily connote knowledge that the water may contain radionuclides, such as Ra-226, as would be the case if institutional knowledge of the repository were lost. Conceptually, this can happen after the 100-year institutional control period, required by UAC R313-25-29, expires). Additionally, well testing for radioactivity is currently beyond local government testing requirements for groundwater use applications. On the other hand, it should also be noted that treatment of the water to remove dissolved solids will also remove many radionuclides, thus reducing, but not eliminating, potential ingestion exposures.

For this DU PA review, DEQ made a simple scoping calculation to show that exclusion of the ingestion pathway would not understate doses in a significant way. For the ingestion exposure pathway, the same Energy*Solutions* well model developed for chronic exposure and described in list item 5A) above was used. The water was assumed to be treated by RO to reduce TDS to potable levels. However, it was also conservatively assumed that the decontamination factor[20] for the radionuclides was 10. Because higher decontamination factors may be required to meet TDS standards, the amount of radioactivity removed is likely understated. Based on this model and assuming standard annual water consumption levels, ingestion doses were very small: less than 0.2 mrem/yr. This value is well below the inadvertent intruder dose limit of 500 mrem/yr,[21] as well as the general population dose limit of 4 mrem/yr specified for the groundwater pathway in UAC R313-25-20. These conservative bounding results are also included in Table 4-5 (Section 4.2) under "Chronic Ingestion of Groundwater."

As previously stated, the upper aquifer does not produce sufficient water to be a productive source of water. Nonetheless, Section 4.2.2 summarizes a calculation that shows that a

consistent with mean TDS values in groundwater reported to DRC for monitoring wells at the site, which average 42,237 mg/L (ES 2013d).

[19] Based on two samples from Energy*Solutions* deep monitoring wells GW-19B and I-1-100 collected in 1991 (both 100 feet deep); see the October 9, 1991, Bingham Environmental Hydrogeologic Report, Appendix C.

[20] The decontamination factor is the ratio of the water concentrations prior to and after processing through the RO unit.

[21] DEQ has determined the 500 mrem/yr maximum dose limit for an inadvertent intruder to be acceptable, based on the 1981 NRC draft environmental impact statement; see NUREG-0782, Vol. 1, p. 29 (NRC 1981) and proposed NRC revisions to 10 CFR 61. Use of this value is consistent with the requirements of UAC R313-25-9(5)(a), in which the Director is authorized to rely on "ongoing guidance and rulemaking from NRC."

significant amount of upper-to-lower aquifer leakage[22] would need to occur before the dose due to the ingestion of groundwater would exceed the UAC R313-25-19 dose-from-groundwater limit of 4 mrem/yr. Also, if disposal of DU-containing recycled uranium is not permitted as proposed in this SER, then the undiluted upper aquifer groundwater ingestion dose is calculated to be below the UAC limit.

If the water is treated by RO to achieve potability, the reject stream from the RO process creates another exposure pathway: the reject brine stream contains most of the dissolved solids. The same basic model (e.g., upper aquifer water concentration, mixing with the lower aquifer, exposure pathways, exposure times, etc.) as used for the chronic industrial worker exposure scenario was used to calculate exposures from the reject (brine) stream, except that the water radionuclide concentrations were multiplied by a concentration factor to account for the effect of the RO unit. The concentration factor was determined as shown in Equation (5) below:

$$C_B = \frac{1 - \left(\frac{1 - f_B}{DF}\right)}{f_B} \quad (5)$$

where: C_B = Brine flow concentration factor
= 1.9
DF = RO unit decontamination factor
= 10 (assumed)
f_B = Brine flow fraction
= 0.50 (assumed)

As with the other scenarios, the doses from the reject stream were very small, with mean values less than 10^{-4} mrem/yr. The results are included in Table 4-5 under "Chronic Exposure to RO Brine."

The results in Table 4-5 are based on the same model as described in Rogers 2014, but DEQ extended the results to 10,000 years. Since progeny in-growth would be greater, the number of radionuclides was increased to cover the significant uranium daughter products. Results are included in Table 4-5 and indicate that doses remain very low for up to 10,000 years.

7) **Other Intruder Scenarios** – Energy*Solutions* developed several additional inadvertent intruder scenarios based on expected activities at the site. These included ranch workers, hunters, and OHV enthusiasts who may enter the site after active institutional controls are defunct. Scenario details are provided in Appendix 11 to the DU PA Model (Neptune 2014l).

Table 4-6 summarizes results from these scenarios based on modeling exposures over 10,000 years (Neptune 2014a, Table 4). Energy*Solutions* also included an industrial worker in the

[22] The leakage would need to be large enough so that the lower aquifer water would be composed of 9 percent or more of leaked upper aquifer water.

November 2013 revised Compliance Report (ES 2013b) issued prior to the DU PA Model v1.2 final report. The industrial worker was assumed to be exposed to the same pathways as the ranch worker, but his exposure was 2,000 hours per year, as opposed to the exposure times given in Appendix 16, Table 80 (Neptune 2014c) for the ranch worker. Since the industrial worker's dose was calculated by Energy*Solutions* prior to version 1.2 of the DU PA, this dose was adjusted by DEQ based on the ratio of the ranch worker exposure in version1.2 versus 1.0 of the DU PA.

Table 4-6 – Annual Peak of Mean Doses (TEDE) for Exposure to Inadvertent Intruders Operating on the Proposed Federal Cell Disposal Site (simulation period = 10,000 years)

Inadvertent Intruder	Exposure Pathways Considered	Peak of Mean TEDE (mrem/yr)	
		All DU	No Recycle[a]
Ranch Worker (ES)	• Ingestion • Inhalation • External radiation	1.63E-02 (peak at 10,000 years)	1.63E-02 (peak at 10,000 years)
Hunter (ES)	• Ingestion • Inhalation • External radiation	7.99E-04 (peak at 10,000 years)	7.99E-04 (peak at 10,000 years)
OHV Enthusiast (ES)	• Ingestion • Inhalation • External radiation	1.27E-03 (peak at 10,000 years)	1.27E-03 (peak at 10,000 years)
Industrial Worker (ES)	• Ingestion • Inhalation • External radiation	2.40E-02 (peak at 10,000 years)	2.40E-02 (peak at 10,000 years)
Acute Inadvertent Well Driller (ES)	• External exposure from unshielded contaminated drill cuttings pile • Inhalation of contaminated cuttings	1.7E-06 (peak at 3,500 years)	6.6E-08 (peak at 10,000 years)
Chronic Inadvertent Industrial Intruder (ES)	• External exposure from photon-emitting radionuclides in unshielded, surface-sprayed wastewater • Inhalation of radionuclides suspended in air from surface-sprayed wastewater	8.4E-05 (peak at 3,500 years)	3.1E-06 (peak at 10,000 years)
Chronic Inadvertent Industrial Intruder (DEQ)	• Ingestion: Worker consumes 1,095 L of reverse-osmosis-treated well water annually	1.4E-01 (peak at 3,500 years)	4.7E-03 (peak at 10,000 years)
Chronic Inadvertent Industrial Intruder (DEQ)	• External exposure from photon-emitting radionuclides in unshielded, surface-sprayed wastewater • Inhalation of radionuclides suspended	1.6E-04 (peak at 3,500 years)	5.9E-06 (peak at 10,000 years)

	in air from surface-sprayed wastewater		

[a] Note on waste contamination: Doses are overstated because DEQ intends to require as a condition of any license amendment that DU containing fission and activation products, such as Tc-99 from recycled uranium, not be accepted at Clive.

All of the doses are well below the 500 mrem/yr total effective dose equivalent (TEDE) limit for inadvertent intruders in the 1981 NRC draft environmental impact statement for LLRW (see NRC 1981, Vol. 1, p. 29). As will be discussed subsequently in Section 5.3, DEQ is proposing that no DU waste containing recycled uranium[23] be accepted for disposal in the Federal Cell at Clive. This will eliminate mobile isotopes such as Tc-99 and I-129. Since the doses in Table 4-6 include contributions from these radionuclides, they are overstated.

The resultant doses are also well below the limits set for members of the general public in UAC R313-25-20:

> *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 0.25 mSv (0.025 rem) to the whole body, 0.75 mSv (0.075 rem) to the thyroid, and 0.25 mSv (0.025 rem) to any other organ of any member of the public. 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.*

The doses for the first five scenarios in Table 4-6 are almost totally from radon releases at the surface of the proposed Federal Cell and, therefore, the most sensitive parameter is the radon escape-to-production ratio that defines the amount of radon leaving the waste matrix and entering the air-filled porosity of the waste material.

Conclusion: Based on the information provided by Energy*Solutions*, together with independent analysis performed by DEQ's contractor, DEQ concludes that sufficient information exists at this point to indicate that, in compliance with the requirement of UAC R313-25-21, 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 will be adequately protected.

References

Brodeur, 2006

[23] Irradiated uranium fuel from the plutonium weapons production reactors was chemically reprocessed to recover plutonium and uranium. The recovered ("recycled") uranium was returned to the GDPs for further enrichment. Since the chemical separation processes did not remove all the activation and fission products, the recycled uranium introduced as feed to the GDP plants contained small quantities of activation and fission products such as Tc-99, I-129, and Np-237, which contaminated the UF_6 feed to the GDPs. Some of this contamination partitioned to the DU tails and was retained in the UF_6 tails and its containment cylinders. It is estimated that about 4 percent of the DU available from DOE is contaminated with recycled uranium (ES 2014b, Appendix 6 to Appendix A, Table 1).

ES, 2012a; 2013a; 2013b; 2013d; 2014b; 2014d

Freeze and Cherry, 1979

Marschke, 2015

Neptune, 2011a; 2014a; 2014c; 2014f; 2014k; 2014l

NRC, 1981; 2000; 2013b; 2014b

Rogers, 2014

4.4 10 CFR 61.44 – STABILITY OF THE DISPOSAL SITE AFTER CLOSURE (UAC RULE R313-25-23)

UAC Rule R313-25-23 (formerly R3-1-25-22) states:

> *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.*

The regulatory languages of 10 CFR 61.44 and of UAC R313-25-23 are nearly identical.

UAC Rule R313-25-9(4)(d) also requires (emphasis added):

> *(d) Analyses of the long-term stability of the disposal site shall be based upon analyses of active natural processes including erosion, mass wasting, slope failure, settlement of wastes and backfill, infiltration through covers over disposal areas and adjacent soils, surface drainage of the disposal site,* ***and the effects of changing lake levels****. The analyses shall provide reasonable assurance that there will not be a need for ongoing active maintenance of the disposal site following closure.*

This last rule reference differs from UAC R313-25-23 (and 10 CFR 61.13(d) 61.43) in one important way: it specifically requires analysis of the effects of pluvial lake formation, under deep time scenarios, that may have an adverse effect on the DU disposal embankment.

In the June 2011 DU PA (Neptune 2011b), Energy*Solutions* proposed a rock armor cover for the proposed Federal Cell similar to the DRC-approved rock armor cover for the CAW 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 (ES 2013b, p. 2-7):

- ***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 5x10-8 cm/sec and a lower radon barrier consisting of 12 inches of compacted clay with a hydraulic conductivity of 1x10-6 cm/sec or less.*

The total thickness of these five layers was to be 6 feet. The side slope (of similar composition as the top slope) has a calculated infiltration rate of 0.168 cm/yr. For the original performance assessment, the infiltration rates were calculated with the Hydrologic Evaluation of Landfill Performance (HELP) model.

Because of concerns about the infiltration rates of the rock armor cover, Energy*Solutions* subsequently proposed replacing this cover with an ET cover. The ET cover is described in Appendix 5, *Unsaturated Zone Modeling for the Clive DU PA*, dated June 12, 2014 (Neptune 2014k).

Beginning at the top of the cover, the layers above the waste used for the ET cover design are as follows (see Section 3.4 for a description of each layer):

- Surface Layer
- Evaporative Zone Layer
- Frost Protection Layer
- Upper Radon Barrier

- Lower Radon Barrier

The total thickness of the ET cover design is to be 5 feet. Energy*Solutions* calculated infiltration rates for the ET cover with the code HYDRUS-1D and abstracted the results into GoldSim. Energy*Solutions* claimed that previous work with HYDRUS had shown that sub-surface lateral flow was not significant, so the 1D model was sufficient. Based on 20 runs, the infiltration flux ranged from 0.0007 to 0.29 cm/yr with an average value of 0.042 cm/yr, about half the value for the rock armor cover (Neptune 2014k, Section 12.9).

However, DRC staff point out several potential issues:

1) The 20 runs in the HYDRUS model do not account for the full range of in-service saturated hydraulic conductivity (K_{sat}) and van Genuchten α values recommended for use in cover systems in NUREG/CR-7028 (C. H. Benson et al. 2011), so calculated infiltration rates obtained from the current model cannot be relied on. For example, only a single value of K_{sat} was employed in the HYDRUS model for the Surface Layer and the Evaporative Zone, and only a single value of α was employed for the radon barriers, despite one of them being treated by a phosphate compound that markedly changes its properties (e.g., hydraulic conductivity decreases by nearly two orders of magnitude).
2) The current model in the DU PA does not account for the reported statistical correlation existing between van Genuchten α values and saturated hydraulic conductivity (K_{sat}), as discussed and documented in DEQ comments concerning Interrogatory CR R313-25-7(2)-189/3: Modeling Impacts of Changes in Federal Cell Cover-System Soil Hydraulic Conductivity and Alpha Values. In fact, the model assumes no correlation between these parameters at all, so calculated infiltration rates obtained from the current model cannot be relied on.
3) Until the infiltration rates are determined with more realistic soil parameters assigned to the cover system, it is unknown whether Licensee's assumption that a 1D model can effectively model flow of water in a top slope of 2.4 percent grade. If infiltration rates exceed K_{sat} values in any of the model layers, lateral flow will be initiated. However, the assumption of neglecting lateral flow to the overall performance of the Federal Cell may be conservative. This is because some percent of the infiltrating water would be diverted laterally and discharged through the sides of the embankment and into the collection drain prior to reaching the wastes.

Among the factors that can affect the long-term stability of the disposal site after closure are erosion of the cover, settlement of the waste and cover, intrusion by deep-rooting plants, intrusion by burrowing insects and animals, frost penetration, desiccation cracking, and damaging natural phenomena (e.g., earthquakes, tornados, pluvial lake formation). These phenomena are discussed for the proposed cover system and also in DRC comments to responses by the Licensee regarding the Round 3 Interrogatory (DRC 2015) for the updated site-specific performance assessment for disposal of blended and processed waste (ES 2015b). However, before these factors can be considered, one must establish confidence that the modeling of the ET cover was done properly. Each of these factors is discussed in detail below.

References

Benson et al., 2011

DRC, 2015

ES, 2013b; 2015b

Neptune, 2011b; 2014k

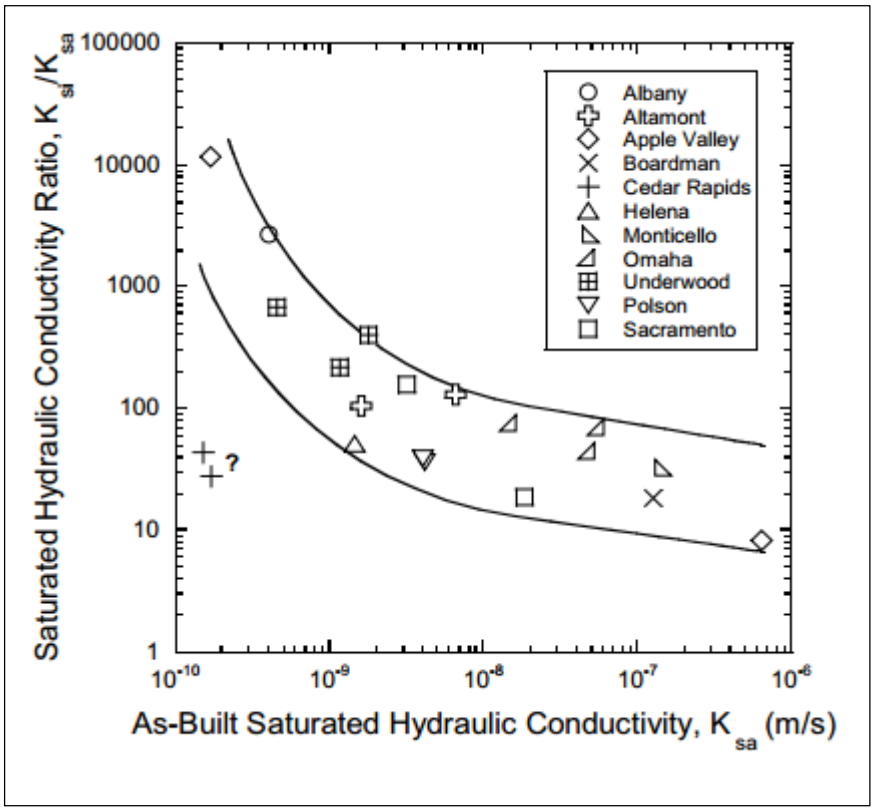
4.4.1 Infiltration

An important component of assessing infiltration rates and contaminant concentrations as a function of time in the proposed Federal Cell is the modeling of realistic changes in saturated hydraulic conductivity (K_{sat}) values and van Genuchten α values simultaneously for all cover-system soils near the ground surface. Based on field-scale testing involving a large number of embankment cover systems, NRC guidance provided in NUREG/CR-7028 (C. H. Benson et al. 2011) demonstrates that, to properly estimate infiltration rates, the design and modeling of new cover systems must account for expected degradation of the shallow portions of these cover systems over time, e.g., increases in soil permeability. A variety of physical and biological processes combine to cause this degradation. These processes may include frost heave, other freeze-thaw activity, wet-dry cycling, distortion, insect and animal burrowing, plant root intrusion, and other disruptive processes.

Changes in field-scale K_{sat} and α values for cover-system soils occur soon after cover-system construction. These changes tend to be dramatic. For low- to moderate-permeability soils, the changes usually are at least one order of magnitude and often two or three orders of magnitude in value, depending on the initial, or as-built, K_{sat} and α values. The changes tend to happen within several years of cover-system construction. These changes occur regardless of cover-system design or climate (C. H. Benson et al. 2011). In terms of modeling for 1,000 or 10,000 years, or longer, the changes tend to occur so rapidly following embankment construction, on a relative basis, that modeled K_{sat} and α values, if they are limited in the model to single values for all time for a given soil layer, should reflect long-term in-service conditions rather than short-term as-built conditions. Therefore, in-service cover-system K_{sat} values for soils should be modeled within the ranges described in NUREG/CR-7028 (C. H. Benson et al. 2011). The guidance in this document, which is based on extensive studies, should be applied to all soils within 10 feet of the surface. As stated in NUREG/CR-7028:

> *For covers of typical thickness (< 3 m), the saturated hydraulic conductivity of earthen barrier and storage layers will increase over time in response to processes such as wet-dry and freeze-thaw cycling, with larger increases occurring in layers having lower as-built saturated hydraulic conductivity.* [C. H. Benson et al. 2011, p. 10-2]

The relationship between the in-service and the as-built values extracted from NUREG/CR-7028, Figure 6.8, is shown in Figure 4-8.



Source: C. H. Benson et al. (2011), Figure 6.8.

Figure 4-8 – Relationship between as-built saturated hydraulic conductivity and in-service measurements

The discussion of unsaturated zone modeling in Appendix 5 to the DU PA Model v1.2 (Neptune 2014k) indicates that the saturated hydraulic conductivities assigned to the ET layer for the modeling were derived from site soil cores and range from 5.97×10^{-7} cm/s to 5.16×10^{-5} cm/s. It is important to note also that actual field-scale hydraulic conductivity values are typically much larger than those obtained as a result of laboratory testing using conventional small-scale core samples. As NUREG/CR-7028 states, "*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*" (C. H. Benson et al. 2011). This is significant because the hydraulic conductivities assumed in the DU PA model are based on testing of conventional small-scale soil specimens, which may be orders of magnitude smaller than actual field-scale hydraulic conductivities at Clive.

The van Genuchten α values assumed for modeling moisture in a particular soil layer within the cover system must be correlated with the hydraulic conductivity assigned during modeling to that soil layer whenever measured values are not available. These α values cannot be modeled as being random or uncorrelated with hydraulic conductivity. The information needed

to make these correlations is readily available. Two very large sets of commonly used soil properties data exhibit good correlations, as is illustrated in Figure 4-9.

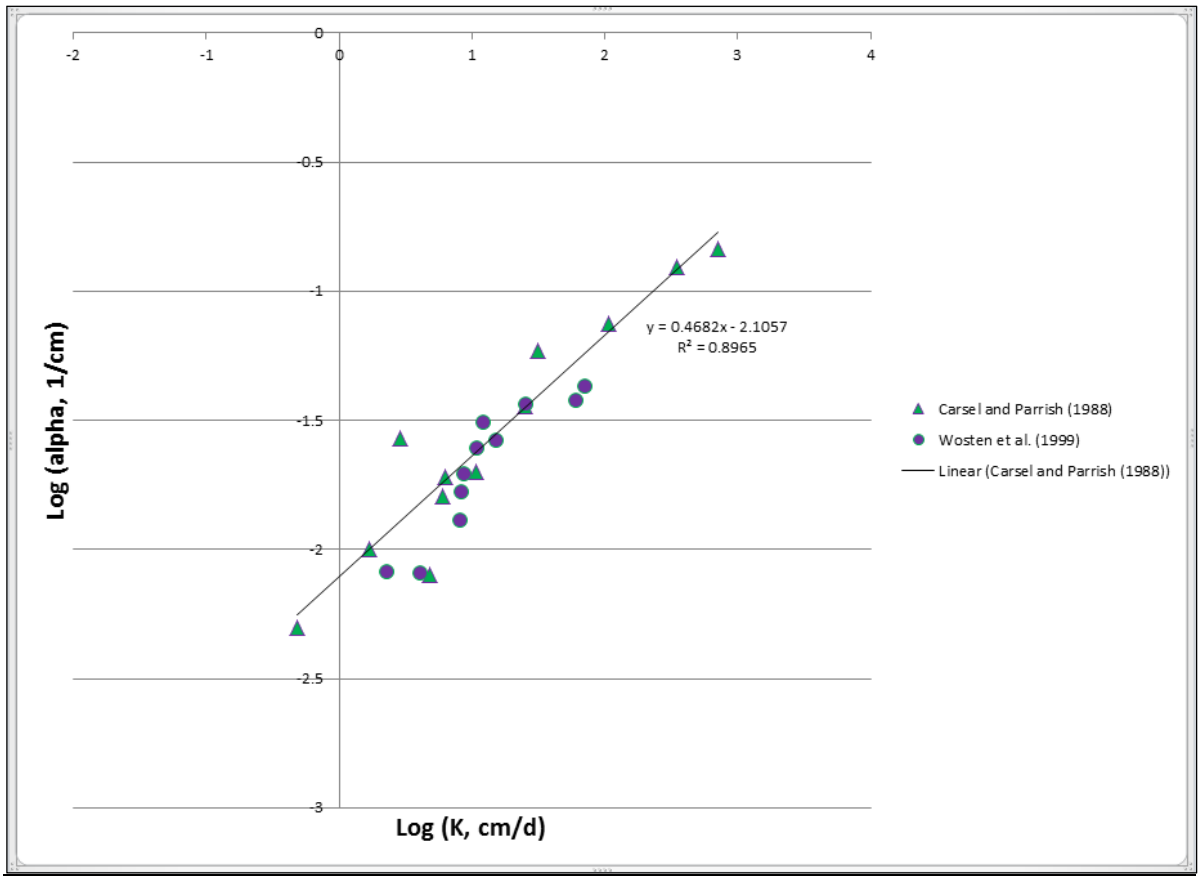


Figure 4-9 – Correlation of saturated hydraulic conductivity and van Genuchten alpha

Carsel and Parrish (1988) grouped a soil data set of 5,093 samples with reported K_{sat} (shown as "K_s" in Figure 4-9) and α values into 12 U.S. Department of Agriculture soil textural classifications (e.g., sandy loam). This is the largest North American database dedicated to hydraulic properties of soils. In Figure 4-9, DEQ has plotted K_{sat} versus α for each of the 12 soil textural classifications. A regression of the data indicates a very strong correlation ($R^2 = 0.8965$) between log(α) versus log(K_{sat}). Wösten et al. (1999) collected data from 20 institutions of higher learning in 12 European countries to develop the database HYPRES (Hydraulic Properties of European Soils). This is the largest European database dealing with hydraulic properties of soils. Wösten et al. (1999) grouped their data into 11 soil textural classifications, each with reported K_{sat} and α values. As shown in Figure 4-9, these data exhibit some variability but generally fall in a similar range to the Carsel and Parrish (1988) data.

A Google search indicates that the Carsel and Parrish (1988) publication has been cited by 1,198 other articles that are peer reviewed. Statistical data based on Carsel and Parrish (1988) are included in NUREG/CR-6565 (Meyer et al. 1997), NUREG/CR-6656 (NRC 1999), and NUREG/CR-6695 (NRC 2001). DEQ developed the regression equation in Figure 4-9

[$\log(\alpha) = 0.4682 \times \log(K_{sat}) - 2.1057$] based solely on the Carsel and Parrish (1988) data. The NUREG/CR-6346 (NRC 1996) data are for one site described in this NRC guidance document. It is interesting to note that an equation for a linear regression for the NUREG/CR-6346 (NRC 1996) data is very similar—almost identical—to that developed for the Carsel and Parish (1988) data.

Given these data sets in the professional literature, it is not clear that Energy*Solutions* has used appropriate data for the saturated hydraulic conductivity or reflected the correlation between $\log(\alpha)$ and $\log(K_{sat})$ or between α and K_{sat}. In its response to Round 3 Interrogatory CR R313-25-7(2)-189/3: Modeling Impacts of Changes in Federal Cell Cover-System Soil Hydraulic Conductivity and Alpha Values (ES 2014b), Energy*Solutions* stated that there was no correlation found between K_{sat} and α. It plotted the Rosetta database (Schaap 2002) values on a plot similar to Figure 4-9 and stated that there was no correlation. The Carsel and Parrish (1988) database is a much larger database (about an order of magnitude larger than the Rosetta database). The Wösten et al. (1999) database is also quite large. Furthermore, an equation exists for the relationship between α and K_{sat} based on soil physics that can be readily shown to be transformable to $\log(\alpha) = 0.5 \times \log(K_{sat}) - 2.14$, which is nearly identical to the correlation equation for the Carsel and Parrish (1988) data (Guarracino 2007). Meyer et al. (1997) and Zhu et al. (2007) have also described correlation between $\log(\alpha)$ and $\log(K_{sat})$ or between α and K_{sat}. Given the apparent differences in the Rosetta database and that of Carsel and Parrish (1988) and others regarding whether or not correlation exists between α and K_{sat}, it would seem that a comparative analysis should be undertaken.

In order determine the impact of changes in the hydraulic properties and the correlation between K_{sat} and α on the infiltration rate, a local sensitivity analysis is required. DEQ recommends that Energy*Solutions* develop hydraulic properties for the cover system based on the approach outlined by Dr. Craig H. Benson in Appendix E to this SER. These infiltration rates can be compared with the range of values used in the DU PA Model v1.2 (0.0007–0.29 cm/yr). Depending on how these new rates compare with those used in the DU PA, additional GoldSim modeling may be required.

Conclusion: Before the DU PA can be determined to be adequate, additional modeling of the ET cover infiltration rates must be conducted based on in-service hydraulic properties and correlated $\log(\alpha)$ and $\log(K_{sat})$ values, as discussed in Appendices E and F. Without this information, DEQ is unable to conclude if the infiltration rates predicted by the DU GoldSim model are reliable or representative of future conditions (i.e., $\geq$ 10,000 years).

References

C. H. Benson et al., 2011

Carsel and Parrish, 1988

ES, 2014b

Guarracino, 2007

Meyer et al., 1997

Neptune, 2014k

NRC, 1996; 1999; 2001

Schaap, 2002

Wösten et al., 1999

Zhu et al., 2007

4.4.2 Erosion of the Cover

In the June 2011 DU PA (Neptune 2011b), Energy*Solutions* used a gully model described as follows (Neptune 2011b, 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 1and 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. To apply the effects of gully formation to doses, the average waste concentrations exposed by the gully and the average waste concentration of material removed by the gully are used. The exposure area for this waste concentration is the surface area of the fan plus the surface area of the gully for which waste layers are exposed.*

As stated by the June 2011 DU PA (Neptune 2011b), the gully model was a stylized model designed to provide a basis for discussion on the importance of gullies in exposing waste. The number of gullies was arbitrary and not based on any site-specific information. For the June 2011 DU PA, Energy*Solutions* considered three possible waste burial depths: 3 meters, 5 meters, and 10 meters. However, Energy*Solutions* subsequently committed to burial of all the DU waste below original grade, which can be approximated by the 10-meter burial depth.

Table 4-7, based on Tables 3 and 4 of the DU PA v1.0 (the 10-m case, Neptune 2011b) and Table 4 of the DU PA Model v1.2 (Neptune 2014a), summarizes screening calculations for doses to onsite intruders and offsite receptors with and without gullies. The DU PA Model v1.2 did not provide data on doses for the case where there were no gullies. However, v1.0 did provide such a comparison and it is included here for reference.

Table 4-7 – Energy*Solutions* Peak of the Mean Doses within 10,000 Years to Individuals with and without the Effects of Gullies

Receptor	Peak of the Mean TEDE (mrem/yr)		
	Without Gullies DU PA v1.0	With Gullies, DU PA v1.0	With Gullies, DU PA v1.2
Ranch worker	0.00596	0.00594	0.01631
Hunter	0.000253	0.000257	0.000799
OHV enthusiast	0.000388	0.000386	0.00127
I-80 receptor	1.53E-07	1.58E-07	4.87E-07
Knolls receptor	1.62E-06	1.64E-06	4.36E-06
Railroad receptor	2.42E-07	2.48E-07	7.65E-07
Rest area receptor	3.13E-05	3.17E-05	0.000102[a]
UTTR access road receptor	7.81E-05	7.83E-05	0.000247

[a] The 1.02E-05 mrem/yr reported in Neptune (2014a), Table 4, is a typo.
Source: DU PA Model v1.0, Tables 3 and 4 (Neptune 2011b); DU PA Model v1.2, Table 4 (Neptune 2014a).

Although Neptune 2011b and Neptune 2014a both claim that the doses summarized in Table 4-7 include the effect of gullies, this is misleading. Neptune (2014b, page 3) explicitly states that "*No associated effects, such as biotic processes, effects on radon dispersion, or local changes in infiltration are considered within the gullies*." Since the radon exposure pathway is the dominant contributor to both the general population and inadvertent intruder doses, not considering the effect of gullies on radon dispersion is tantamount to not including the effect of gullies in the dose calculations. Nonetheless, as shown in Section 4.2, because the calculated doses due to radon exposure are all several orders of magnitude below the dose limits, completely removing the ET cover (e.g., by gully erosion) would not affect the site's ability to meet the general population or inadvertent intruder inhalation exposure criteria even though there could be over an order of magnitude increase in the associated doses (see Table 4-4 for the ET cover's radon attenuation).

Similarly, as discussed in greater detail in Section 4.4.3, not considering the effects of gullies in combination with associated biotic processes and their ability to achieve penetration through the fine-grained, low-permeability cover system soils, and allow access of water into the sand-like fill above the DU can result in underestimation of deep infiltration and, consequently, of contaminant transport.

In version 1.2 of the DU PA, (Neptune 2014a), Energy*Solutions* made calculations with the landscape evolution model SIBERIA (Willgoose 2005), using a borrow pit at Clive as the basis for the model. SIBERIA is designed to capture the interaction between the runoff response and the elevation changes of the landform surface over long time periods (Neptune 2014h). As described on p. 3 of the DU PA Model v1.2 (Neptune 2014a):

> *A subset of the borrow pit model domain was selected to represent the cover. Gully depths estimated by the erosion model were extrapolated to 10,000 years and a statistical model was developed that generated values of the percentage of the cover where gullies ended within a given depth interval. This model provided an estimate of the volume of embankment cover material removed by gullies. The depositional area of the gully fan is assumed to be the same as the area of waste exposed in the gullies, using projections onto the horizontal plane. If these embankment materials include DU waste components, then this leads to some contribution to doses and uranium hazards.*

Results of the doses based on the revised model are included in the fourth column of Table 4-7 and indicate small increases from the values derived in version 1.0 of the DU PA.

However it is important to note that the DU PA does not consider effects of gullies on biotic processes, radon dispersion, or local changes in infiltration, nor does it consider the effects of biotic processes on gullying.

In explanation for these omissions, Energy*Solutions* stated in the response to Round 2 Interrogatory CR R317-6-2.1-20/2: Groundwater Concentrations (ES 2014a):

> *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.*

Figure 2 in Appendix 10 to DU PA Model v1.2 (Neptune 2014h) appears to show that about 1 percent of the surface has gullies that are 1 meter deep or greater. If this is the correct interpretation of Figure 2, then the assumed influence of gullies on radon release and infiltration should be small. However, Appendix 10 does not make clear how the SIBERIA modeling was actually incorporated into DU PA Model v1.2 because discussion of the initial screening model and the SIBERIA model are so interwoven in the text. Energy*Solutions* should fully describe and justify how the models were interrelated and confirm that this is the correct interpretation of Figure 2. Figure 2 in Appendix 10 is based on only five model realizations. Energy*Solutions* should also demonstrate through modeling that gullying through the cover system will not appreciably affect infiltration and contaminant transport. Energy*Solutions* should also confirm that the distribution in Appendix 10, Figure 2 (Neptune 2014h) is unaffected when all the realizations are considered.

Although the SIBERIA model allows for several hundred meters of ground surface upslope from the sloping pit face, the ground surface itself in the model only slopes at a 0.3 percent (0.003) slope. This is minimal. By contrast, as illustrated in Licensee Drawing No. 14004-V3A(1), the waste under the top slope above and upslope from the side slopes of the embankment has a slope of up to 2.4 percent (0.024)—this is eight times as great as what is modeled in SIBERIA. This means that the SIBERIA model does not begin to account for the flow of water (and transported soil) down the top slope and into the gullies in the more steeply sloping side slopes. Thus, it is possible that SIBERIA would underestimate rates of water flow from upslope areas and their contribution, along with that of transported soil particles, to erosion of the side slopes, the shoulders, and adjacent portions of the top slope.

Conclusion: Before the DU PA can be determined to be adequate, Energy*Solutions* needs to clarify certain issues relating to Appendix 10 to the DU PA Model v1.2 (June 5, 2014; Neptune 2014h) as described in Section 4.4.2. DRC is currently reviewing a license amendment request to use an ET cover of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.

References

ES, 2014a

Neptune, 2011b; 2014a; 2014b; 2014h

Willgoose, 2005

4.4.3 Effect of Biological Activity on Radionuclide Transport

Biointrusion can, in some instances, dramatically increase downward infiltration rates. 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.*"

As described Round 3 Interrogatory CR R313-22-32(2)-10/3 (DRC 2014c), Energy*Solutions* speculates that the effect of biointrusion (e.g., by ants) on radionuclide transport might be small. However, 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*."

Energy*Solutions* indicates in its response to Round 2 Interrogatory CR R313-25-7(2)-05/2 (ES 2014a) that "*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).*"

This assertion may be correct with respect to the physical transport of the DU waste, but it does not address the concern of ant burrows leading to higher infiltration rates and subsequent enhanced leaching of the wastes.

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 percent. Hakonson (1999) indicates that pocket gophers can increase rates of infiltration by 200 to 300 percent. 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 same 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 DU PA should account for greater infiltration through the cover system as a result of biointrusion by animals in general.

In its response to Round 3 Interrogatory CR R313-22-32(2)-10/3 (ES 2014b), Energy*Solutions* acknowledges that biointrusion can result in increased saturated hydraulic conductivities (K_{sat}) within waste cover layers, and possibly subsequent increased infiltration depending on other factors. Energy*Solutions* further notes that available data also indicate that there is little or no change in water storage and infiltration between lysimeters with and without animal burrows; it cites the following passage in support:

> 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.*"

Although this paper was not readily available on the Internet, the conclusion cited by Energy*Solutions* only indicates that long-term water storage was not facilitated at depth and does *not* mention whether infiltration rates were affected. The retention of water within the matrix porosity is a different process than infiltration and, although bioturbation may not affect the degree to which water is retained in the porosity, similar retention properties are not an indication that infiltration rates will not be higher in areas where animal burrows allow recharge to focus, particularly after high-intensity rainfall events or during periods of prolonged snow melt.

Biointrusion by plant roots can also damage cover systems, increase infiltration, and hasten migration of contaminants by increasing the hydraulic conductivity of cover-system soils penetrated by roots. This can be especially problematic at clay radon barriers. Waugh and Smith (1998) indicate that, at a DOE LLRW 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 groundwater modeling, long-term in-service hydraulic properties of all near-surface (i.e., within 10 feet of ground surface) cover-system soils should be increased from as-built values to values within the ranges given by NRC guidance in NUREG/CR-7028 (C. H. Benson et al. 2011).

In its response to Round 3 Interrogatory CR R313-25-7(2)-150/3 (ES 2014b), Energy*Solutions* indicates that "*deep rooting plants within waste covers is not necessarily problematic*." To support this statement, Energy*Solutions* cites the following passage from SWCA Environmental Consultants (SWCA) (2013, p. 23):

> *As has been demonstrated at operational ET covers (…), some deep-rooting plant cover is desirable because it increases water release from deep soil layers (…). Deeply rooting vegetation stabilizes soils, reduces erosion, and increases water storage in the root zone (…). Deep-rooting shrub species currently occupy functioning cover systems at Hanford (big sagebrush, rabbitbrush…) and Monticello (big sagebrush, bitterbrush, rabbitbrush…).*

It would seem that the release of water from the deep soil layers would be desirable provided that the water is transpired at a faster rate than any increases in infiltration caused by the roots. It needs to be kept in mind, however, that the shrubs will eventually die, and the decaying roots may leave macropores allowing for rapid focused recharge (infiltration). Also, as stated by Burt and Cox (1993), "*Radon gas is soluble in water and is readily taken up by plants (…). It is transported via mass flow of water through the plants and then out the leaves into the air…. Plant roots can deplete water from clay layers, resulting in shrinkage and cracks enabling the roots to move deeper into the clay layer seeking water…. As roots advance through the cover, they introduce organic matter into the cover, and upon their death leave conduits through which liquids and gasses may pass readily*."

Greasewood is a deep-rooting plant indigenous to the site. A number of researchers indicate that greasewood may potentially root down to depths of as much as 55–60 feet in search of groundwater and capillary fringe water. Among these researchers are Chimner and Cooper (2004), Cooper et al. (2006), Harr and Price (1972), Meinzer (1927), Nichols (1993), Waugh and Smith (1998), and White (1932).

Energy*Solutions* also supports its argument that deep-rooting plants are not a concern in its response to Round 3 Interrogatory CR R313-25-8(4)(A)-28/3 (ES 2014b) that:

> *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 do not extend below the compacted clay layer at 24 inches. Rather, both taproots and fine roots were found to extended 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 Licensee's expression, "multiple soil excavations at the site," in the passage quoted above actually refers to only two small pits dug by a consultant to investigate rooting by two small greasewood plants (see the SWCA response on Page 39, Appendix C, ES 2013c). This digging of two small pits covering a relatively small area took place on a section of land (Section 32) used by the Licensee for its operations that, by contrast, covers over 27,000,000 square feet in area. The DRC therefore has issues with the scientific validity of generalized claims or statements about how plants throughout the site would root or tend to grow, or how cover-system soils may or may not be disturbed by rooting, based on the highly limited number of observations of roots and soils involving only two small pits. Conclusions for the DU PA should be based on more substantive data.

The Licensee's statement is in contrast to observations made by DRC staff in the past, where plant roots at the site have been observed in borrow pits to extend as deep as 10 or more feet. Further, the distribution of the root systems today may be very different from those observed

over the next 500 years, 10,000 years, or more as other physical weathering processes (e.g., erosion) affect the integrity of the ET cover.

The Energy*Solutions* response to Round 3 Interrogatory CR R313-25-7(2)-150/3 concludes (ES 2014b):

> *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.*

However, penetration of radon barriers by plant rooting has been observed elsewhere. As referred to earlier, for example, Waugh and Smith (1998) report that roots at a DOE LLRW site at Burrell, Pennsylvania penetrated the radon cover and locally increased the hydraulic conductivity of that cover by two orders of magnitude. As stated in Benson (2009), "*Roots seek out water in wet fine-grained soils, e.g., clay radon barriers*."

Radon barriers in the proposed DU waste disposal facility are only 3 feet deep. By contrast, site-specific data at Clive indicate the presence of greasewood roots down to depths of 13 feet. Section 4 of Envirocare (2000) and Hoven et al. (2000) report much deeper black greasewood rooting at Clive than the "*maximum rooting depth of dominant woody plant species ranging from 16 to 28 inches*" (1.3 to 2.3 feet) reported on page 2-5 of the Utah Radioactive Material License-Condition 35 (RML UT2300249) Compliance Report (Revision 2) of July 8, 2014, submitted with the performance assessment (ES 2014c):

> *A field evaluation of individual specimens on the Clive site found tap roots extending to 11 and 11.5 feet; with fine roots extending as deep as 13 feet beneath the surface.*

A depth of 13 feet for site-specific greasewood rooting depth at Clive as determined by field evaluation is approximately 5.6 to 10 times greater than the deepest depth assumed in the Compliance Report (ES 2014c).

If roots do penetrate the radon barriers, they will have also penetrated the overlying cover materials; therefore, the saturated hydraulic conductivity of all of the materials would have to be raised simultaneously to adequately capture the potential impacts on performance for this scenario.

Not only are the range and mean values of hydraulic properties important in evaluating the impacts of potential increases in infiltration, but also the infiltration rates will be sensitive to the hydraulic properties (e.g., K_{sat}, α, theta-r) of each layer relative to one another.

Conclusion: Energy*Solutions* has not shown that the cover system is sufficiently thick or designed with adequate materials to protect the cover system or the underlying bulk waste in the embankments against deep rooting by indigenous greasewood (a species known to penetrate soils

at other sites down to 60 feet) or other plants, or against biointrusion by indigenous ants or mammals (e.g., with maximum documented burrowing depths greater than the proposed cover thickness). Higher rates of infiltration are typically associated with higher contaminant transport rates. Under Utah rules, infiltration should be minimized [see UAC Rule R313-25-25(3) and (4)]. DEQ cannot determine the adequacy of the DU PA until Energy*Solutions* accounts for potentially greater infiltration through the cover system at the proposed Federal Cell embankment due to biointrusion by plant roots and by animals.

References

Benson, 2009

C. H. Benson et al., 2011

Breshears et al., 2005

Burt and Cox, 1993

Chimner and Cooper, 2004

Cooper et al., 2006

DRC, 2014c

Dwyer et al., 2007

Envirocare, 2000

ES, 2013c; 2014a; 2014b; 2014c

Gaglio et al., 2001

Hakonson, 1999

Harr and Price, 1972

Hoven et al., 2000

Landeen, 1994

Laundre, 1993

Link et al., 1995

Meinzer, 1927

Nichols, 1993

SWCA, 2013

Waugh and Smith, 1998

White, 1932

4.4.4 Frost Damage

As DRC described in Interrogatory CR R313-25-8(4)(d)-155/2 (DRC 2014b), 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. Furthermore, repeated cycles of frost heave can move gravel in a soil to the ground surface. Accumulated gravel at the surface of even several centimeters can greatly inhibit evaporation [see Weaver (1919); Benoit (1961); Kemper and Corey (1968); Bowley and Burghardt (1971); Hadas and Hillel (1972); Johnson and Hansen (1974); Johnson and Wood (1978); Anderson (1980); Modaihsh et al. (1985); Groenevelt et al. (1989); Reith and Caldwell (1990); Kemper et al. (1994); Pérez (2000); Xiaoyan et al. (2002); Yamanaka et al. (2004); Yuan (2009); Albright et al. (2010)]. This can increase infiltration rates, resulting in faster contaminant transport rates.

Freezing or close-to-freezing temperatures were measured by the Licensee using thermocouple temperature probes at the midpoint of the sacrificial soil in the Cover Test Cell during testing in January 2002 and January 2004, at a depth of about 30 inches (Edwards 2011). Currently, in the DU PA Model v1.2 (Neptune 2014a), the top of the radon barrier is proposed to be located at a depth of 36 inches. However, these incidents of freezing at 36 inches noted in the past took place during portions of winter that were not especially cold. Mean monthly low air temperatures at Dugway, Utah for January 2002 and January 2004 were, respectively, 15.45 degrees Fahrenheit (°F) and 11.35 °F (see Western Regional Climate Center 2013). However, in the 56 years between 1951 and 2006, inclusive, there were 13 years (i.e., 23 percent 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 (see Western Regional Climate Center 2013).

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 deeper than the 30 inches into the cell that were measured in January 2004.

The frost penetration equation used in Utah by the Utah Department of Transportation (UDOT) (2014) is shown in Equation (6):

$$\text{Frost Penetration} = 1.482(\text{Freezing Index})^{0.4911} \quad (6)$$

This equation gives a value for 100-year frost penetration depth for nearby Dugway, Utah of 44.9 inches, based on the National Oceanographic and Atmospheric Administration air freezing index of 1,037 for a 100-year frost at Dugway (NOAA n.d.).

Energy*Solutions*' position is summarized in its Round 3 response to Interrogatory CR R313-25-8(4)(d)-155/3 (ES 2014b):

> *A calculation of the frost depth for the evapotranspiration (ET) cover.…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; Depts. 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).*
>
> *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.*

The Energy*Solutions* position raises several topics that require further consideration. Nixon and McRoberts (1973), as quoted in USACE (2012), state that the physically based modified Berggren equation is generally more accurate relative to the exact solution (i.e., the Neumann model) than are certain simpler empirical or semi-empirical equations (see several listed in Table 1 of USACE 2012). These simpler equations include the original rudimentary Stefan equation. However, the additional accuracy afforded by use of the modified Berggren equation, is, according to Table 1, at most 12.4 percent [14.2 percent deviation of the Stefan equation - 1.8 percent deviation of the ModBerg (the modified Berggren) approach]. For the Clive site, assuming a 100-year recurrence interval for frost conditions, the calculated deviation only represents a decrease of about 5 inches, which, compared to 44.9 inches, does not substantially modify DEQ conclusions. This adjusted frost depth (39.9 inches) is still deeper than the top of the radon barrier at 36 inches. Frost should not only not be permitted to encounter the radon barrier, since freezing damages clays (Benson and Othman 1993), but frost should not be allowed to exist even close to the radon barriers. Frost heave involves pulling up water from deeper soil to create ice lenses, and frost heave within inches or even within several feet of the underlying radon barriers would likely dry out, or partially dry out, the radon barriers, leading to potential wet/dry cycling and fracturing. Upward movement of soil water in response to freezing conditions in overlying soil is known to crack underlying clays (e.g., see Benson and Othman, 1993). These effects would adversely impact infiltration of water and perhaps the release of radon. Moreover, factors such as how long the recurrence interval is for certain types of frost conditions are much more important than an additional 12.4 percent deviation from an exact mathematical solution. The original value of 44.9 inches calculated by DEQ using the UDOT equation (as well as the recent calculations made by the Licensee) are based on a frost index using a recurrence interval of only 100 years. This recurrence interval is one to which DEQ is limited because of a lack of published data for local frost index recurrence intervals much greater than that.

As explained in Section 4.4.1, Dr. Benson has raised a number of concerns regarding the potential impacts of freezing and thawing on the hydraulic conductivity of clay barriers used in the final covers at the disposal facility. See Appendix F for a detailed discussion of these concerns.

Conclusion: Although the empirical data for the Cover Test Cell can be used to determine the most applicable equations (i.e., model) for estimating frost penetration depths under general site conditions, it cannot be used directly to estimate frost depth in the proposed DU embankment cover system. This is because the proposed DU embankment cover system will consist of different materials, with different thermal properties, than the Cover Test Cell cover system materials (e.g., with 2 feet of rock armor cover). Furthermore, there are still several issues pertaining to the selection of parameter values for the clay barriers that need to be resolved (see Appendix F).

With the current proposed Federal Cell design, Energy*Solutions* should account in modeling for substantial disruption of near-surface layers above and within the radon barriers by frost, with accompanying decreases in ET and increases for initially low-permeability soil in both hydraulic conductivity and correlated α values, which could affect modeled infiltration and radon release rates. UAC R313-25-25(3) and (4) require a licensee to minimize infiltration; therefore, Energy*Solutions* must model infiltration under realistic long-term assumed site conditions before DEQ can consider this requirement to be resolved. Without resolution of this issue, DEQ cannot determine if the requirements of UAC R313-25-25(3) and (4) have been met nor determine the adequacy of the proposed Federal Cell.

References

Albright et al., 2010

Anderson, 1980

Benoit, 1961

Benson & Othman, 1993

Bowley & Burghardt, 1971

Depts. of Army and Air Force, 1988

DRC, 2014b

Edwards, 2011

ES, 2014b

Groenevelt et al., 1989

Hadas & Hillel, 1972

Johnson & Hansen, 1974

Johnson & Wood, 1978

Kemper & Corey, 1968

Kemper et al., 1994

Modaihsh et al., 1985

Neptune, 2014a

Nixon & McRoberts, 1973

NOAA, n.d.

Pérez, 2000

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Xiaoyan et al., 2002

Yamanaka et al., 2004

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5.0 OTHER DEPLETED URANIUM PERFORMANCE ASSESSMENT ANALYSES

5.1 DEEP TIME ANALYSIS [UAC RULE R313-25-9(5)(a)]

UAC Rule R313-25-9(5)(a) states:

> *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 initial analysis performed by Energy*Solutions* to demonstrate compliance with this portion of the regulation is summarized in the DU PA Model v1.2 (Neptune 2014a), Section 5.1.8 (input assumptions), Section 5.4.7 (model structure), and Section 6.5 (results), with more details of the deep time analysis being provided in the deep time assessment (Neptune 2014e). The DU PA v1.2 (Neptune 2014a) and deep time assessment (Neptune 2014e) both argue that because the "*waste is buried below grade then none of the DU waste is likely to be dispersed directly*." The Energy*Solutions* Round 3 response (ES 2014b) has furthered that argument and has even presented a preliminary estimate of what the U-238 sediment concentration would be under those assumptions.

Subsequently, major revisions were made by Energy*Solutions*/Neptune to the deep time model (Neptune 2014n). DEQ/SC&A reviewed and provided comments on the revised deep time model (SC&A 2014), and Energy*Solutions*/Neptune further refined their deep time model (Neptune 2015a). Although the DU PA v1.2 deep time model and its results have not been rescinded, it is clear that Neptune (2014a) and Neptune (2014e) no longer represent Energy*Solutions*'/Neptune's deep time analysis. Therefore, this evaluation only addresses the supplemental deep time assessment prepared by Energy*Solutions*/Neptune after the DU PA Model v1.2 was issued (Neptune 2014n; 2015a).

References

ES, 2014b

Neptune, 2014a; 2014e; 2014n; 2015a

SC&A 2014

5.1.1 Deep Time Supplemental Analysis

The original Deep Time Supplemental Analysis (DTSA; Neptune 2014n) was provided by Energy*Solutions*/Neptune in December 2014. The DEQ/SC&A review of the original DTSA (SC&A 2014) identified four areas of concern:

1) The DU and all of the material above the DU was modeled as Unit 4 material in the DTSA, while in the DU PA Model v1.2, the DU and the material disposed of above the DU was modeled as Unit 3 material.

2) Neptune (2014n) limited the return of the first Intermediate Lake to 50,000 years (or 40,000 years after the 10,000-year Compliance Period).
3) A very high Intermediate Lake sedimentation rate was used.
4) The mean aeolian deposition rate appeared to be acceptable, but the standard deviation that was used appeared to be too small.

Details of each of these four concerns may be found in SC&A (2014) and will not be repeated here.

In March 2015, Energy*Solutions*/Neptune provided the DEQ with a revised DTSA (Neptune 2015a). This section of the SER evaluates how the revised Energy*Solutions*/Neptune DTSA addresses or modifies the four DEQ/SC&A concerns listed above.

To evaluate the revised Energy*Solutions*/Neptune DTSA, SC&A re-ran the GoldSim model for the following six cases:

- Neptune: DRSA1 Results — Duplicates Neptune's results.
- SC&A: SE to SD — Uses the standard deviation in the aeolian deposition depth distribution definition, instead of the standard error of the mean.
- SC&A: Unit 3 — Assumes that the DU and material above the DU was Unit 3 (instead of Unit 4) type material.
- SC&A: 10x Large Lake — Assumes an Intermediate Lake sedimentation rate that was 10 times the Large Lake sedimentation rate.
- SC&A: Large Lake — Assumes no surface radon flux when a Large Lake is present.

Detailed descriptions of each of the five SC&A GoldSim cases are provided below, while Figure 5-1 shows the time-dependent ground surface radon fluxes for the GoldSim deep time runs that were made by SC&A, and Table 5-1 provides the peak mean flux for each run.

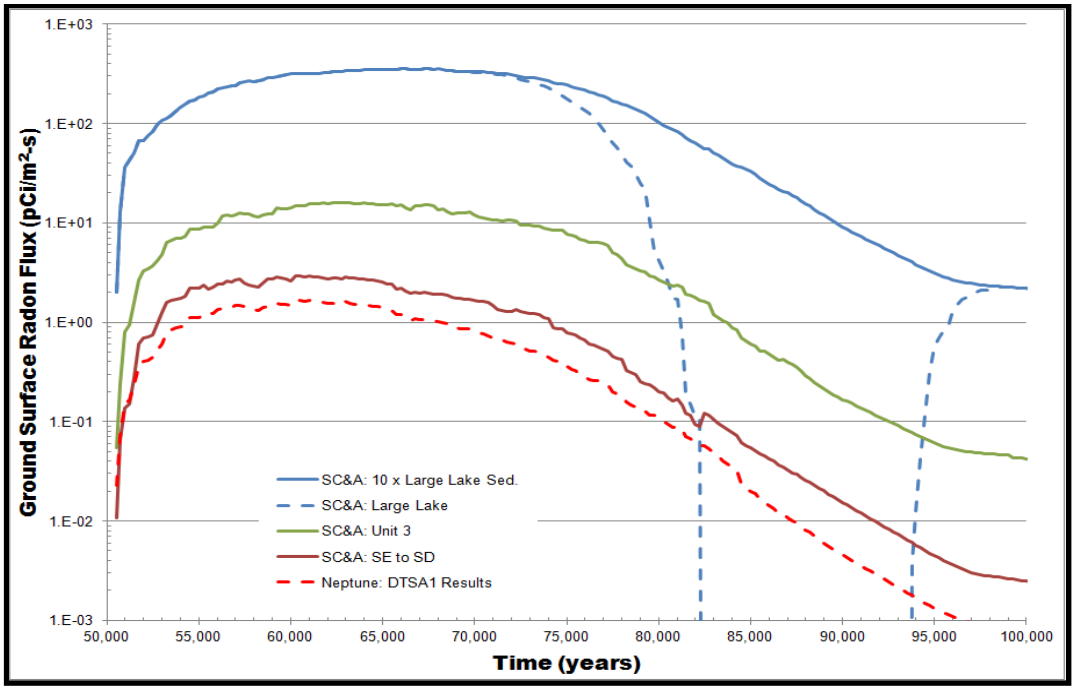

Figure 5-1 – Mean radon flux above depleted uranium

The current Energy*Solutions*/Neptune DTSA GoldSim model (Neptune 2015a) calculates the radon flux above the embankment regardless of the presence or absence of a lake. In reality, if a lake is present, the lake water would attenuate the radon such that the flux on the lake surface would be negligible. For example, an early return of a Large Lake could significantly reduce peak mean radon flux. The last SC&A case (SCA: Large Lake) demonstrates this effect utilizing the revised DTSA GoldSim model and shows that peak mean radon flux would occur sufficiently early so as not to be affected by the return of a Large Lake. Because of the short duration of Intermediate Lakes (i.e., a mean of 500 years [Neptune 2014e, Table 1]), which is on the same order as the GoldSim time step, this effect has conservatively not been modeled for Intermediate Lakes.

Table 5-1 – Peak Mean Radon Flux Above Depleted Uranium After the Lake Recedes

Case	Flux	Ratio to	
	(pCi/m^2-s)	Previous	Neptune
Neptune: DTSA1 Results	1.7	—	—
SC&A: SE to SD	2.9	1.7	1.7
SC&A: Unit 3	16.1	5.5	9.7
SC&A: 10 x Large Lake Sed.	356	22.0	213

In addition to providing the peak mean ground surface radon fluxes for each run, Table 5-1 provides the ratio of each run's results to the previous run's results, as well as to the Neptune

DTSA1 results. From these ratios, it can be seen that reducing the Intermediate Lake's sedimentation rate to 10 times the Large Lake's sedimentation rate results in the largest increase in the peak mean radon flux. Also, when all four of the SC&A assumption modifications are taken into account, the peak mean radon flux is about 350 times larger than the flux reported in the Energy*Solutions*/Neptune revised DTSA (Neptune 2015a).

The Figure 5-1 dashed blue curve (SC&A: Large Lake) is the same as the SC&A: 10x Large Lake case (the solid blue curve) except that ground surface radon flux has been set to zero whenever a Large Lake is present. Because their durations are about the same length as the time-step used in the GoldSim model, it was not feasible to set the radon flux to zero during the presence of an Intermediate Lake. Since the peak mean radon flux occurs following the first Intermediate Lake, setting the flux to zero during the presence of a Large Lake has no impact on the peak mean radon flux, as shown by Figure 5-1.

References

Neptune, 2014e; 2014n; 2015a

SC&A, 2014

5.1.1.1 Aeolian Deposition

In December 2014, after publication of the original DTSA (Neptune 2014n), field studies of the aeolian depositional history at the Clive Disposal Site were conducted by Energy*Solutions*/ Neptune to provide information for describing aeolian deposition rates for the DTSA model. The results of those field studies are reported in Neptune (2015b), and have been incorporated in the revised DTSA (Neptune 2015a).

The field studies made silt deposition thickness measurements from 11 soil test pits on the Clive site. The measured silt thicknesses ranged from 55 to 110 cm, with a mean of 72.7 cm and a standard deviation of 16.6 cm (Neptune 2015b, Table 1). A distribution of the deposition duration was made based on minimum, maximum, and most likely durations of 13,000, 15,000, and 13,500 years, respectively, and a beta distribution (Neptune 2015b, Section 5.1.6.2). Combining the thickness and duration distributions, Neptune (2015b) reported a long-term mean depositional rate of approximately 0.05 millimeters per year (mm/yr).

SC&A reviewed the field studies submitted by Energy*Solutions*/Neptune, and concurs that the average aeolian deposition rate in the Clive area is about 0.05 mm/yr (Jewell 2015). However, during review of the DTSA GoldSim model it was discovered that the standard error of the mean (i.e., 5.0 cm) was entered when the aeolian deposition depth distribution was being defined, instead of the standard deviation value (16.6 cm), as shown in the Figure 5-2 GoldSim screen capture.

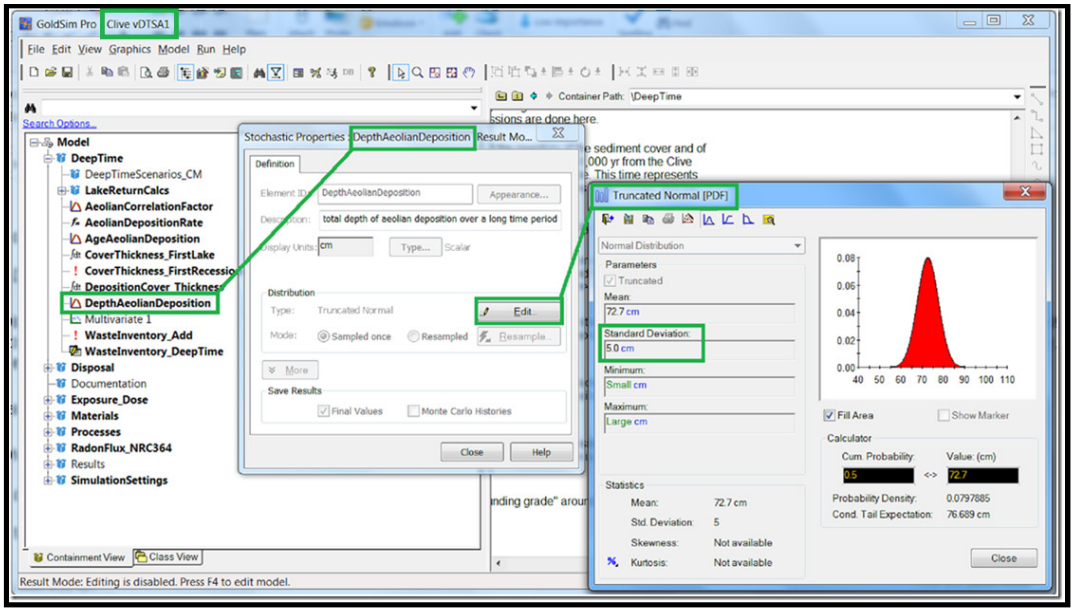

Figure 5-2 – GoldSim screen capture

Figure 5-3 shows the impact that using the standard error instead of the standard deviation would have on the aeolian deposition depth. For comparison purposes, Figure 5-3 also shows the distribution of the 11 depths (i.e., silt thicknesses) that were obtained from the field studies (Neptune 2015b, Table 2). When compared to the standard deviation, the standard error of the mean tends to remove the extremes from the analysis. If the measurements were of annual deposition rates, where there is expected to be a wide variation from year to year, then the use of the standard error of the mean would be appropriate. However, the measurements that were taken are of the total sedimentation depth accumulated over thousands of years, which accounts for any year-to-year fluctuation in the sedimentation rate. Thus, the use of the standard deviation is believed to be appropriate.

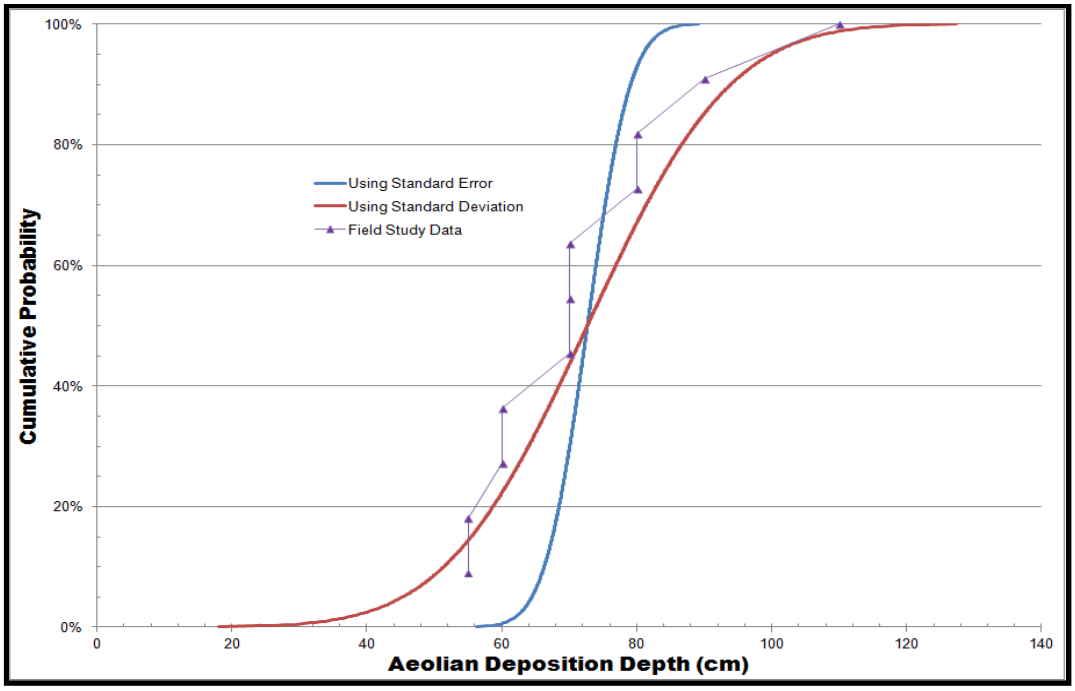

Figure 5-3 – Comparison of standard error to standard deviation

Figure 5-3 shows that the "tails" of the standard error distribution are much shorter than the "tails" of the standard distribution. In fact, the aeolian deposition depth calculated from the standard error distribution never reaches the maximum depth of 110 cm that was measured in the field studies. It is believed that the Figure 5-3 standard deviation curve is a much better match to the field study data than the Figure 5-3 standard error curve.

For all subsequent GoldSim analyses, SC&A used an aeolian deposition distribution as described by Neptune (2015a), except that the aeolian deposition depth distribution was described using the standard deviation of 16.6 cm, rather than by the standard error of 5.0 cm. As shown in Table 5-1, this change results in an increase in the GoldSim-calculated ground surface radon flux by about a factor of 1.7 over what was reported by Energy*Solutions*/Neptune (Neptune 2015a).

References

Jewell, 2015

Neptune, 2014n; 2015a; 2015b

5.1.1.2 Unit 3 Material

The revised Energy*Solutions*/Neptune DTSA report (Neptune 2015a) contains the following statement repeated word-for-word from the original DTSA (Neptune 2014n):

> *For the DTSA model, an assumption is made that the material above the below-grade DU waste and the additional lake sedimentation is homogenous material with properties similar to those of the surrounding Unit 4 sediments.*

However, in both version 1.0 and version 1.2 of the DU PA Model (Neptune 2011b; 2014a), the DU layers and the layers immediately above were assumed to be composed of Unit 3 material (i.e., silty sand). Neither the original nor revised DTSA provides any basis for why the DU and other materials should be considered as silty sand (Unit 3 material) up to 10,000 years, and after 10,000 years be considered as silty clay (Unit 4 material).

A major difference between Unit 3 and Unit 4 material is their moisture content distributions. Figure 5-4 shows that the Unit 4 mean moisture content (taken from Neptune 2014n, Figure 1) is 0.2559, while the Unit 3 mean moisture content is only 0.114 (taken from GoldSim). This is important because the radon diffusion coefficient is related to the moisture content, such that the higher moisture content of the Unit 4 material results in a reduced radon flux at the ground surface when compared to the Unit 3 material.

Unit 4 Moisture Content

Percentiles

Cum.Prob.	Value
0.001	0.11
0.01	0.157513
0.05	0.222678
0.25	0.24552
0.5	0.255866
0.75	0.265074
0.95	0.277332
0.99	0.285745
0.999	0.296523

Statistics

Realizations:	10000
Mean:	0.2529
5%/95%:	+/- 0.00035392
Std. Dev.:	0.021516
Skewness:	-2.8769
Kurtosis:	14.571

Unit 3 Moisture Content

Percentiles

Cum.Probability	Value
0.001	0.1056
0.01	0.1078
0.05	0.1096
0.25	0.1122
0.5	0.114
0.75	0.1158
0.95	0.1184
0.99	0.1202
0.999	0.1224

Statistics

Statistic	Value
Number of Samples	1000
Mean	0.114
5% Conf. Bound	0.1139
95% Conf. Bound	0.1141
Standard Deviation	0.002661
Skewness	-0.01936
Kurtosis	-0.05287

Figure 5-4 – Unit 3 and Unit 4 moisture content

When SC&A changed the DU layers and the layers immediately above the DU from Unit 4 material to Unit 3 material and re-ran GoldSim, the ground surface radon flux increased by about a factor of 5.5 to 16.1 pCi/m^2-s, as shown in Table 5-1.

References

Neptune, 2011b; 2014a; 2014n; 2015a

5.1.1.3 Intermediate Lake Sedimentation

In the DU PA Model v1.2, Appendix 13, Table 1 (Neptune 2014e), Energy*Solutions*/Neptune indicated that there was an Intermediate Lake mean sedimentation rate of 2.82 meters, and a

mean lake duration of 500 years. Combining those two parameters gives a sedimentation rate of 5.64 meters per 1,000 years. Meanwhile, for the Large Lake, the sedimentation rate is given in the same table as 0.00012 meters per year, a factor of 47 less. To obtain an idea of the impact of such a large sedimentation rate, SC&A re-ran GoldSim with an Intermediate Lake sedimentation rate of 10 times greater than the Large Lake sedimentation rate, which is still expected to be a factor of 4.7 less than what Energy*Solutions*/Neptune used for the Intermediate Lake. As Table 5-1 shows, the ground surface radon flux increased by a factor of 22 to 356 pCi/m^2-s for this case.

Because of the large increase in the radon flux and due to the arbitrary nature of using 10 times the Large Lake sedimentation rate, SC&A asked Dr. Paul Jewell of the University of Utah's Department of Geology & Geophysics for his opinion regarding Intermediate Lake sedimentation rates. In Dr. Jewell's email on the subject, he indicated that "*so-called 'intermediate lakes' seem not to have* [sedimentation] *rates that are much greater than the long term records*" (Jewell 2014). In support of this, Dr. Jewell provided the compiled information on Great Basin lake sedimentation rates included in Table 5-2 (Jewell 2014).

Table 5-2 – Summary Table of Published Sedimentation Rates, Eastern Great Basin, Utah

Lake	Period Covered	Sedimentation Rate (mm/yr)	Reference
Lake Bonneville and predecessors	758 ky to present	0.12	Oviatt et al. (1999)
Blue Lake (western side of Bonneville basin)	44 ky to present	0.18	L.V. Benson et al. (2011)
Great Salt Lake	Holocene (~11 ky to present)	0.20–0.83	Colman et al. (2005)
Bear Lake	Holocene (~11 ky to present)	0.3-0.8	Colman et al. (2009)
Lake Bonneville and predecessors	287 ky to present	0.4	Balch et al. (2005)
Bear Lake	Late Pleistocene to present	0.5	Colman et al. (2009)

From Dr. Jewell's information, it can be concluded that a sedimentation rate of 1.2 mm/yr for intermediate lakes is likely too large, thereby understating the radon flux. Thus, in order to provide additional perspective, SC&A investigated three other hypothetical sedimentation rates for the Intermediate Lake based on the available data: (1) a normal distribution based on the Large and Intermediate Lake means (0.12 and 5.64 mm/yr, respectively), (2) a lognormal distribution based on the Large and Intermediate Lake means, and (3) a lognormal distribution based on the smallest [0.12 mm/yr from Oviatt et al. (1999)] and largest [0.83 mm/yr from Colman et al. (2009)] Table 5-2 sedimentation rates. Figure 5-5 shows each of these lake sedimentation rate distributions, while Table 5-3 presents the characteristics of the analyzed Intermediate Lake Sedimentation rate distributions. Also shown in Figure 5-5 are the

Energy*Solutions*/Neptune Large and Intermediate Lake sedimentation distributions (the two dashed curves), and the Table 5-2 Great Basin sedimentation rates (the six dotted vertical lines).

Table 5-3 – Analyzed Sedimentation Rate (mm/yr) Distributions

Identifier	Minus 2 Std Dev	Plus 2 Std Dev	Distribution Type	Mean	Standard Deviation
SC&A: Oviatt-Colman LN	0.12	0.83	Lognormal	0.32	1.62
SC&A: Lognormal Distribution	0.12	5.64	Lognormal	0.82	2.62
SC&A: Normal Distribution	0.12	5.64	Normal	2.88	1.38

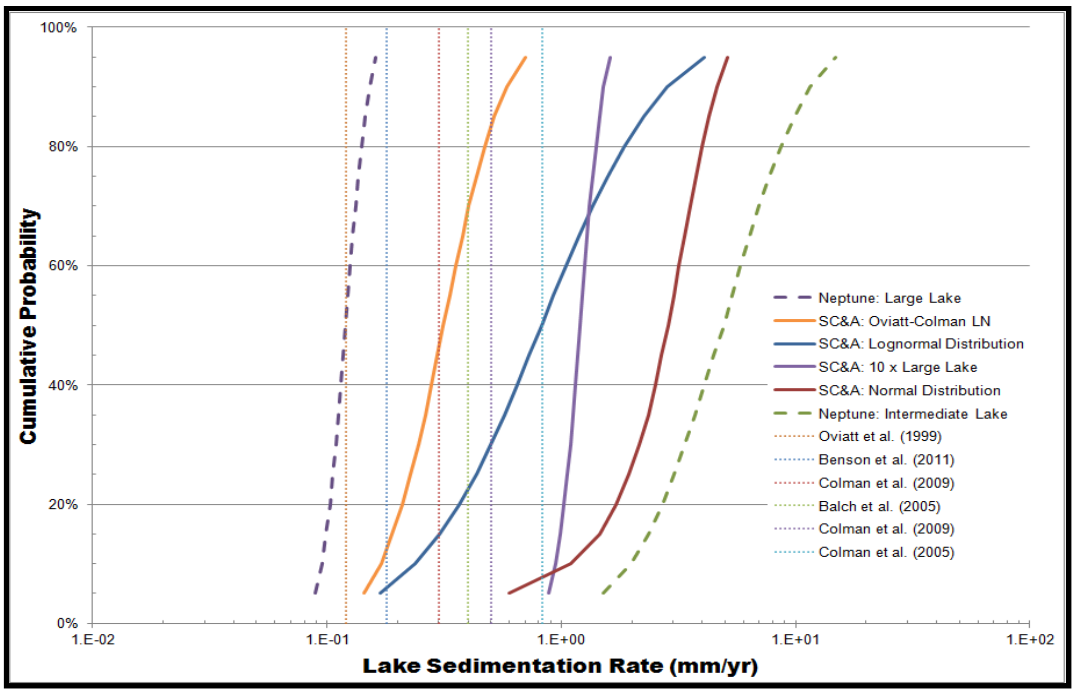

Figure 5-5 – Comparison of Intermediate Lake sedimentation rates

SC&A re-ran the DTSA GoldSim model with each of the Figure 5-5 sedimentation rates, with the resulting ground surface radon fluxes shown in Figure 5-6 and the peak mean flux given in Table 5-4.

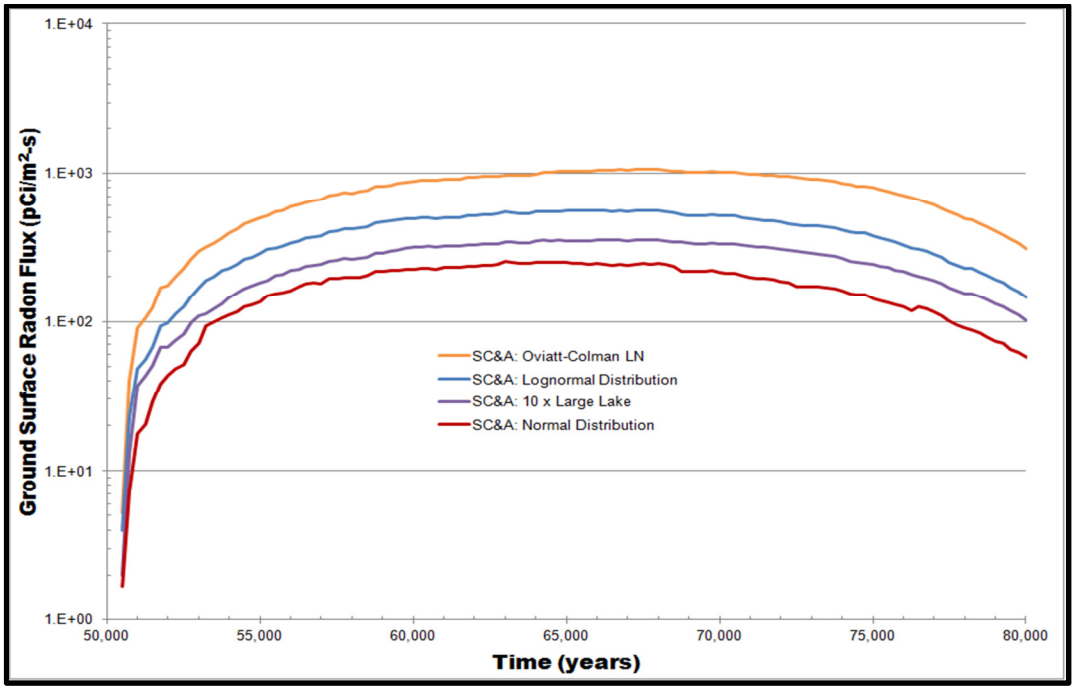

Figure 5-6 – Mean radon flux with different sedimentation rates

Table 5-4 – Peak Mean Radon Flux with Different Sedimentation Rates

Case	Radon (pCi/m^2-s)	Ratio
SC&A: Neptune IL Sed.	16.1	—
SC&A: Normal Distribution	253	15.7
SC&A: 10 x Large Lake Sed.	356	22.0
SC&A: Lognormal Distribution	562	34.9
SC&A: Oviatt-Colman LN	1,067	66.3

Table 5-4 shows that regardless of which sedimentation rate distribution is selected for the Intermediate Lake, the resulting ground surface radon flux will be significantly larger than what would have been calculated using the Energy*Solutions*/Neptune rate. For the remainder of this review, the 10 times the Large Lake sedimentation rate results will be used; however, it should be kept in mind that the ground surface radon flux could be substantially larger if a different sedimentation rate distribution is determined to be appropriate.

References

Balch et al., 2005

L.V. Benson et al., 2011

Colman et al., 2005; 2009

Jewell, 2014

Neptune, 2014e

Oviatt et al., 1999

5.1.1.4 Early Lake Return

SC&A (2014), Attachment 1 indicated that the basis for assuming that the lake does not return for the next 50,000 years is weak. However, after further review (Bradley 2013, 2014), SC&A has determined that "*it is extremely unlikely that a return to an intermediate lake level will occur before 50,000 years from present*" (Bradley 2014). Bradley (2013) made the following observations:

- "*The model…is based on a very reasonable set of assumptions regarding the return of both large and small lakes,…. Paleoclimatic records clearly indicate that major climate* [global] *variations over the last ~800,000 years have operated primarily on a ~100,000-year cycle, with shorter term variability focused at the ~41,000-year timescale*."
- "*We can have very high confidence that there will be much higher lake levels in the region in the (distant) future and that they will inundate the Clive site many times over the next 2 million years*."
- "*Overall, orbital changes indicate that lakes in the Great Basin that were typical of glacial epochs in the past will be delayed well beyond the next 10,000 years*."
- "*Model simulations under higher levels of greenhouse gases all point to warmer and drier conditions, not wetter, in the western United States (…). This will lead to reductions in winter snowpack, seasonal runoff, and soil moisture content, and thus an overall trend towards aridification of the entire great Basin region (…).*"

Thus, the early return of an Intermediate Lake is no longer a concern, and has not been analyzed.

References

Bradley, 2013; 2014

SC&A, 2014

5.1.1.5 Qualitative Analysis

For the deep time, UAC R313-25-20(5)(a) requires that:

> *Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.*

This section presents a qualitative evaluation of the deep time ground surface radon flux analysis results. Although doses have been calculated and presented in the tables that follow, this is not a risk assessment, and the calculated doses are not meant as a compliance indicator. Rather,

following the guidance provided by the NRC (2013a), "dose" is being used as a "*surrogate, to evaluate relative risk and the degree of isolation of the waste to minimize future problems at the sites*."

Using the methodology from Yu et al. (2001), Appendix C, the radon and radon progeny outdoor concentrations due to a radon flux of 356 pCi/m^2-s (i.e., SC&A: 10 x Large Lake) were calculated, and are shown in Table 5-5 [see SC&A (2015) for more information on how these outdoor concentrations were calculated]. Table 5-5 also shows the dose that an individual worker would receive from inhaling these concentrations for 2,000 hours per year. To calculate these doses, the inhalation dose factors for radon and the radon progeny were obtained from Table 2 of Kendall and Smith (2002). For comparison purposes, the concentrations and doses due to a radon flux of 20 pCi/m^2-s are also presented in Table 5-5. National Council on Radiation Protection and Measurements (NCRP) Report No. 160, *Ionizing Radiation Exposure of the Population of the United States* (2009, p. 54) indicates that the average outdoor (ambient) radon concentration in the United States is 405 picocuries per cubic meter (pCi/m^3) [15 becquerels per cubic meter (Bq/m^3)]. Again for comparison, Table 5-5 indicates what the radon progeny concentrations and doses would be for this ambient radon concentration.

Table 5-5 – Calculated Outdoor Radon Concentration and Exposure

Nuclide	Clive Deep Time	EPA[a]	U.S. Average[b]
	Radon Flux (pCi/m^2-s)		
Rn-222	356	20	Not Given
	Concentration Outdoor (pCi/m^3)		
Rn-222	1.7E+04	9.8E+02	4.1E+02
Po-218	2.8E+03	1.6E+02	6.5E+01
Pb-214	4.0E+01	2.3E+00	9.4E-01
Bi-214	5.8E-01	3.2E-02	1.3E-02
	Dose Outdoor (2,000 hr/yr) (mrem/yr)		
Rn-222	2.1E+01	1.2E+00	4.8E-01
Po-218	5.7E+01	3.2E+00	1.3E+00
Pb-214	4.0E+00	2.2E-01	9.2E-02
Bi-214	5.0E-02	2.8E-03	1.2E-03
Total	8.2E+01	4.6E+00	1.9E+00

[a] EPA regulations at 40 CFR Part 61, Subparts Q, R, T, and W, as discussed below.
[b] NCRP (2009, p. 54) gives the U.S. mean outdoor (ambient) radon concentration as 15 Bq/m^3 (405 pCi/m^3).

In 40 CFR Part 61, the EPA has set radon emission standards for several different types of radium-containing facilities, but not for a DU disposal facility. The relevant subparts of Part 61 are as follows:

- Subpart Q National Emission Standards for Radon Emissions from Department of Energy Facilities
- Subpart R National Emission Standards for Radon Emissions from Phosphogypsum Stacks
- Subpart T National Emission Standards for Radon Emissions from the Disposal of Uranium Mill Tailings
- Subpart W National Emission Standards for Radon Emissions from Operating Mill Tailings

All four of these 40 CFR Part 61 subparts contain the identical radon emission standard of 20 pCi/m^2-s. Thus, in order to measure how well the Clive DU disposal facility compares to other radium-containing facilities, it seems appropriate to use a radon emission level of 20 pCi/m^2-s as a gauge, and this information has been included in Table 5-5.

Table 5-5 shows that the calculated ground surface radon flux results in outdoor radon and radon progeny concentrations and doses that are about 100 times larger than the U.S. average and about 18 times larger than those due to the limiting radon flux from other types of radium-containing facilities.

Likewise, using the methodology from Yu et al. (2001), Appendix C, the radon and radon progeny inside concentrations due to a radon flux of 356 pCi/m^2-s (i.e., case SC&A: 10 x Large Lake) were calculated and are shown in Table 5-6 [see SC&A (2015) for more information on how these inside concentrations were calculated]. Because the radon is contained and not immediately blown away, the radon progeny have a chance to grow in when the radon flux occurs within a structure. Again, the dose to an individual worker who inhales these concentrations for 2,000 hours per year has been calculated and is shown in Table 5-6.

DEQ has a program that allows Utah residents to obtain test kits and test the radon concentration in their home, work location, or public building. As of December 2014, DEQ has obtained 38,407 indoor radon test results and has categorized them by zip code. Based on these test results and using the Yu et al. (2001) methodology, SC&A has calculated the radon progeny concentration and dose for the average radon concentration within the State of Utah, Tooele County, and the 84029 zip code (the closest to the Clive site), as well as for the largest measured radon concentration in the 84029 zip code. These concentrations and doses are also provided in Table 5-6 for comparison. It is important to note that the Table 5-5 doses are in units of mrem/yr, while the Table 5-6 doses are in rems per year (rem/yr), and that 1 rem/yr is equal to 1,000 mrem/yr.

Table 5-6 – Calculated Inside Radon Concentration and Exposure

Nuclide	Clive Deep Time	EPA[a]	U.S. Average[b]	Utah Radon Measurement Program Results			
	Radon Flux (pCi/m^2-s)			State of Utah	Tooele County	Zip Code: 84029	
	356	20				Average	Largest
	Concentration Inside (pCi/m^3)						
Rn-222	1.3E+05	7.2E+03	1.3E+03	5.2E+03	5.7E+03	1.1E+04	9.8E+04
Po-218	1.2E+05	6.7E+03	1.2E+03	4.8E+03	5.3E+03	1.1E+04	9.1E+04
Pb-214	7.3E+04	4.1E+03	7.1E+02	2.9E+03	3.2E+03	6.4E+03	5.6E+04
Bi-214	4.9E+04	2.8E+03	4.8E+02	2.0E+03	2.2E+03	4.3E+03	3.8E+04
	Dose Inside (2,000 hr/yr) (rem/yr)						
Rn-222	1.5E-01	8.5E-03	1.5E-03	6.1E-03	6.7E-03	1.3E-02	1.2E-01
Po-218	2.4E+00	1.4E-01	2.4E-02	9.8E-02	1.1E-01	2.1E-01	1.9E+00
Pb-214	7.2E+00	4.0E-01	7.0E-02	2.9E-01	3.2E-01	6.3E-01	5.5E+00
Bi-214	4.2E+00	2.4E-01	4.1E-02	1.7E-01	1.9E-01	3.7E-01	3.2E+00
Total	1.4E+01	7.8E-01	1.4E-01	5.7E-01	6.2E-01	1.2E+00	1.1E+01

[a] EPA regulations at 40 CFR Part 61, Subparts Q, R, T, and W, as discussed above.
[b] NCRP (2009, p. 46) gives the U.S. mean inside radon concentration as 46.3 Bq/m^3 (1,251 pCi/m^3).

Table 5-6 shows that the calculated radon flux results in inside radon and radon progeny concentrations and doses that are about 102, 25, and 11 times larger than the national, state, and local radon concentrations and about 18 times larger than those due to the limiting radon flux from other types of radium-containing facilities.

In addition to elevated radon flux levels, the DU would also result in the direct-shine dose rate to anyone standing on the embankment. The Energy*Solutions* DTSA did not address the direct dose above the DU. However, DEQ performed a simple MicroShield® (Grove 2009) analysis to estimate what the dose rate might be on top of the embankment. For the MicroShield® analysis, the mean radionuclide concentrations from Neptune (2014i), Table 2 were entered, and MicroShield® was then allowed to decay and build up the inventory at various times up to 100,000 years, resulting in the full suite of uranium-series radionuclides being included in the analysis.

Rather than being totally exposed once the embankment has been washed away, the DU would be covered to a depth equal to the amount of aeolian deposition prior to the lake's return and lake sedimentation prior to the lake receding. Figure 5-7 shows the shine dose directly above the DU as a function of the depth of material covering the DU at 10,000, 50,000, and 100,000 years.

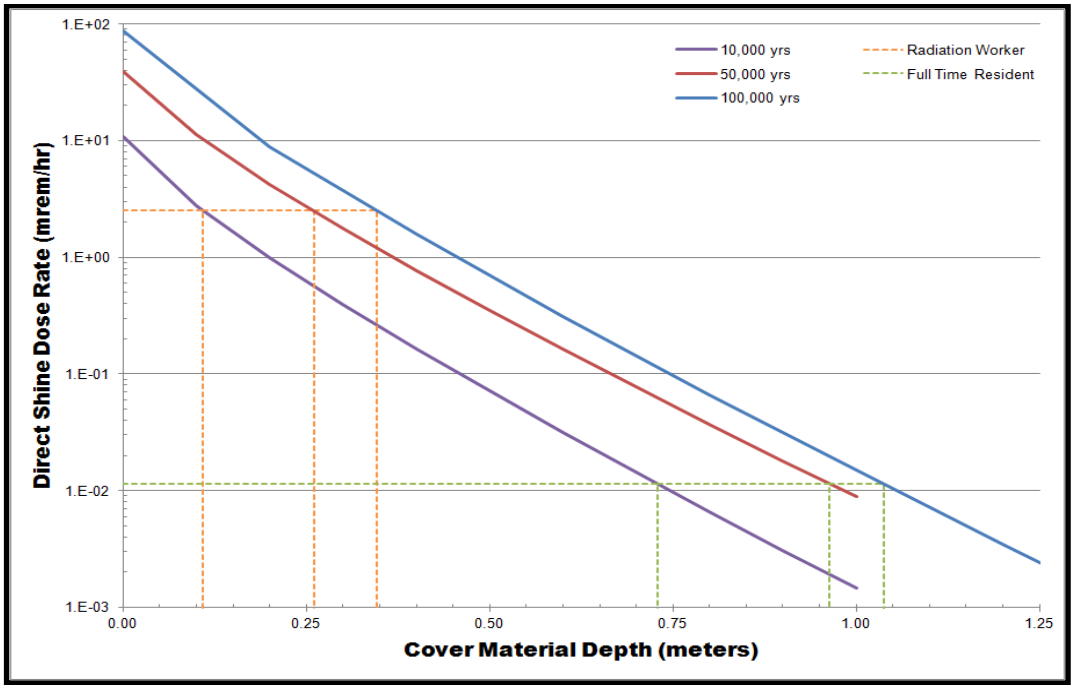

Figure 5-7 – Dose rate above covered depleted uranium

The dashed lines in Figure 5-7 show the amount of cover material needed to reduce the direct shine dose to below the UAC R313-15-201(1)(a)(i) occupational limit of 5 rem/yr (the orange line), assuming 2,000 work-hours/year and below the UAC R313-15-301(1)(a) dose limit for individual members of the public of 100 mrem/yr (the green line), assuming full-time (i.e., 8,766 hr/yr) occupancy. Table 5-7 shows the various amounts of cover material necessary to reduce the direct shine dose to each of the two limits.

Table 5-7 – Required Depth of Cover Material

Time (years)	Required Depth (m)		Aeolian Deposition Depth (m)	Lake Sedimentation Depth (m)
	Member of the Public	Radiation Worker		
10,000	0.73	0.11	0.53	0.6
50,000	0.96	0.26	2.65	0.6
100,000	1.04	0.35	5.30	0.6

Table 5-7 shows the amount of cover material that would result from aeolian deposition prior to an intermediate lake returning and the amount of sedimentation that would occur while the lake was present. The bases for these estimates are discussed above. As indicated in Table 5-7, there is expected to be sufficient deposited material to attenuate the direct shine dose to below both the occupational and general population dose limits.

In its response to Interrogatory R313-25-8(5)(a)-03: Deep Time – Sediment and Lake Concentrations (ES 2014a), Energy*Solutions* argued against supplying doses or another metric to compare the calculated deep time sediment and lake water concentrations. In formulating its argument, Energy*Solutions* relied heavily on a quote from NUREG-1573, which was published in 2000 (NRC 2000). More recently, associated with proposed revisions to 10 CFR Part 61, the NRC has published additional material regarding the post-compliance time "qualitative analysis," often referred to as the Performance Period. For example, in an August 29, 2013, response to concerns raised by the Advisory Committee on Reactor Safeguards (ACRS) (NRC 2013a), the NRC staff stated that:

> *the performance assessment and intruder assessment that would be required by the proposed rulemaking are not intended to be risk assessments (i.e., they are not calculating human risk even though they calculate a dose). Instead they are assessment methods, using "dose" as a surrogate, to evaluate relative risk and the degree of isolation of the waste to minimize future problems at the sites.*

Additionally, in the preamble to the draft proposed rule in the Performance Period, in the long-term analyses discussion the NRC states (NRC 2013b, page 30):

> *Although a dose limit is not prescribed, it is recommended that doses or concentrations and fluxes of radionuclides in the environment are calculated as they are appropriate to use to compare alternatives using a common metric.*

These statements clearly show that, contrary to Energy*Solutions*' assertion, calculating doses in the deep time qualitative analysis does not invalidate the express purpose for the evaluation but rather is consistent with current NRC staff's goals for the "qualitative analysis."

During a December 3, 2013, ACRS meeting to hear presentations from stakeholders and discuss the proposed revisions and technical basis for revisions to 10 CFR Part 61, Daniel Shrum, representing Energy*Solutions*' Clive facility, made the following statement (NRC 2014a, page 143):

> *The second tier is performance period. And that's used to capture longer-lived isotopes. And I believe, it's my opinion that they need to be looking more to catastrophic effect, not 25 millirem, not even 500 millirem to the inadvertent intruder which is being proposed, but into the 1 to 10 rem range. And the reason for that is it's speculative anyway. People live—I mean we're allowed to give our employee five rem a year. That's allowed. And, you know, that's a known thing that we can do. And so as we project these things into the future, increasing the threshold might be a reasonable way to handle that.*

Although unsure of the proposed dose range (i.e., 1 to 10 rem), DEQ agrees with the basic concept being espoused by Mr. Shrum for the Performance Period "qualitative analysis."

Regarding the NRC (2013a) statement that the deep time "qualitative analysis" is intended to "*evaluate relative risk and the degree of isolation of the waste to minimize future problems at the sites*," it can be argued that the Energy*Solutions* deep time analysis has already performed that function. In Energy*Solutions*' DU PA v1.2, Neptune (2014a, page 6) states:

> *The utility of such a calculation, aside from responding to the UAC, is to inform decisions regarding the placement of wastes in the embankment. With downward pathways influencing groundwater concentrations, and upward pathways influencing dose and uranium hazard, a balance must be achieved in the placement of different kinds of waste. In version 1.0 of the Clive DU PA Model (…), three different options for configuration of the DU waste within the Class A South embankment (subsequently renamed the Federal DU Cell) were evaluated. These options included a "3-m model", named because the top of the DU waste was 3 m below the embankment cover, and also 5-m and 10-m models.*

One of the reasons for abandoning the "3-m" and "5-m" alternatives is because of the insights gained from the Clive DU PA v1.0, including the deep time analysis.

Due to the fact that, unlike LLRW, the danger associated with DU increases with time due to the buildup of U-238 progeny, it is paramount that all precautions be taken to ensure that the DU remains buried at all times. The deep time analysis performed by Energy*Solutions* /Neptune and supplemented by the DEQ analyses clearly show that at some point in the distant future the buried DU will become un-buried due to the erosion of the Federal Cell's embankment by a returning pluvial lake. At that point, the analyses demonstrate that the potential exists for individuals to be exposed to radioactive material, regardless of whether the un-buried DU is dispersed within a limited area around the site (i.e., the v1.2 scenario), dispersed throughout the entire returning lake volume (i.e., as analyzed by DEQ), or remains undispersed where it was disposed.

There has been much discussion between DEQ and Energy*Solutions* regarding what is the proper metric to use to judge the adequacy of the deep time "qualitative analysis" (i.e., Performance Period). As an adequacy metric, DEQ has suggested using dose rates and/or regulatory criteria that are not specific to 10 CFR Part 61 but that act upon the same media type (e.g., 40 CFR 192.12(a) for Ra-226 soil concentration, 40 CFR 61.252(a) for radon flux). Energy*Solutions* has resisted all of the DEQ suggestions and has insisted that "background concentrations" is the proper metric. One reason stated by Energy*Solutions* for rejecting dose as an adequacy metric is "*the huge uncertainty in predicting human society and evolution that far into the future*." DEQ acknowledges this concern but still believes that dose rates (as separate from pathway doses) is an appropriate adequacy metric that has advantages over "background concentrations." For example, there will be a dose rate above an area of contaminated sediment regardless of what happens to human society, and that dose rate can and should be compared to some appropriate benchmark (e.g., background, occupational exposure, regulatory criteria). To support its argument for excluding dose as an adequacy metric, Energy*Solutions* relies heavily on a quote from NUREG-1573, Section 3.2.1, which in essence says that dose should not be calculated if the site is uninhabitable due to a glacier or lake being present (NRC 2000). DEQ agrees with the NRC on this approach and is only proposing that Performance Period doses be calculated once the pluvial lake has receded.

A few paragraphs later, NUREG-1573, Section 3.2.1 (NRC 2000), has more to say concerning the deep time analysis:

> *Assurance about site performance into the far future is also provided by limiting the amounts of long-lived radionuclides that may be disposed of at an LLW disposal facility, including those shown by analysis to be significant only after tens of thousands of years have passed. The effect of placing inventory limits on long-lived radionuclides is to mitigate, given what is foreseeable today,* ***the potential consequences of waste disposal to generations in the distant future****.* [emphasis added]

From this it is clear that DEQ's approach to the deep time analysis is completely consistent with the NRC's guidance: limiting the potential consequences (i.e., doses) to generations in the distant future (i.e., after the pluvial lake has receded).

Conclusion: Since the revised DTSA provided by Energy*Solutions*/Neptune does not address most of the concerns raised by DEQ on the original DTSA (e.g., use of Unit 4 versus Unit 3 material properties, use of a large intermediate lake sedimentation rate), DEQ believes that there are still open questions related to ground surface radon fluxes reported in the revised DTSA (Neptune 2015a). Furthermore, recent calculations performed by DEQ/SC&A have shown that the ground surface radon fluxes after an Intermediate Lake recedes could be substantially above those presented in the Energy*Solutions*/Neptune revised DTSA (Neptune 2015a). Comparing the calculated post-Intermediate Lake inside radon concentration to national, state, and local radon concentrations shows the calculated concentration to be 102, 25, and 11 times larger, respectively, and it could be substantially larger if a different lake sedimentation rate distribution is determined to be appropriate. Therefore, based upon our current understanding of the uncertainties contained within the deep time analysis, DEQ/SC&A is unable to determine at this time that the DTSA portion of the DU PA Model v1.2 is satisfactory.

References

ES, 2014a

Grove, 2009

Kendall & Smith, 2002

NCRP, 2009

Neptune, 2014a; 2014i; 2015a

NRC, 2000; 2013a; 2013b; 2014a

SC&A, 2014; 2015

Yu et al., 2001

5.2 URANIUM ORAL TOXICITY

Although not required as part of the DU PA, Energy*Solutions* analyzed whether ingestion of uranium could cause non-carcinogenic biological damage such as kidney failure. EPA has established reference doses for ingestion (RfD) based on an assumed threshold below which non-carcinogenic damage is not expected (EPA 2000, 2011). The ratio of the actual dose to the

RfD is the hazard quotient for a particular exposure pathway. The hazard index is the sum of the hazard quotients over all pathways for the particular chemical species. A hazard index of less than 1 indicates that the exposures are of no concern. Energy*Solutions* selected two values of RfD from the literature—one based on the EPA drinking water maximum contaminant level (MCL) for uranium [0.0006 milligrams per kilogram per day (mg/kg-day)] (EPA 2000) and one based on the Superfund Integrated Risk Information System (IRIS) (EPA 2011) (0.003 mg/kg-day)—and assumed for the performance assessment that the RfDs were equally probable. The results of the uranium oral toxicity analysis are presented in Table 5-8.

Table 5-8 – Peak of Mean Uranium Hazard Index: Statistical Summary, Peak Uranium Hazard Index within 10,000 Years

Receptor	Mean	Median (50th %ile)	95th %ile
Waste emplaced below grade			
Ranch worker	2.47E-10	7.71E-19	6.87E-11
Hunter	7.95E-12	2.94E-20	2.42E-12
OHV enthusiast	1.03E-11	3.97E-20	3.04E-12

Source: Neptune 2014a, Table 6.

From this table, it is apparent that the hazard indices are very small for the scenarios considered. Exposure pathways evaluated included ingestion of surface soils, ingestion of game meat, and ingestion of beef. The DU PA Model v1.2 did not calculate the uranium hazard index for either the acute or chronic driller intrusion scenarios discussed in Section 4.3 above. However, as noted in Figure 4-6, the doses from uranium ingestion are small: less than 0.001 mrem/yr at 10,000 years. As both the radiological dose from uranium ingestion and the oral toxicity dose are functions of the uranium concentration in the water, the hazard index should also be minimal.

Conclusion: Since both the calculated uranium hazard indices and the implied hazard indices for the acute or chronic driller intrusion scenarios are very small, DEQ considers this portion of the DU PA to be adequate with all issues resolved.

References

EPA, 2000; 2011

Neptune, 2014a

5.3 COMPLIANCE WITH GROUNDWATER PROTECTION LEVELS

GWQ Permit No. UGW450005 for the Clive site specifies GWPLs for uranium and various other radionuclides. Under the terms of the permit, local ground water quality conditions must not exceed respective GWPLs for a minimum of 500 years. Relevant GWPL concentrations are listed in Table 1A of the GWQ Permit and are summarized here in Table 5-9. Beyond the 500-year evaluation period specified in the GWQ Permit, limits on groundwater radionuclide concentrations are established by the requirements of UAC R313-25-20, which specifies 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*." Compliance with UAC R313-25-20 pertains to the minimum Compliance Period of 10,000 years for the DU PA as specified in UAC R313-25-9(5)(a). This longer-term compliance [i.e., with UAC R-25-9(5)(a)] was discussed briefly in Section 4.1.2.

Table 5-9 – GWPLs for Radioactive Contaminants at Clive, Utah

Contaminant	GWPL (pCi/L)	Basis for GWPL[a]
Np-237	7	EPA draft MCL, <1E-04 lifetime risk
Sr-90	42	EPA draft MCL, <1E-04 lifetime risk
Th-230	83	EPA draft MCL, <1E-04 lifetime risk
Th-232	92	EPA draft MCL, <1E-04 lifetime risk
U-233	26	EPA draft MCL, <1E-04 lifetime risk
U-234	26	EPA draft MCL, <1E-04 lifetime risk
U-235	27	EPA draft MCL, <1E-04 lifetime risk
U-236	27	EPA draft MCL, <1E-04 lifetime risk
U-238	26	EPA draft MCL, <1E-04 lifetime risk
I-129	21	EPA draft MCL, <1E-04 lifetime risk
Tc-99	3,790	Annual TEDE < 4 mrem/yr
Ra-226 + Ra-228	5	EPA final MCL
U total	0.030 (mg/L)	EPA final MCL

[a] See Table 1A of GWQ Permit No. UGW450005.

Notice in Table 5-9 that most of the GWPLs are based upon the assumption that an individual would consume the groundwater and be exposed to an increased lifetime cancer risk of <1E-04 or to a dose of <4 mrem/yr. However, since the groundwater at the Clive site is non-potable due to its high salinity, it would require treatment before it could be consumed. Because such treatment would likely remove some of the radionuclides as well as other dissolved solids, use of the Table 5-9 GWPLs at the Clive site is protective of the population.

To evaluate compliance with the GWPLs listed in Table 5-9, Energy*Solutions* modeled concentrations of contaminants in a hypothetical well at the edge of Federal Cell buffer zone. The hypothetical well was 90 feet from the edge of the side slope and 240 feet from the edge of the DU waste. (No DU waste is to be emplaced under the side slopes.) The results are summarized in Table 5-10.

Table 5-10 – Energy*Solutions* Shallow Aquifer Peak of the Mean Groundwater Activity Concentrations within 500 Years, Compared to GWPLs (pCi/L) with the Waste Placed at or Below Grade

Radionuclide	GWPL (pCi/L)	Mean (pCi/L)	Median (50th %ile) (pCi/L)	95th %ile (pCi/L)
Sr-90	42	0	0	0
Tc-99	3,790	740	19.5	4,460
I-129	21	0.482	6.76E-07	3.39
Th-230	83	1.85E-26	0	3.35E-31
Th-232	92	1.44E-32	0	2.09E-37
Np-237	7	9.75E-18	0	1.32E-24
U-233	26	3.86E-22	0	1.00E-25
U-234	26	1.51E-21	0	8.10E-26
U-235	27	1.10E-22	0	6.77E-27
U-236	27	2.24E-22	0	1.08E-26
U -238	26	1.12E-20	2.21E-36	6.35E-25

Source: Neptune 2014a, Table 2.

It can be seen from Table 5-10 that, with the exception of the fission products Tc-99 and I-129, the concentrations of the other radionuclides are insignificant. The calculated concentrations are so small that any changes in infiltration rate based on ET cover modeling changes discussed elsewhere in this SER would not create concerns regarding compliance with the GWPLs. In addition, as discussed in previously in Section 4.1.2 and 4.2.2, a proposed condition for any license amendment addressing disposal of DU waste would specify that recycled uranium (the source of Tc-99, Np-237, and I-129) not be permitted as a constituent in the DU waste.

Assuming that the specific activity of U-238 is 3.3E-7 curies per gram (Ci/g) then, based on the mean U-238 concentration in Table 5-10 of 1.12E-20 picocuries per liter (pCi/L), the mass concentration of U-238 is 0.34E-25 grams per liter (g/L) [1.12E-20 pCi/L ÷ (3.3E-07 Ci/g × 1E+12 picocuries per curie] or 0.34E-19 µg/L. Because U-238 constitutes most of the uranium mass, the uranium concentration is well below the GWPL for total uranium specified in Table 5-10 (i.e., 30 µg/L). The results of this hand calculation are in reasonable agreement with the value of 8.1 E-20 µg/L calculated with GoldSim v1.2 using 1,000 realizations.

Presumably the in-growth of Ra-226 at 500 years was sufficiently small that it was not included in the Energy*Solutions* report. To check this assumption, DEQ extracted additional information from the Energy*Solutions*/Neptune GoldSim results and determined that the mean Ra-226 and Ra-228 groundwater concentrations at 500 years were 2.9E-12 and 3.4E-29 pCi/L, respectively.

These values are well below the Ra-226 and Ra-228 combined GWPL of 5 pCi/L. Likewise, the uranium concentration of 2.8E-18 mg/L is well below the GWPL of 30 mg/L.

As noted above, the only two radionuclides with significant concentrations relative to the GWPLs are I-129 and Tc-99. Since no iodine was detected in the SRS depleted uranium trioxide (DUO_3) samples, the I-129 concentration was set at the lower limit of detection for the DU PA calculations. However, additional research conducted during the Clive DU PA Model v1.2 modeling revealed that the I-129 concentration was overstated by about six orders of magnitude (Neptune 2014i). Thus, the likely I-129 concentration is substantially below the GWPL rather than only slightly below as suggested in Table 5-10.

As shown in Table 5-10, the mean Tc-99 concentration 500 years after Federal Cell closure is about 20 percent of the GWPL (740 pCi/L predicted; GWPL = 3,790 pCi/L). At the 95th percentile, the Tc-99 concentration exceeds the GWPL by 18 percent (4,460 pCi/L predicted) for a 500-year simulation. The Tc-99 source term is based on sampling of the DUO_3 from SRS, where the average measured concentration was 2.38E+04 pCi/g of DU waste with a standard deviation of 1.16E+04 pCi/g (Neptune 2014i, Table 2). The same Tc-99 concentration was assumed for the DU_3O_8 being generated from DU from the GDPs. The use of surrogate data from SRS for establishing the Tc-99 concentration in the DU_3O_8 from the GDPs was questioned in Interrogatory CR R313-25-7(9)-51/3: Nature of Contamination; and Interrogatory CR R313-25-7(9)-89/3: Contamination Levels in DUF_6 (DRC 2014c). In Interrogatory CR R313-25-7(9)-89/3, DRC pointed out that the estimated Tc-99 concentration in the GDP-based oxides could be understated by a factor of 3.7 based on data from Hightower et al. (2000). Because the assumed Kd for technetium is zero, a 3.7-fold increase in the source term should be reflected in a similar increase at the hypothetical well, causing the Energy*Solutions* 500-year simulation of Tc-99 GWPL to be exceeded. In its Round 3 response to Interrogatory CR R313-25-7(9)-89/3 (ES 2014b), Energy*Solutions* explained that the Tc-99 concentrations used in the DU PA were based on SRS data from which the mean and standard deviation were determined. The data from Hightower et al. (2000) were an upper-bound estimate. The upper-bound calculation of the mass of Tc-99 based on 10,000 iterations from the Clive DU PA Model v1.2 is 75,424 kg, while the upper-bound estimate from Hightower et al. (2000) is 95,650 kg (Interrogatory CR R313-25-7(9)-89/3, DRC 2014c, Table 3). As the Tc-99 concentration is already borderline when compared to the GWPL at 500 years, the Hightower data cannot be dismissed.

The high level of uncertainty surrounding the quantities of contaminants in the DU waste was characterized by Energy*Solutions* in Appendix 4 to the Clive DU PA Model v 1.2 (Neptune 2014i). The authors noted on pages 2–3 that:

> *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 DUF_6 waste equal to those in the SRS DUO_3 waste, as shown in Table 2* [Summary of mean and standard deviations for SRS DUO_3 concentrations, assuming a normal distribution]. ***This is only a rough***

> ***approximation and will need to be revised as data from the GDP waste are provided*** [emphasis added].

The Energy*Solutions*/Neptune statement that this "is only a rough approximation" confirms the high level of uncertainty in the amount of Tc-99 (and other contaminants) present in the GDP recycled DU.

Another example of the uncertainty and, possibly, underestimation of the contaminants from recycled uranium involves the number of cylinders with contaminated heels. According to Energy*Solutions*/Neptune (Neptune 2014i, p. 25):

> *The cylinders at Portsmouth also need to be considered. The Depleted Uranium Management Information Network reports the numbers as 16,109 from the Portsmouth GDP, and 4,822 from the K-25 GDP, now moved to Portsmouth (DOE, 2010). These cylinders* ***are also considered unlikely to be contaminated*** *(personal communication, Tammy Stapleton, May 2011)* [emphasis added].

and:

> *Consequently, the fraction of Pre-1988 cylinders at Paducah that is assumed to be contaminated is about 9% [1,335 / (1,335 + 13,240)]. The Portsmouth cylinders might also* ***have a small fraction that are contaminated****. 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, May 2011)* [emphasis added].

In contrast to the assumption that there is little recycled uranium in the Portsmouth GDP (PORTS) [and Oak Ridge GDP (ORGDP)] cylinders, Hightower et al. 2000 note in Table C.6 the following regarding the heels in cylinders containing recycled uranium feeds:

Plant	**Tc-99 (kg)**
ORGDP (K-25)	21
PGDP	57
PORTS	17
Total	95

Based on this information, about 40 percent of the Tc-99 is in cylinders from Portsmouth and ORGDP. In fact, the highest concentration of Tc-99 in the cylinder heels is reported as 5,700,000 ppb for Portsmouth (Hightower et al. 2000, Table C.7).

The concentrations of radionuclides in the upper, unconfined aquifer will continue to build beyond the 500-year evaluation period established in the GWQ Permit. Figure 5-8 shows the change in concentration with time for selected radionuclides determined using the Energy*Solutions*' DU PA GoldSim Model. Note that, due to its mobility, the Tc-99 concentrations are substantially higher that for the other nuclides. The Tc-99 concentration at the hypothetical 90-foot well in the upper, unconfined aquifer increases from 740 pCi/L [27.4 becquerels per liter (Bq/L)] at 500 years to 150,600 pCi/L (5,573 Bq/L) at 3,500 years and then decreases to 61,780 pCi/L (2,286 Bq/L) at 10,000 years. The impacts of these post-500-year

higher Tc-99 (and other radionuclide) concentrations on the potential groundwater ingestion dose are discussed in the Section 4.2.2.

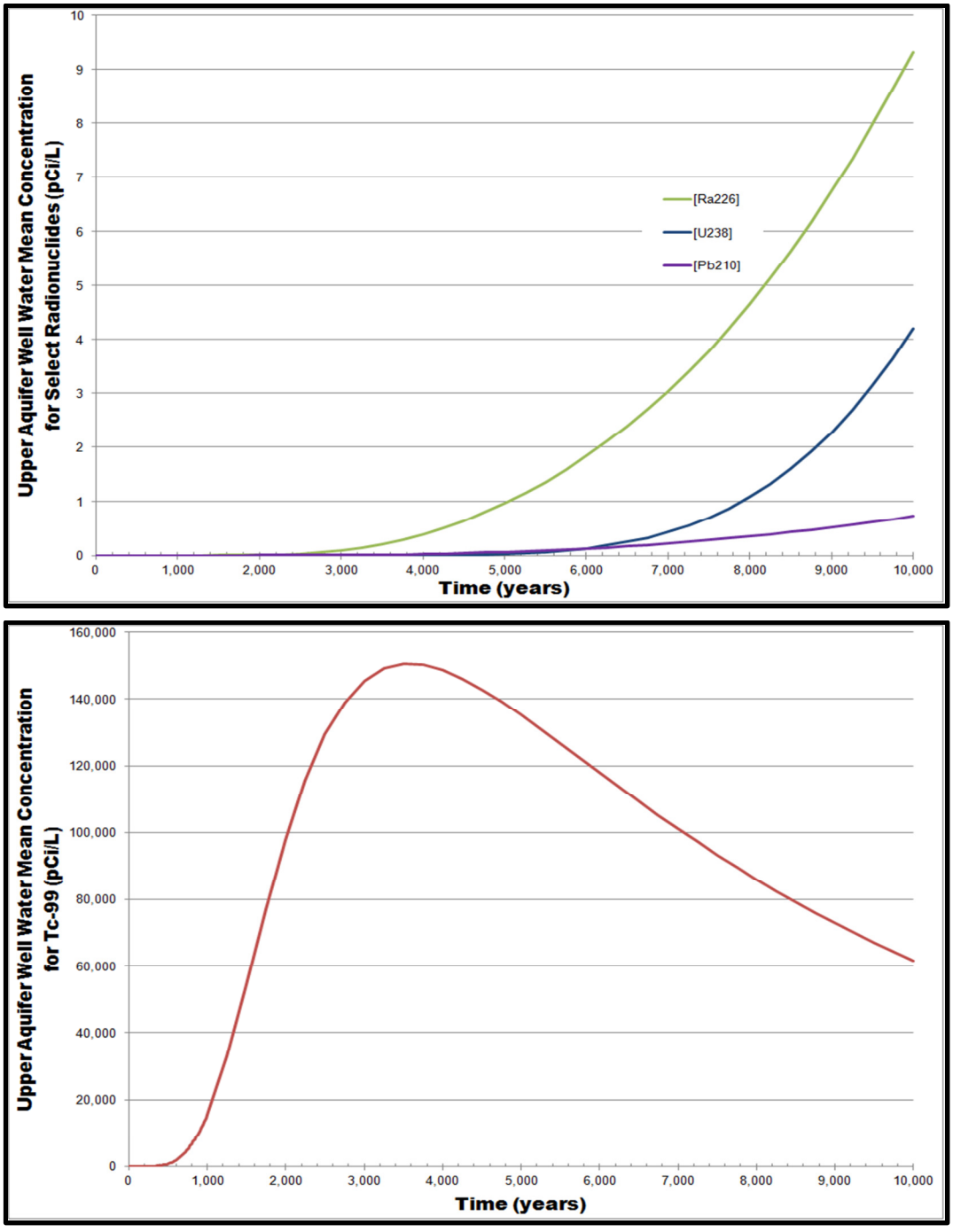

Figure 5-8 – Concentrations of selected radionuclides in upper, unconfined aquifer

Figure 5-9 shows the fraction of the GWPL for various radionuclides as a function of time (based on 1,000 iterations with GoldSim Model v1.2 as determined by DEQ). The fractions of GWPL values in Figure 5-9 are obtained by dividing the well concentrations for each radionuclide obtained from the GoldSim model v1.2 by the GWPLs from Table 5-10. For this simulation, all of the DU waste inventory was included. It can be seen that Tc-99, I-129, and Ra-226 exceed the GWPLs at the 90-foot shallow well at some point in time within the 10,000-year simulation period. This simulation is simply an extension of all inputs and assumptions used by Energy*Solutions* for its 500-year GWQ Permit evaluation period analysis.

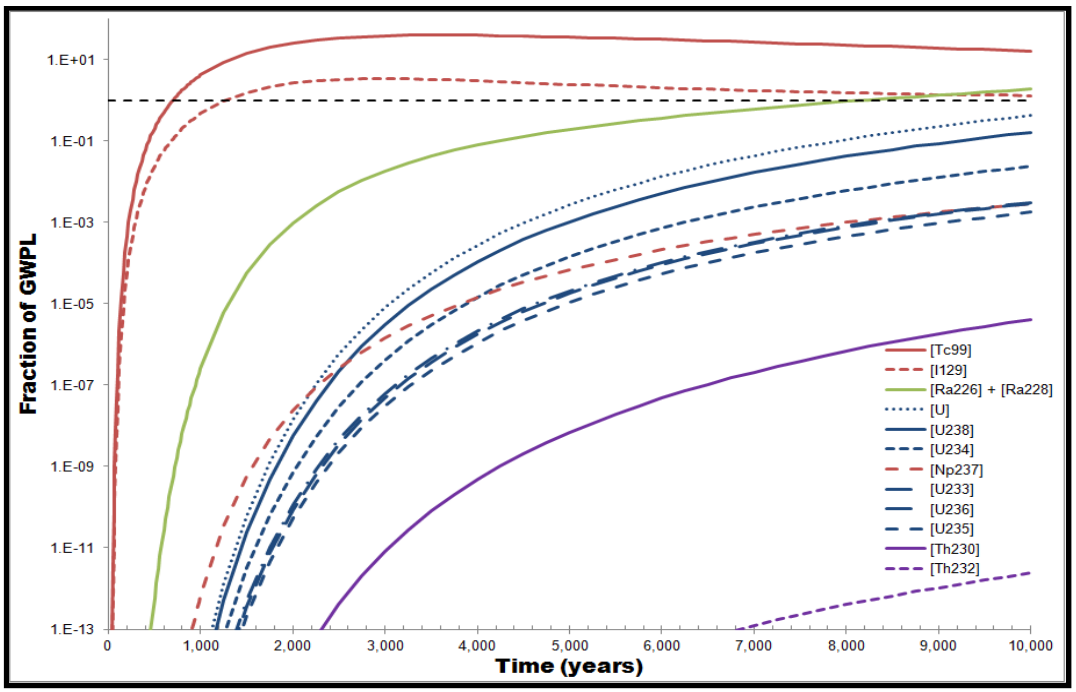

Figure 5-9 – DEQ-calculated fraction of GWPL for various radionuclides as a function of time based on all DU PA inventory at the 90-foot well (unconfined aquifer)

Even though Figure 5-9 shows that after the 500-year GWQ Permit evaluation period some of the GWPLs are exceeded, the groundwater ingestion analysis discussed in Section 4.2.2 indicated that the UAC Rule R313-25-20 groundwater pathway dose limit of 4 mrem/yr is not exceeded.

For the second case, DEQ assumed that only clean DU (no fission or activation products) was emplaced. The results are shown in Figure 5-10. At about 8,500 years, the Ra-226 + Ra-228 concentration exceeds the GWPL of 5 pCi/L, while at 10,000 years the Ra-226 + Ra-228 concentration is 21 pCi/L. Thus, the radium GWPL of 5 pCi/L in the upper, unconfined aquifer would be exceeded at the 90-foot buffer zone well, but not until long beyond the 500-year GWPL evaluation period. Based on the Energy*Solutions* Round 2 Response to Interrogatory CR R313-25-19-182/2: Groundwater Exposure Pathways (ES 2014a), the dilution factor [as calculated in Energy*Solutions* (2014e) using the Dupuit-Thiem equation] between the upper, unconfined aquifer and the lower, confined aquifer is 3.28E8-03, which would result in radium

concentrations in the lower aquifer being substantially below the GWPL. As described in the Energy*Solutions* Round 2 response to Interrogatory 182 (ES 2014a), the dilution factor for the upper aquifer contaminated water mixing with the lower aquifer "clean" water is the ratio of the downward leakage rate [4.37E+02 cubic meters per year (m^3/yr)] divided by the total rate of water produced from the deep aquifer well (1.33E+05 m^3/yr), or 4.37E+02 ÷ 1.33E+05 = 3.29E-03. The other radionuclides remain below their respective GWPLs in the upper aquifer for at least 10,000 years.

It is important to note that the GWPL results presented here are determined based on infiltration rates through the ET cover presented by Energy*Solutions* in the DU PA Model v1.2. If the infiltration results are understated because, for example, the values for the saturated hydraulic conductivities are too low, then the groundwater contaminant fractions presented in Figure 5-9 and Figure 5-10 would change. However, even if the infiltration rate were as high as 0.122 cm/yr for a rock armor cover (Neptune 2011c) as compared to the average infiltration rate of 0.042 cm/yr for the proposed Federal Cell ET cover (Neptune 2014k, Section 12.9), the three orders of magnitude dilution between the upper and lower aquifers would be more than adequate to compensate for a less-than-one order of magnitude increase in infiltration rate. As a result of the model's dependency on DU waste dilution in the deep aquifer, any revised license would contain a condition requiring characterization and installation of a confined aquifer monitoring well network. Ongoing compliance sampling, analysis, and reporting for key DU contaminants would also be required. These data will then serve as a baseline for determination of possible future contamination of the confined aquifer at Clive.

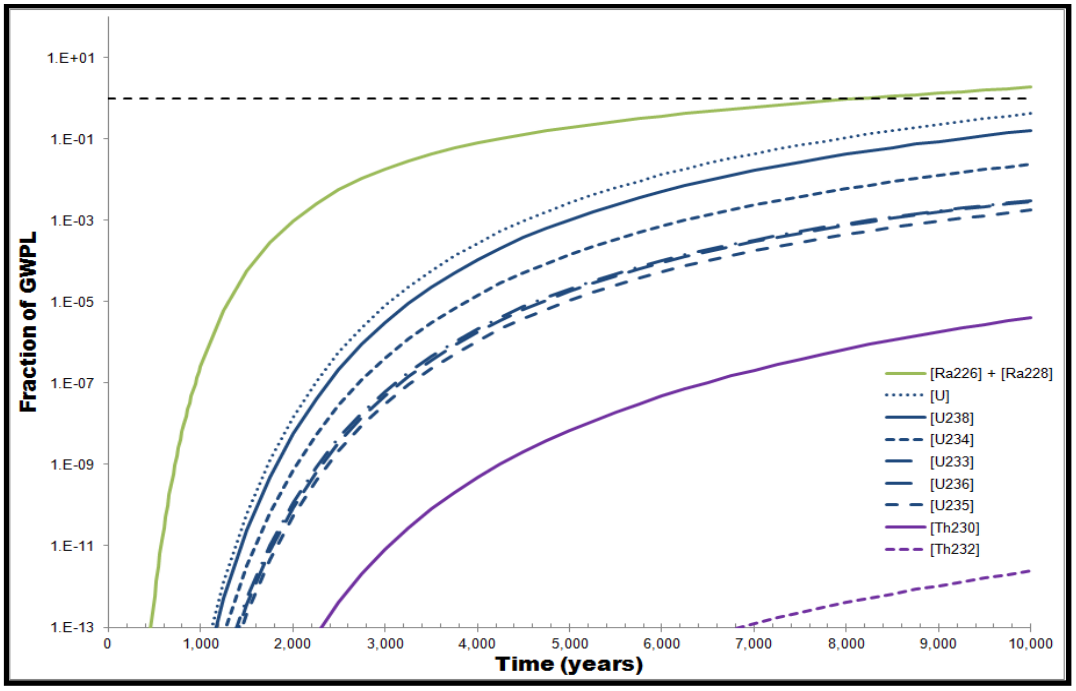

Figure 5-10 – DEQ-calculated fraction of GWPL for various radionuclides as a function of time based on inventory of clean DU waste only (fission products absent) at the 90-foot well (unconfined aquifer)

While the Ra-226 + 228 concentration will exceed the GWPL in the upper aquifer after about 8,000 years, the 500-year compliance point specified in Utah GWQ Permit No. UGW450005 is met, as discussed previously. In addition, the maximum ingestion dose within the first 10,000 years from Ra-226 is 2.32E-03 mrem/yr and from all radionuclides is 9.24E-02 mrem/yr. Clearly, these values are well below the exposure limit for members of the general public—4 mrem/yr TEDE from groundwater as specified in UAC R313-25-20.

Conclusion: Because there is significant uncertainty regarding the Tc-99 concentration in the DU_3O_8 to be produced from the GDP tailings, and because Tc-99 may exceed the GWPL at 500 years, issues related to this portion of the DU PA are resolved based on the condition that no DU waste containing recycled uranium be accepted for disposal in the Federal Cell at Clive. Based on this restriction, GWPLs for the 500-year evaluation period can easily be met regardless of uncertainties in the infiltration rate through the ET cover. This action will also minimize contamination in the lower confined aquifer over longer times. If the evaluation period for the GWPLs was extended to longer times, DEQ has determined that radium contamination level in the shallow aquifer would be exceeded after about 8,000 years into the future. However, because the yield from this aquifer is very low, it cannot be used as a source of drinking water. Nevertheless, an ongoing characterization program needs to be established to gain a better understanding of the spatial and temporal characteristics of the hydrogeologic system, particularly as related to the lower aquifer. This program would be defined by a condition for approval of any license amendment request.

References

DOE, 2010

DRC, 2014c

ES, 2014a; 2014b; 2014e

Hightower et al., 2000

Neptune, 2011c; 2014a; 2014i;2014k

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Based upon the evaluations presented in Sections 4 and 5 of this SER, DEQ makes the following conclusions regarding the approval of the Clive DU PA Model v1.2. Related UAC rules are provided in parentheses. All conclusions in the SER, including determinations that issues have been resolved, conditionally resolved, or not yet resolved,[24] are tentative in that they are subject to notice and comment and reconsideration by the agency in light of comments made and the record as a whole. A final approval would also be subject to the specific license conditions described in Section 6.2 below.

6.1.1 Resolved

Protection of the General Population from Releases of Radioactivity [UAC R313-25-20] – As discussed in Section 6.1.3, there remains much uncertainty regarding the performance of the ET cover to reduce infiltration into the embankment. Nonetheless, based on the DU PA and DEQ contractor calculations summarized in Section 4.2, DEQ concludes that the design of the proposed Federal Cell provides adequate protection of the general population from releases of radioactivity from disposed DU waste as required by UAC R313-25-20. This conclusion is contingent upon the belief that, although the infiltration rate may increase once all of the ET cover concerns have been resolved, it is unlikely that the increase will be significant enough to cause the doses reported in Section 4.2 to exceed the UAC R313-25-20 limits. However, should the resolution of the ET cover concerns result in an infiltration rate of 1 cm/yr, or greater, then this conclusion will need to be revisited. Furthermore, a characterization program needs to be established to gain a better understanding of the spatial and temporal characteristics of the hydrogeologic system, specifically the lower confined aquifer.

Protection of Individuals from Inadvertent Intrusion [UAC R313-25-21] – Based on the information provided by Energy*Solutions*, together with independent analyses performed by DEQ's contractor, DEQ concludes that sufficient information exists to indicate that the requirement of UAC R313-25-21 regarding 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 will be met.

Uranium Oral Toxicity [EPA 40 CFR 141.66] – Since both the calculated uranium hazard indices and the implied hazard indices for the acute or chronic driller intrusion scenarios are very small, DEQ considers this portion of the DU PA to be adequate with all issues resolved.

[24] "Resolved" means that a determination has been made that there is sufficient information to demonstrate that this requirement will be met. "Conditionally resolved" means that a determination has been made that there is sufficient information to demonstrate that this requirement will be met, provided that the applicable condition is also met. "Not resolved" means that a determination has been made that sufficient information has not yet been provided to DEQ to demonstrate that this requirement will be met. "Not resolvable" means that there is sufficient information to show that this condition cannot be met.

Uranium Solubility [UAC R313-25-7(3)(c); R313-25-8(2), and (3); R313-25-9(5)(a); and R313-25-19] – In the Clive DU PA Model, GoldSim samples solubilities from a statistical distribution that was developed based on thermodynamic models that assume that all uranium is in the form of UO_3 for the 10,000-year simulations. This is conservative, because the solubility of UO_3 is orders of magnitude higher than U_3O_8 solubility. Given the inability of GoldSim to simulate the dependency of uranium solubility on kinetics and thermodynamics, the stochastic approach that was taken in the DU PA is judged to be acceptable.

6.1.2 Conditionally Resolved

Compliance with Groundwater Protection Levels [UAC-R317-6-4] – Because there is significant uncertainty regarding the Tc-99 concentration in the DU_3O_8 to be produced from the GDP tailings, and because Tc-99 and other mobile isotopes may exceed the GWPL at 500 years, DEQ has determined that all issues related to this portion of the DU PA have been resolved with the condition that no DU waste containing recycled uranium be accepted for disposal inside the Federal Cell at Clive. Based on this restriction, GWPLs for the 500-year evaluation period can easily be met regardless of uncertainties in the infiltration rate through the ET cover. Nevertheless, a characterization program needs to be established to gain a better understanding of the spatial and temporal characteristics of the hydrogeologic system, particularly as related to the lower aquifer. This program would be defined by a condition for approval of any license amendment request.

Kind, Amount, Classification, and Specifications of the Material [UAC-R313-25-8(9)] – DEQ has determined that issues related to this portion of the DU PA are resolved based on the assumption that a new license condition regarding the Waste Acceptance Criteria will be added to any revised license. This resolution is further predicated upon adding another condition: that disposal of DU waste produced from UF_6 contaminated with the activation and fission products in recycled uranium not be permitted.

Waste Emplacement and Backfill [UAC R315-25-8(2), (3), (5), (6), and (10); R313-25-26(4), (5), and (10)] – Based on prior approvals, use of qualified procedures in the CQA/QC Manual, clarifications provided through interrogatories, and new license conditions to be imposed, DEQ believes that the requirements of UAC Rule R313-25-8 are satisfied with regard to waste emplacement and backfill. Therefore, DEQ has determined that all issues related to this portion of the performance assessment have been conditionally resolved.

6.1.3 Not Resolved

Evapotranspiration Cover [UAC R313-25-8(2) and (3)] – There are still a number of unresolved issues with respect to the selection of parameter ranges, distributions, and correlations, as well as the modeling approach and predicted sensitivities. These concerns are detailed in Appendix B. Further, because the model-predicted infiltration rates will be sensitive to the hydraulic properties assigned to each ET layer, DEQ recommends that Energy*Solutions* develop hydraulic properties for the cover system based on the approach outlined by Dr. Craig H. Benson in Appendix F to this SER. Issues related to this portion of the performance assessment cannot be closed until these concerns have been resolved.

Clay Liner [UAC R313-25-8(2)] – As with the ET cover, there is still an unresolved concern that K_{sat} values will increase greatly over time, and that the α and K_{sat} values assumed for modeling flow through the liner must either be correlated or a sensitivity analysis be conducted to demonstrate that the lack of correlation assumed does not adversely affect the modeling results. In addition, there are problems with assumed liner hydraulic conductivity values. Furthermore, the DU PA Model v1.2 does not account for liner degradation over time. These issues must be resolved before DEQ can determine the adequacy of this portion of the DU PA.

Deep Time Analysis [UAC Rule R313-25-9(5)(a)] – Since the revised DTSA provided by Energy*Solutions*/Neptune does not address most of the concerns raised by DEQ on the original DTSA (e.g., use of Unit 4 versus Unit 3 material properties, use of a large intermediate lake sedimentation rate), DEQ believes that there are still open questions related to ground surface radon fluxes reported in the revised DTSA (Neptune 2015a). Furthermore, recent calculations performed by DEQ/SC&A have shown that the ground surface radon fluxes after an Intermediate Lake recedes could be substantially above those presented in the Energy*Solutions*/Neptune revised DTSA (Neptune 2015a). Comparing the calculated post-Intermediate Lake inside radon concentration to national, state, and local radon concentrations shows the calculated concentration to be 102, 25, and 11 times larger, respectively, and it could be substantially larger if a different lake sedimentation rate distribution is determined to be appropriate. Therefore, based upon our current understanding of the uncertainties contained within the deep time analysis, DEQ/SC&A is unable to determine at this time that the DTSA portion of the DU PA Model v1.2 is satisfactory.

GoldSim Quality Assurance [UAC Rule R313-25-8(10)] –Specific instances where additional information and data are needed from Energy*Solutions* in order to allow DEQ to perform the necessary verification of Clive DU PA Model v1.2 have been identified in Appendix B and other sections of the SER (e.g., Section 4.4.1 for infiltration). Once all of those additional requests have been satisfactorily completed, DEQ will consider this concern to be resolved.

Infiltration [UAC R313-25-8(2)] – Before the adequacy of the DU PA can be determined, additional modeling of the ET cover infiltration rates must be conducted based on in-service hydraulic properties and correlated $\log(\alpha)$ and $\log(K_{sat})$ values as described in Appendix E. Without this information, DEQ is unable to conclude if the infiltration rates predicted by the DU GoldSim model are reliable or representative of future conditions (i.e., ≥ 10,000 years).

Erosion of Cover [UAC R313-25-25)] – Before the adequacy of the DU PA can be determined, Energy*Solutions* needs to clarify certain issues relating to Appendix 10 to the DU PA Model v1.2 (June 5, 2014; Neptune 2014h) as described in Section 4.4.2. DRC is currently reviewing a license amendment request to use an ET cover of similar design to that proposed for the Federal Cell in the DU PA. Any recommendations and conclusions from that review must be applied to the proposed Federal Cell as well.

Effect of Biologicals on Radionuclide Transport [UAC R313-25-24(3) and (4)] – Energy*Solutions* has not shown that the cover system is sufficiently thick or designed with adequate materials to protect the cover system or the underlying bulk waste in the embankments against deep rooting by indigenous greasewood (a species known to penetrate soils at other sites

down to 60 feet) or other plants, or against biointrusion by indigenous ants or mammals (e.g., with maximum documented burrowing depths greater than the proposed cover thickness). Higher rates of infiltration are typically associated with higher contaminant transport rates. Under Utah rules, infiltration should be minimized [see UAC Rule R313-25-25(3) and (4)]. DEQ cannot determine the adequacy of the DU PA until Energy*Solutions* accounts for greater infiltration through the cover system at the proposed Federal Cell embankment due to biointrusion by plant roots and by animals.

Frost Damage [UAC R313-25-25(3) and (4)] – DEQ's position is that the empirical data collected at the Cover Test Cell during the testing conducted in January 2002 and January 2004 should, along with modeling using much greater identified and justified return intervals, form the primary basis for testing models designed for estimating frost depths.

Although the empirical data for the Cover Test Cell can be used to determine the most applicable equations (i.e., model) for estimating frost penetration depths under general site conditions, it cannot be used directly to estimate frost depth in the proposed DU embankment cover system. This is because the proposed DU embankment cover system will consist of different materials, with different thermal properties, than the Cover Test Cell cover system materials (e.g., with two feet of rock armor cover). A demonstration that the modeled frost depth predictions are reasonably close to the frost depths measured at the Cover Test Cell provides a means of verifying the predictive capabilities of the model. However, the model will have to account for much greater return intervals for extreme low temperature and deep frost penetration. If the model yields a good match to the empirical data, it may be used to estimate the frost penetration depth of the materials used for the DU embankment cover system, along with a return period for extreme cold of at least 1,000 years, assuming that the model can simulate the particular cover materials.

With the current proposed Federal Cell design, Energy*Solutions* should account in modeling for substantial disruption of near-surface layers above and within the radon barriers by frost, with accompanying decreases in ET and increases for initially low-permeability soil in both hydraulic conductivity and correlated α values, which could affect modeled infiltration rates and radon release rates. UAC R313-25-25(3) and (4) require a licensee to minimize infiltration; therefore, Energy*Solutions* must model infiltration under realistic long-term assumed site conditions.

6.1.4 Not Resolvable

As a result of DEQ evaluations, there are no topics in the Energy*Solutions* DU PA that cannot be resolved because of affirmative information that standards cannot be met.

6.2 ADDITIONAL CONDITIONS FOR APPROVAL

In the event the DU PA is approved, the following additional conditions will apply to any amended license.

6.2.1 Condition 1: Agreement with DOE.

Energy*Solutions* shall provide a written agreement letter between DOE and Energy*Solutions* that:

a) Includes Energy*Solutions*' agreement to convey and DOE's agreement to accept, after decommissioning, ownership of that portion of Energy*Solutions*' facility on which concentrated DU has been land disposed;

b) Is enforceable by DEQ even if Energy*Solutions* no longer exists; and

c) Has been approved by the Governor of the State of Utah.

In addition, at closure of the Federal Cell, a separate fund must be created (statutorily), so that DOE has access to the funds needed during the post-closure period.

In case of approval to dispose of large quantities of concentrated, DU at Clive, Utah and DOE will establish an annual review process to assure that technical and financial assurance is acceptable to DOE.

Basis for Condition:

R313-25-28(1) states:

> *Land Ownership. Disposal of waste received from other persons may be permitted only on land owned in fee by the Federal or a State government.*

Although this provision has been waived for other disposal at Energy*Solutions*, it is appropriate to condition disposal of DU on DOE's firm agreement to take title to the area of disposal because of DOE's legal responsibility for the waste, and because establishing long-term control of and responsibility for the land is critical for disposal of DU. This is of particular importance because significant quantities of very long-lived radionuclides, including DU daughter products, will remain in the waste.

6.2.2 Condition 2: Disposal below grade.

All DU waste must be disposed of below the original-grade level of the proposed Federal Cell (i.e., 4,272 ft-amsl).

Basis for Condition:

As discussed in Section 5.1, below-grade disposal is required to minimize release of radioactivity should a pluvial lake invade the site of the proposed Federal Cell at some time in the future.

6.2.3 Condition 3: Depleted uranium will continue to be Class A waste.

Energy*Solutions* shall provide, for approval by the Director, a written statement from the NRC that the Commission will not be addressing reclassification of DU.

Basis for Condition:

The Utah Legislature has made a policy choice with UCA 19-3-103.7 not to allow land disposal facilities in the state to accept waste for disposal that is greater than Class A under NRC

classification regulation 10 CFR 61.55, "Waste Classification." The NRC has, in recent years, indicated that it is considering changing the waste classification for DU. See, e.g., SRM-SECY-08-0147, dated March 18, 2009 (NRC 2009). In considering conditional approval of the disposal of DU, the State of Utah is relying on the appropriateness of the NRC's classification of DU. With this condition, DRC is seeking to ensure that the NRC will, before this approval is effective, complete its internal review and conclude that DU will continue to be considered a Class A waste.

6.2.4 Condition 4: Remainder of waste will be modeled.

To meet the requirements of UAC R313-25-9(5)(a), Energy*Solutions* shall submit a revised performance assessment that meets the requirements of that provision and addresses the total quantities of concentrated DU and other radioactive wastes the facility now proposes to dispose in the Federal Cell. This revised performance assessment shall be subject to notice and comment and must be approved by the Director prior to the land disposal of other radioactive waste.

Basis for Condition:

UAC R313-25-9(5)(a) requires analysis of "*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*." This requirement will be met through this condition.

6.2.5 Condition 5: Waste Acceptance Criteria.

Prior to any land disposal of significant quantities of DU, the Licensee shall submit for Director approval a written Waste Acceptance Criteria plan. The purpose and performance objective of this plan is to ensure that all DU waste containers and shipments received by the Licensee are equivalent to and in conformance with all physical, chemical, and radiologic properties assumed in the Director-approved DU PA modeling report.

Basis for Condition:

The results of the DU PA are driven, in part, by the assumed properties of the waste. The Licensee must provide assurance through a Waste Acceptance Criteria plan that the properties of the delivered waste fall within the range of properties assumed in the DU PA.

6.2.6 Condition 6: Prohibition of recycled uranium in DU waste.

The Licensee is prohibited from land disposal of any quantity of DU waste that was produced at DOE facilities from uranium-bearing materials containing recycled uranium.

Basis for Condition:

Activation and fission product contamination in recycled uranium may result in excessive groundwater contamination. As discussed in Section 5.3, mobile radionuclides such as Tc-99 are particularly troublesome and could present problems in meeting prescribed GWPLs.

6.2.7 Condition 7: Hydrological and hydrogeological properties of lower confined aquifer.

The Licensee shall develop and implement a program to provide more detailed hydrogeologic knowledge of the shallow unconfined aquifer and deeper confined aquifer. In particular, a better understanding is required to characterize the current conditions and to predict the vulnerability to groundwater resources into the future. Specific types of information include: groundwater flow velocities, aquifer transmissivities, water quality, sorption properties, and the degree of hydraulic interconnection between the upper and lower aquifers.

Basis for Condition:

The possibility exists that contaminated groundwater could flow from the upper aquifer to the lower aquifer, resulting in exposure to inadvertent intruders or members of the public who use the lower aquifer groundwater for beneficial purposes (see Sections 4.2.2 and 4.3). Only limited information is currently available in this area.

6.3 RECOMMENDATIONS

At this time, DEQ has not made a final recommendation. A final recommendation will be made after all public comments have been considered.

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