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FEP Analysis for Disposal of Depleted Uranium at the Clive Facility

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Prepared by
NEPTUNE AND COMPANY, INC.
1505 15th St, Suite B, Los Alamos, NM 87544

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	Name	Date
4. Originator	Jenifer Linville	28 May 2011
5. Reviewer	John Tauxe	28 May 2014
6. Remarks		

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1.0 Introduction

The safe storage and disposal of depleted uranium (DU) waste is essential for mitigating releases of radioactive materials and reducing exposures to humans and the environment. Currently, a radioactive waste facility located in Clive, Utah (the "Clive facility") operated by Energy*Solutions* is proposed to receive and store DU waste that has been declared surplus from radiological facilities across the nation. The Clive facility has been tasked with disposing of the DU waste in an economically feasible manner that protects humans from radiological releases.

To assess whether that the proposed Clive facility DU disposal location and containment technologies are suitable for protection of human health, specific performance objectives for land disposal of radioactive waste set forth in Title 10 Code of Federal Regulations Part 61 (10 CFR 61) Subpart C, promulgated by the U.S. Nuclear Regulatory Commission (NRC), must be met. In order to support the required radiological performance assessment (PA), a detailed computer model is being developed to evaluate the potential detrimental effects on human health that would result from the disposal of DU and its associated radioactive contaminants.

A key activity in developing a PA for a radiological waste repository is the comprehensive identification of relevant external factors that should be included in quantitative analyses. These factors, termed "features, events, and processes" (FEPs), form the basis for scenarios that are evaluated to assess site performance.

Although it is not a governing regulation for the disposal of LLW and DU at Clive, Title 40 CFR Part 191, promulgated by the U.S. Environmental Protection Agency (EPA), provides a useful and general definition for the scope of a PA analysis of a radiological disposal facility. The PA 1) identifies the processes and events that might affect the disposal system, 2) examines the effects of these processes and events on the performance of the disposal system, and 3) estimates the cumulative releases of radionuclides considering the associated uncertainties caused by all significant processes and events (40 CFR 191). The identification of FEPs is essential to the development of the conceptual site model (CSM) and model scenario development process (see *Conceptual Site Model* ~~for Disposal of Depleted Uranium at the Clive Facility~~white paper).

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This report serves to document and examine the universe of FEPs that may apply to the disposal of depleted uranium (DU) waste at the Clive Facility. FEPs that are screened and identified as relevant for the Clive facility PA are identified in this white paper and are further elaborated in the CSM ~~document~~white paper.

This document is considered to be a living document that is synchronized with current conceptual models, analysis, and modeling of the PA. As concepts and modeling evolve, so too will this document.

2.0 Identification of Features, Events, and Processes

The identification of FEPs for use in the Clive ~~facility PA~~ DU PA Model was an iterative process that began with compiling an exhaustive list of candidate FEPs that could affect the long-term performance of the radiological waste repository. As an initial step, all potentially relevant FEPs from a variety of reference sources were collected. The initial list from external sources was modified as additional FEPs were identified that are specific to the Clive facility.

This exhaustive initial compilation of FEPs led to significant redundancy across the original sources. Redundancy was addressed by the modification of the candidate list of FEPs through normalization (removal of redundant FEPs) and assignment of FEPs categories (grouping of common FEPs). This section describes the FEP identification process, including implementation of the normalization, categorization and screening processes.

2.1 Compilation of FEPs

The initial list of FEPs pertaining to the efficacy of disposal of radioactive wastes in general was compiled from several scenario development documents published for other nuclear waste disposal facilities, including those for Yucca Mountain Project, the Waste Isolation Pilot Plant, and several foreign radioactive waste projects. The primary literature source for FEP analysis is Guzowski and Newman (1993). They compiled over 700 potentially disruptive FEPs from a review of scenario documentation from other waste repositories around the world.

The facilities considered in Guzowski and Newman have substantially different geological, environmental and regulatory settings from those of the Clive facility. Consequently, the collection of FEPs in Guzowski and Newman provides a substantial list that should be considered for any PA, but they are also missing FEPs that pertain more particularly to the waste disposal facility at Clive. Site-specific understanding of the environmental and engineered attributes of the Clive facility, and the potentially affected region and population, was used to augment the initial compilation of FEPs.

Additional FEPs were also identified from the Nuclear Energy Agency database (NEA, 2000). In this initial compilation step, nearly 1,000 FEPs were identified from the literature and site-specific considerations. Initial FEPs compiled from all sources are listed in Table 1 in the Appendix.

2.2 Normalization and Consolidation of FEPs

Subsequent to the initial compilation of FEPs, steps were taken to reduce redundancy. Initially, FEPs were sorted alphabetically and duplicates were deleted. Recorded FEP values that were different only in vernacular/diction (e.g., “climate change” versus “change in climate”) were normalized to capture a single primary FEP value for a series of identical or closely-related concepts.

To address duplication of FEPs where similar terminology was stated dissimilarly, initial FEPs were grouped by keyword content (e.g., “climate,” “waste,” “groundwater,” etc.) and evaluated for possible normalization or consolidation. Where possible, FEPs were normalized to a standard terminology.

Similar but not identical FEPs were maintained, to be evaluated as part of the consolidation step. At this point, each FEP was considered for its similarity to other FEPs, so that they could be grouped into fewer classes, making the list more manageable. For example, all geochemical processes were grouped together. These would be easier to address as a group for inclusion in the CSM. Likewise, all coastal processes could be considered for exclusion as a group. For each FEP, the rationale behind its grouping was noted. No FEPs were excluded at this step, but nearly all were consolidated with others. This consolidation process reduced the total number to 135 unique FEP groupings.

3.0 Classifying Features, Events, and Processes

Following the normalization and consolidation steps, the 135 unique FEP groups were carried forward to the classification step and were considered for inclusion in the conceptual model scenarios. The classification is principally an organizational tool for the FEP analysis, although the categories identified also relate to components of the CSM. The 135 unique FEP groups were classified into the following 18 categories:

- Celestial
- Climate change
- Containerization
- Contaminant Migration
- Engineered Features
- Exposure
- Hydrology
- Geochemical
- Geological
- Human Processes
- Hydrogeological
- Marine
- Meteorology
- Model Settings
- Other Natural Processes
- Source Release
- Tectonic/Seismic/Volcanic
- Waste

These categories are relevant to the development of scenarios and are integral to the CSM for the Clive Facility. Occasionally, a FEP could have been classified into more than one category. However, the overall goal of the FEP analysis is to identify those processes that should be carried forward into the CSM, and subsequently into the modeling. Provided each FEP is identified in one of the categories, it was carried forward to the CSM. Ultimately, each FEP was given due consideration, and the implementation of relevant FEPs in the final modeling was rather independent of the classification.

4.0 Screening of FEPs

The long list of FEPs was screened in consideration of regulatory concern and professional judgment based on physical reasonableness, probability of occurrence, severity of consequence, and assessment scope.

The most basic screening criterion is regulatory concern. Regulatory requirements for performance of EnergySolutions' Clive facility are published in 10 CFR 61 and Utah Administrative Code R313. While the mention of something that can be construed as a feature, event, or process in the text of a regulation triggers its consideration in this FEP analysis, it does not mean that the FEP must become part of the PA analysis or modeling.

A subjective element of the FEP screening process is consideration of assessment scope and physical reasonableness. Physical reasonableness is a professional judgment based on logical arguments using available data and information to support a conclusion of whether or not conditions can exist within the period of regulatory concern that will result in the occurrence of a particular event or process that affects disposal system performance. In addition to meeting screening criteria, some FEPs were retained as model parameters specifically because they pertain to scenario development itself (e.g., exposure terms).

The inclusion or dismissal of FEPs and associated rationale is documented in support of constructing the conceptual model and scenarios. The product of this screening procedure is the identification of those FEPs that, either alone or in conjunction with others, could affect the performance of the disposal system.

4.1 Regulatory Considerations, Guidance, and Supporting Information

This section discusses the regulatory language, guidance, and other supporting information to be considered in developing scenarios and conceptual models for the Clive ~~Facility PA~~DU PA Model. Specific considerations of NRC's land disposal performance requirements (10 CFR 61 Subpart C) are required for the ~~PA~~ scenario development and are important to document as part of the FEP compilation and screening activity. In addition, observations and recommendations previously published by radioactive waste disposal facility working groups and technical advisers are also considered, although most of these are focused on geologic disposal of radioactive wastes.

Specific provisions of regulations for the operation and closure of a land-disposal LLW facility were specifically considered if they were mentioned in a regulatory document.

Based on these provisions, 55 of 135 FEPs were identified as relevant for evaluation in the conceptual model or exposure scenarios. The remaining FEPs were dismissed from further consideration for various reasons. Some, like a direct impact from a large meteorite, are simply beyond the scope of the ~~PA~~ analysis. Tsunami and other marine phenomena obviously do not apply at the Clive facility. Several FEPs from the original sources were dismissed because they apply only to geologic repositories, or to specific types of containment, like copper canisters for used nuclear fuel.

4.1.1 Nuclear Regulatory Commission: 10 CFR 61

This regulation contains Federal procedural requirements and performance objectives applicable to land disposal of radioactive waste. Specific considerations of 10 CFR 61 include attributes of facility siting, facility engineering (including post-closure stability and control), site monitoring, record-keeping, protection of health and safety, and a minimum time frame for which an assessment must be conducted to ensure long-term stability of the disposal site. The types of ~~FEPs~~ objectives mentioned in 10 CFR 61 include:

- long-term effectiveness based on physical siting of the disposal unit (including site geology and hydrology),
- protection of the general population (in terms of radiological dose),
- protection of inadvertent intruders (dose),
- protection of individuals during operations (dose),
- isolation and segregation of wastes,
- limitation of releases of radionuclides via pathways in air, water, surface water, plant uptake, or exhumation by burrowing animals~~releases of radionuclides via pathways in air, water, surface water, plant uptake, or exhumation by burrowing animals~~,
- long-term stability of the disposal site,
- evaluation of engineering failures, including erosion, mass wasting, slope failure, settlement of wastes and backfill, infiltration through covers, and surface drainage,
- site monitoring requirements,
- identification of natural resources whose exploitation could result in inadvertent exposure, and
- efficacy of institutional controls.

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4.1.2 Utah Administrative Code R313: Radiation Control

The Utah Administrative Code (UAC) Rules 313-15 (*Standards for Protection Against Radiation*) and 313-25 (*License Requirements for Land Disposal of Radioactive Waste*) mirror the provisions for land disposal of radioactive waste provided in 10 CFR 61. Notable performance objectives of near-surface disposal sites established of UAC Rule R313-25 include~~Notable technical performance objectives of near-surface disposal sites established of UAC Rule R313-25 include~~:

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- protection of the general population,
- protection of inadvertent intruders,

- consideration of releases of radionuclides through pathways via air, water, surface water, plant update, and exhumation of burrowing animals,
- protection of individuals during operations,
- long-term stability of the disposal site,
- prevention of erosion, mass wasting, slope failure, settlement of wastes and backfill, infiltration through covers, and surface drainage,
- site monitoring requirements, and
- identification of natural resources whose exploitation could result in inadvertent exposure.

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The majority of the FEPs identified as relevant under 10 CFR 61 are also applicable under UAC Rule R313-25 and are retained for analysis.

4.1.3 Additional Guidance

The NRC's PA working group has identified additional considerations in NRC's *Performance Assessment Methodology* (NRC 2000). The working group identifies two specific areas of interest in conducting a PA: pathway analysis and dose assessment.

Pathway analysis involves the mechanisms of radionuclide transfer through the biosphere to humans. These mechanisms, or transport and exposure pathways, must be identified and modeled. Pathway analysis should result in the determination of the total intake of radionuclides by the average member of the critical group. The critical group is defined as the "...group of individuals reasonably expected to receive the greatest dose from radioactive releases from the disposal facility over time, given the circumstances under which the analysis would be carried out" (NRC 2000).

Various considerations should be taken into account when analyzing the transport of radionuclides through the biosphere (to humans). These considerations should include

- modeling the movement of radionuclides through the environment and the food chain, adequately reflecting complex symbiotic systems and relationships,
- considering mechanisms of (biotic and) human uptake of radionuclides, and
- identifying usage, production, and consumption parameters, for various food products and related systems, that may vary widely, depending on regional climate conditions, local or ethnic diet, and habits.

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The dose assessment requires that the dosimetry of the exposed individual be modeled. The objective of dose modeling in a LLW PA is to provide estimates of potential doses to humans, in terms of the average member of the critical group, from radioactive releases from a LLW disposal facility, after closure.

A "current conditions" philosophy is initially applied to determine which pathways are to be evaluated. That is to say that current regional land use and other local conditions in place at the time of the analysis will strongly influence pathways that are considered to be significant. The conceptual model and scenarios must consider each of the general pathways discussed in 10 CFR 61.13. Additional pathways for consideration are published in NUREG/CR-5453 (Shipers, 1989) and NUREG-1200 (NRC, 1994). NUREG-1200 discusses example potential "scenarios by which radioactivity may be released from the disposal facility and cause the potential for radiological impacts on individuals." Shipers (1989) identifies exposure pathways, and scenarios regarding transport mechanisms that could contribute to the release of radioactive materials from the disposal facility leading to human exposure, in the context of near-surface LLW disposal.

4.2 Scope of Assessment and Physical Reasonableness

The final phase of FEP screening is the application of professional judgment in terms of the scope of the PA and the physical reasonableness of evaluating those FEPs in the CSM and scenarios. Performance objectives include protection of the general population from releases of radioactivity (10 CFR 61.41), protection of individuals from inadvertent intrusion (§61.42), and stability of the site after closure (§61.44). Assumptions of the scope of the PA include:

- Performance assessment reflects post-closure conditions. Because PA considers the site only after closure, consideration of the protection of individuals during operations (§61.43) is not within the scope of the evaluation and FEPs related to operations are not considered relevant to the CSM or scenarios.
- Land-use assumptions relative to human exposures post-closure are based on current conditions and likely future conditions. Therefore urban settlement, residential use, farming, and aquaculture and FEPs pertaining to these incongruous uses are not included in the CSM or scenarios because of the high concentrations of salt in the soil and groundwater of this site. However, hunting, ranching, and recreational use are considered viable scenarios.
- Intentional human intruders are not protected.

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5.0 Screening Results

Using the identification and screening processes described in Sections 1 through 3, FEPs consolidated from an exhaustive list of over 900 to 135 FEPs or FEP categories. consolidation, 90 FEPs are retained for further consideration and 45 FEPs were inclusion in the PA model. All FEPs considered and retained for inclusion in the scenarios are reported in

Table 2~~Table 2~~ in the Appendix. FEPs that were considered and dismissed from evaluation in the CSM and scenarios are listed in Table 3, along with a brief rationale for their exclusion.

In summary, FEPs retained for consideration in the PA, CSM, and scenarios pertain to regulatory aspects of post-closure protection of human health and long-term stability of the disposal facility for the duration and spatial scope of the assessment period. FEPs that were dismissed from consideration in the PA include those that do not fall within the scope of the PA, were characterized as extremely unlikely to occur or having a low magnitude of consequence of affecting the performance of the repository, or were dismissed based on site-specific considerations.

6.0 Use of FEPs for Conceptual Model and Scenario Development

The CSM provides detailed descriptions of the physical environment, the engineered disposal facility, the sources and chemical forms of disposed wastes, potentially affected media, potential release pathways and exposure routes, and potential receptors. The CSM considers broad categories of FEPs that are relevant to these attributes, but individual FEPs may or may not be addressed in the CSM based on the scope of the assessment and the scenarios developed. This section identifies the FEPs that are considered for inclusion in the CSM and are addressed in the development of scenarios for the PA model. These are grouped into several categories, and listed in tabulated form in Appendix B. Those FEPs that were dismissed from consideration in the modeling are listed in Appendix C. Some FEPs may overlap or repeat between categories.

Meteorology

Frost weathering and other meteorological events (e.g., precipitation, atmospheric dispersion, resuspension) are considered in the conceptual model. Weathering may occur from frost cycles. Resuspension of particulates from surface soils allows them to be redistributed by atmospheric dispersion, which is a meteorological phenomenon. Dust devils are also possible at the site and a tornado occurred in Salt Lake City in 1999, which was the first tornado in Utah in over 100 years.

Climate change

Features, events, and processes of climate change considered in the conceptual model include effects on hydrology (including lake effects), hydrogeology, biota, and human behaviors. Lake effects include appearance/disappearance of large lakes and associated phenomena (sedimentation, wave action, erosion/inundation). Wave action, including seiches, is included in the CSM.

Hydrology

Hydrology is addressed in the conceptual model since it influences many processes in contaminant transport. Examples of FEPs considered for the conceptual model include groundwater transport, inundation, and water table changes.

Hydrogeological

Several hydrogeological FEPs were identified for consideration in the conceptual model. Groundwater transport, in both the unsaturated and saturated zones, is potentially a significant transport pathway. For some model endpoints, such as groundwater concentrations that are compared to groundwater protection levels (GWPLs), it is the only pathway of concern.

Groundwater flow and transport processes include advection-dispersion, diffusion, fluid migration, waterborne contaminant transport, changes in the flow system, recharge, water table movements, and brine interactions. Inundation of the site may occur due to changes in lakes or reservoirs, which is included in lake effects of climate change.

Geochemical

Geochemical effects include chemical sorption and partitioning between phases, aqueous solubility, precipitation, chemical stability, complexation, changes in water chemistry (redox potential, pH, Eh), fluid interactions, speciation, interactions with clays and other host materials, and leaching of radionuclides from the waste form. These processes are addressed in the model.

Other Natural Processes

The broad category of other natural processes considered for the conceptual model include ecological changes and pedogenesis (soil formation). Ecological changes are associated with catastrophic events (e.g., inundation), evolution, or climate change. Pedogenesis is expected on the cap, giving rise to vegetation growth or habitation by wildlife.

Denudation (cap erosion) may be sufficient to expose waste. Erosion of the repository resulting from pluvial, fluvial or aeolian processes can result from extreme precipitation, changes in surface water channels, and weathering. Sediment transport is an inherent aspect of erosion. Sedimentation/deposition onto the repository would also affect disposal at the site.

Note that seismic activity is unlikely to impact the Clive facility. Faults are not present within the vicinity of Clive, although effects of isostatic rebound are still possible in the Lake Bonneville area.

Engineered Features

Engineered features are intended to promote containment and inhibit migration of contaminants. Conditions potentially affecting site performance include failure of general engineered features, repository design, repository seals, material properties, and subsidence of the repository.

Containerization

Two key components of containerization were identified as FEPs: containment degradation and corrosion. Canister degradation, including fractures, fissures, and corrosion (pitting, rusting) could result in containment failure. These processes are evaluated in the conceptual model (*Conceptual Site Model* ~~W~~white ~~P~~paper, Section 8.1).~~.~~

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Waste

Attributes of waste that could influence the performance of the Clive facility include the inventory of radionuclides, physical and chemical waste forms, container performance, matrix performance, leaching, radon emanation, and other waste release mechanisms.

Source Release

Source release can result from many mechanisms, including containment failure, leaching, radon emanation, plant uptake, and translocation by burrowing animals. FEPs that fit in the category of source release include gas generation, radioactive decay and in-growth, and radon emanation.

Contaminant Migration

Contaminant migration for the CSM includes the mechanisms and processes by which radionuclides may come to be located outside of the containment unit. The following contaminant migration processes were identified for consideration in the conceptual model: resuspension, atmospheric dispersion, biotically-induced transport, contaminant transport, diffusion, dilution, advection-dispersion, dissolution, dust devils, tornados, infiltration, and preferential pathways.

Animal ingestion is part of the human exposure model, both as ingestion of fodder and feed by livestock, and ingestion of livestock by humans. Transport by atmospheric dispersion is modeled and is associated with limited resuspension, dust devils, and tornados. Modeling of biotic (plant- and animal-mediated) processes leading to contaminant transport, and the evolution of these processes in response to climate change and other influences, including bioturbation, burrowing, root development, and contaminant uptake and translocation are considered. Contaminant transport includes transport media (water, air, soil), transport processes (advection-dispersion, diffusion, plant uptake, soil translocation), and partitioning between phases. Diffusion occurs in gas and water phases. Dilution occurs when mixing with less concentrated water. Hydrodynamic dispersion is associated with water advection. Dissolution in water is limited by aqueous solubility. Transport in the gas phase includes gas generation in the waste, partitioning between air and water phases, diffusion in air and water, and radioactive decay and ingrowth. Infiltration of water through the cap, into wastes, and potentially to the groundwater is another contaminant migration concern. Preferential pathways for contaminant transport are also addressed.

Human Processes

The FEPs identified as human processes encompass human behaviors and activities, resource use, and unintentional intrusion into the repository. Human process FEPs identified for assessment are related to the human exposure model and include anthropogenic climate change, human behavior, human-induced processes related to engineered features at the site, human-induced transport, inadvertent human intrusion, institutional control, land use, post-closure subsurface activities, waste recovery, water resource management, and weapons training such as that occurring at nearby bombing ranges.

Exposure

Exposure is an integral part of the conceptual model, and may result from reduced site performance. Exposure-relevant FEPs identified for evaluation include those related to dosimetry, exposure media, human exposure, ingestion pathways, and inhalation pathways. Dosimetry as a science is not a FEP *per se* but physiological dose response is accounted for in the PA model.

Transport pathways (e.g. food chains) that lead to foodstuff contamination, and human exposures due to inhalation of gaseous radionuclides and particulates are included. Exposure media include are foodstuffs, drinking water, and environmental media. Exposure pathways (ingestion, inhalation, etc.) and physiological effects from radionuclides and toxic contaminants (e.g. uranium) are also assessed.

Model Settings

Model settings that were identified during the FEP compilation process include model parameterization, period of performance, regulatory requirements, and spatial domain. While these are not FEPs in and of themselves, they are important considerations in the performance assessment model and are included with the FEPs for completeness.

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Appendix: FEP Listings

This appendix lists the features, events, and processes (FEPs) identified for evaluation in Conceptual Site Model and Performance Assessment Scenario development. Table 1 contains all initial FEP values, listed and numbered by reference document.

Table 2~~Table 2~~ lists those FEPs retained for analysis, and Table 3 includes all those FEPs that were dismissed from further consideration.

Table 1. List of Initial FEPs by Reference

Table 1 (continued)

FEP ID	Initial FEP	Reference[1]
1	meteorite	Andersson et al., 1989
2	change in sea level	Andersson et al., 1989
3	desert and unsaturation	Andersson et al., 1989
4	no ice age	Andersson et al., 1989
5	glaciation	Andersson et al., 1989
6	permafrost	Andersson et al., 1989
7	creeping of copper	Andersson et al., 1989
8	common cause canister defects - Quality control	Andersson et al., 1989
9	cracking along welds	Andersson et al., 1989
10	degradation of hole- and shaft seals	Andersson et al., 1989
11	electro-chemical cracking	Andersson et al., 1989
12	internal pressure	Andersson et al., 1989
13	radiation effects on canister	Andersson et al., 1989
14	random canister defects - Quality control	Andersson et al., 1989
15	reactions with cement pore water	Andersson et al., 1989
16	role of chlorides in copper corrosion	Andersson et al., 1989
17	thermal cracking	Andersson et al., 1989
18	corrosive agents, sulphides, oxygen etc	Andersson et al., 1989
19	pitting	Andersson et al., 1989
20	stress corrosion cracking	Andersson et al., 1989
21	accumulation in peat	Andersson et al., 1989
22	colloid generation and transport	Andersson et al., 1989
23	colloid generation - source	Andersson et al., 1989
24	colloids, complexing agents	Andersson et al., 1989
25	accumulation in sediments	Andersson et al., 1989
26	loss of ductility	Andersson et al., 1989
27	matrix diffusion	Andersson et al., 1989

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Table 1 (continued)

FEP ID	Initial FEP	Reference[1]
28	saturation of sorption sites	Andersson et al., 1989
29	solubility and precipitation	Andersson et al., 1989
30	sorption	Andersson et al., 1989
31	extreme channel flow of oxidants and nuclides	Andersson et al., 1989
32	radiation effects on bentonite	Andersson et al., 1989
33	solubility within fuel matrix	Andersson et al., 1989
34	thermal buoyancy	Andersson et al., 1989
35	thermochemical changes	Andersson et al., 1989
36	diffusion - surface diffusion	Andersson et al., 1989
37	dilution	Andersson et al., 1989
38	dispersion	Andersson et al., 1989
39	dissolution chemistry	Andersson et al., 1989
40	dissolution of fracture fillings/precipitations	Andersson et al., 1989
41	methane intrusion	Andersson et al., 1989
42	accumulation of gases under permafrost	Andersson et al., 1989
43	gas transport	Andersson et al., 1989
44	gas transport in bentonite	Andersson et al., 1989
45	flow through buffer/backfill	Andersson et al., 1989
46	preferential pathways in the buffer/backfill	Andersson et al., 1989
47	poorly designed repository	Andersson et al., 1989
48	backfill effects on copper corrosion	Andersson et al., 1989
49	backfill material deficiencies	Andersson et al., 1989
50	changed hydrostatic pressure on canister	Andersson et al., 1989
51	degradation of the bentonite by chemical reactions	Andersson et al., 1989
52	erosion of buffer/backfill	Andersson et al., 1989
53	excavation/backfilling effects on nearby rock	Andersson et al., 1989
54	external stress	Andersson et al., 1989
55	hydraulic conductivity change - excavation/backfilling effect	Andersson et al., 1989
56	hydrostatic pressure on canister	Andersson et al., 1989
57	movement of canister in buffer/backfill	Andersson et al., 1989

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Table 1 (continued)

FEP ID	Initial FEP	Reference[1]
58	thermal effects on the buffer material	Andersson et al., 1989
59	voids in the lead filling	Andersson et al., 1989
60	swelling of bentonite into tunnels and cracks	Andersson et al., 1989
61	swelling of corrosion products	Andersson et al., 1989
62	uneven swelling of bentonite	Andersson et al., 1989
63	mechanical effects - excavation/backfilling effects	Andersson et al., 1989
64	mechanical failure of buffer/backfill	Andersson et al., 1989
65	mechanical failure of repository	Andersson et al., 1989
66	sudden energy release	Andersson et al., 1989
67	coagulation of bentonite	Andersson et al., 1989
68	chemical toxicity of wastes	Andersson et al., 1989
69	complexing agents	Andersson et al., 1989
70	far field hydrochemistry - acids, oxidants. nitrate	Andersson et al., 1989
71	change of ground-water chemistry in nearby rock	Andersson et al., 1989
72	chemical effects of rock reinforcement	Andersson et al., 1989
73	coupled effects (electrophoresis)	Andersson et al., 1989
74	effects of bentonite on ground-water chemistry	Andersson et al., 1989
75	isotopic dilution	Andersson et al., 1989
76	near field buffer chemistry	Andersson et al., 1989
77	oxidizing conditions	Andersson et al., 1989
78	Pb-I reactions	Andersson et al., 1989
79	pH-deviations	Andersson et al., 1989
80	recrystallization	Andersson et al., 1989
81	redox front	Andersson et al., 1989
82	redox potential	Andersson et al., 1989
83	diagenesis	Andersson et al., 1989
84	accidents during operation	Andersson et al., 1989
85	human-induced climate change	Andersson et al., 1989
86	non-sealed repository	Andersson et al., 1989
87	unsealed boreholes and/or shafts	Andersson et al., 1989
88	explosions	Andersson et al., 1989

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Table 1 (continued)

FEP ID	Initial FEP	Reference^1
89	geothermal energy production	Andersson et al., 1989
90	enhanced rock fracturing	Andersson et al., 1989
91	thermo-hydro-mechanical effects	Andersson et al., 1989
92	altered surface water chemistry by humans	Andersson et al., 1989
93	city on the site	Andersson et al., 1989
94	underground dwellings	Andersson et al., 1989
95	loss of records	Andersson et al., 1989
96	archeological intrusion	Andersson et al., 1989
97	postclosure monitoring	Andersson et al., 1989
98	underground test of nuclear devices	Andersson et al., 1989
99	unsuccessful attempt of site improvement	Andersson et al., 1989
100	poorly constructed repository	Andersson et al., 1989
101	future boreholes and undetected past boreholes	Andersson et al., 1989
102	other future uses of crystalline rock	Andersson et al., 1989
103	reuse of boreholes	Andersson et al., 1989
104	chemical sabotage	Andersson et al., 1989
105	nuclear war	Andersson et al., 1989
106	waste retrieval, mining	Andersson et al., 1989
107	human-induced actions on ground-water recharge	Andersson et al., 1989
108	human-induced changes in surface hydrology	Andersson et al., 1989
109	water producing well	Andersson et al., 1989
110	weathering of flow paths	Andersson et al., 1989
111	erosion on surface/sediments	Andersson et al., 1989
112	geothermally induced flow	Andersson et al., 1989
113	sedimentation of bentonite	Andersson et al., 1989
114	changes of ground-water flow	Andersson et al., 1989
115	enhanced ground-water flow	Andersson et al., 1989
116	groundwater recharge/discharge	Andersson et al., 1989
117	resaturation	Andersson et al., 1989
118	saline or fresh ground-water intrusion	Andersson et al., 1989
119	river meandering	Andersson et al., 1989

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FEP ID	Initial FEP	Reference[1]
120	microbes	Andersson et al., 1989
121	repository induced Pb/Cu electrochemical reactions	Andersson et al., 1989
122	Gas generation	Andersson et al., 1989
123	gas generation: He production	Andersson et al., 1989
124	radiolysis	Andersson et al., 1989
125	radiolysis	Andersson et al., 1989
126	recoil of alpha-decay	Andersson et al., 1989
127	reconcentration	Andersson et al., 1989
128	chemical reactions (copper corrosion)	Andersson et al., 1989
129	I, Cs-migration to fuel surface	Andersson et al., 1989
130	interactions with corrosion products and waste	Andersson et al., 1989
131	internal corrosion due to waste	Andersson et al., 1989
132	natural telluric electrochemical reactions	Andersson et al., 1989
133	perturbed buffer material chemistry	Andersson et al., 1989
134	radioactive decay; heat	Andersson et al., 1989
135	release of radionuclides from failed canister	Andersson et al., 1989
136	role of the eventual channeling within the canister	Andersson et al., 1989
137	soret effect	Andersson et al., 1989
138	earthquakes	Andersson et al., 1989
139	faulting	Andersson et al., 1989
140	intruding dikes	Andersson et al., 1989
141	changes of the magnetic field	Andersson et al., 1989
142	stress changes of conductivity	Andersson et al., 1989
143	creeping of rock mass	Andersson et al., 1989
144	intrusion into accumulation zone in the biosphere	Andersson et al., 1989
145	uplift and subsidence	Andersson et al., 1989
146	effect of plate movements	Andersson et al., 1989
147	tectonic activity - large scale	Andersson et al., 1989
148	undetected discontinuities	Andersson et al., 1989
149	undetected fracture zones	Andersson et al., 1989
150	volcanism	Andersson et al., 1989

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FEP ID	Initial FEP	Reference[1]
151	criticality	Andersson et al., 1989
152	H2/02 explosions	Andersson et al., 1989
153	co-storage of other waste	Andersson et al., 1989
154	damaged or deviating fuel	Andersson et al., 1989
155	decontamination materials left	Andersson et al., 1989
156	near storage of other waste	Andersson et al., 1989
157	stray materials left	Andersson et al., 1989
158	Meteorites	Burkholder, 1980
159	climate modification	Burkholder, 1980
160	Glaciation	Burkholder, 1980
161	corrosion	Burkholder, 1980
162	Transport Agent Introduction	Burkholder, 1980
163	fluid migration	Burkholder, 1980
164	dissolutioning	Burkholder, 1980
165	biochemical gas generation	Burkholder, 1980
166	decay product gas generation	Burkholder, 1980
167	differential elastic response	Burkholder, 1980
168	dewatering	Burkholder, 1980
169	canister movement	Burkholder, 1980
170	fluid pressure changes	Burkholder, 1980
171	material property changes	Burkholder, 1980
172	non-elastic response	Burkholder, 1980
173	shaft seal failure	Burkholder, 1980
174	geochemical alterations	Burkholder, 1980
175	diagenesis	Burkholder, 1980
176	gas or brine pockets	Burkholder, 1980
177	reservoirs	Burkholder, 1980
178	undiscovered boreholes	Burkholder, 1980
179	Undetected Past Intrusion	Burkholder, 1980
180	Intentional Intrusion	Burkholder, 1980
181	archeological exhumation	Burkholder, 1980

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FEP ID	Initial FEP	Reference[1]
182	irrigation	Burkholder, 1980
183	establishment of new population center	Burkholder, 1980
184	improper waste emplacement	Burkholder, 1980
185	resource mining (mineral hydrocarbon, geothermal, salt)	Burkholder, 1980
186	mine shafts	Burkholder, 1980
187	sabotage	Burkholder, 1980
188	war	Burkholder, 1980
189	waste recovery	Burkholder, 1980
190	intentional artificial ground-water recharge or withdrawal	Burkholder, 1980
191	weapons testing	Burkholder, 1980
192	Denudation and Stream Erosion	Burkholder, 1980
193	sedimentation	Burkholder, 1980
194	flooding	Burkholder, 1980
195	radiolysis	Burkholder, 1980
196	waste package - geology interactions	Burkholder, 1980
197	breccia pipes	Burkholder, 1980
198	diapirism	Burkholder, 1980
199	far-field faulting	Burkholder, 1980
200	near-field faulting	Burkholder, 1980
201	faults, shear zones	Burkholder, 1980
202	static fracturing	Burkholder, 1980
203	impact fracturing	Burkholder, 1980
204	surficial fissuring	Burkholder, 1980
205	local fracturing	Burkholder, 1980
206	Igneous emplacement	Burkholder, 1980
207	intrusive magmatic activity	Burkholder, 1980
208	hydraulic fracturing	Burkholder, 1980
209	isostasy	Burkholder, 1980
210	lava tubes	Burkholder, 1980
211	Orogenic Diastrophism	Burkholder, 1980
212	Epeirogenic Displacement	Burkholder, 1980

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FEP ID	Initial FEP	Reference[1]
213	undetected features	Burkholder, 1980
214	extrusive magmatic activity	Burkholder, 1980
215	criticality	Burkholder, 1980
216	chemical liquid waste disposal	Burkholder, 1980
217	storage of hydrocarbons or compressed air	Burkholder, 1980
218	non-nuclear waste disposal	Burkholder, 1980
219	Celestial bodies	Guzowski, 1990
220	meteorite impact	Guzowski, 1990
221	sea-level variations	Guzowski, 1990
222	pluvial periods	Guzowski, 1990
223	glaciation	Guzowski, 1990
224	seiches	Guzowski, 1990
225	formation of dissolution cavities	Guzowski, 1990
226	excavation induced stress/fracturing in host rock	Guzowski, 1990
227	subsidence and caving	Guzowski, 1990
228	thermally induced stress/fracturing in host rock	Guzowski, 1990
229	shaft and borehole seal degradation	Guzowski, 1990
230	explosions	Guzowski, 1990
231	Inadvertent Future Intrusions	Guzowski, 1990
232	injection wells	Guzowski, 1990
233	irrigation	Guzowski, 1990
234	drilling	Guzowski, 1990
235	mining	Guzowski, 1990
236	damming of streams or rivers	Guzowski, 1990
237	withdrawal wells	Guzowski, 1990
238	mass wasting	Guzowski, 1990
239	erosion/ sedimentation	Guzowski, 1990
240	flooding	Guzowski, 1990
241	hydrologic stresses	Guzowski, 1990
242	hurricanes	Guzowski, 1990
243	tsunamis	Guzowski, 1990

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FEP ID	Initial FEP	Reference[1]
244	diapirism	Guzowski, 1990
245	faulting	Guzowski, 1990
246	formation of interconnected fracture systems	Guzowski, 1990
247	regional subsidence or uplift (also applies to subsurface)	Guzowski, 1990
248	seismic activity	Guzowski, 1990
249	magmatic activity	Guzowski, 1990
250	volcanic activity	Guzowski, 1990
251	meteorite impact	Hertzler and Atwood, 1989
252	climatic change	Hertzler and Atwood, 1989
253	sea level change	Hertzler and Atwood, 1989
254	dam and reservoir formation from natural causes	Hertzler and Atwood, 1989
255	glacial activity	Hertzler and Atwood, 1989
256	radial dispersion	Hertzler and Atwood, 1989
257	fluid interactions	Hertzler and Atwood, 1989
258	dissolution	Hertzler and Atwood, 1989
259	decay product gas generation	Hertzler and Atwood, 1989
260	infiltration and evapotranspiration	Hertzler and Atwood, 1989
261	thermal changes in burial zone caused by heat generation	Hertzler and Atwood, 1989
262	mechanical effects	Hertzler and Atwood, 1989
263	shaft/borehole seal failure	Hertzler and Atwood, 1989
264	geochemical changes from natural causes	Hertzler and Atwood, 1989
265	diagenesis	Hertzler and Atwood, 1989
266	landslide	Hertzler and Atwood, 1989
267	local subsidence/caving	Hertzler and Atwood, 1989
268	climate control	Hertzler and Atwood, 1989
269	fire and explosion	Hertzler and Atwood, 1989
270	fire and explosion of waste after burial	Hertzler and Atwood, 1989
271	geochemical changes from manmade causes	Hertzler and Atwood, 1989
272	earthquake from man-made causes	Hertzler and Atwood, 1989
273	human surface activities	Hertzler and Atwood, 1989
274	hydrology change from man-made causes	Hertzler and Atwood, 1989

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FEP ID	Initial FEP	Reference[1]
275	unanticipated intrusion	Hertzler and Atwood, 1989
276	undetected past intrusion	Hertzler and Atwood, 1989
277	undetected features or processes	Hertzler and Atwood, 1989
278	intentional intrusion	Hertzler and Atwood, 1989
279	improper waste emplacement	Hertzler and Atwood, 1989
280	mining inadvertent intruder	Hertzler and Atwood, 1989
281	dam and reservoir, man-made	Hertzler and Atwood, 1989
282	well-drilling inadvertent intruder	Hertzler and Atwood, 1989
283	weapons testing	Hertzler and Atwood, 1989
284	land erosion	Hertzler and Atwood, 1989
285	sedimentation/ aggradation	Hertzler and Atwood, 1989
286	lateral ground-water flow in the unsaturated zone	Hertzler and Atwood, 1989
287	hydrology change from natural causes	Hertzler and Atwood, 1989
288	hurricane	Hertzler and Atwood, 1989
289	tornado	Hertzler and Atwood, 1989
290	brush fire	Hertzler and Atwood, 1989
291	chemical effects	Hertzler and Atwood, 1989
292	diapirism	Hertzler and Atwood, 1989
293	earthquake from natural causes	Hertzler and Atwood, 1989
294	faulting	Hertzler and Atwood, 1989
295	igneous activity	Hertzler and Atwood, 1989
296	regional subsidence or uplift	Hertzler and Atwood, 1989
297	criticality	Hertzler and Atwood, 1989
298	chemical liquid waste disposal	Hertzler and Atwood, 1989
299	unanticipated waste composition	Hertzler and Atwood, 1989
300	permafrost affects repository	Hunter, 1983
301	fluids do not recirculate in response to thermal gradients	Hunter, 1983
302	fluids leave along new fault	Hunter, 1983
303	fluids recirculate in response to thermal gradients	Hunter, 1983
304	fluids recirculate in response to thermal gradients	Hunter, 1983
305	normal flow increases	Hunter, 1983

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FEP ID	Initial FEP	Reference[1]
306	diffusive mixing occurs	Hunter, 1983
307	flux through repository is altered	Hunter, 1983
308	head is above outfall	Hunter, 1983
309	head is below outfall	Hunter, 1983
310	subsidence fractures end above repository	Hunter, 1983
311	subsidence fractures reach repository	Hunter, 1983
312	fluids carry waste to rivers or tributaries	Hunter, 1983
313	fluids carry waste to wells or springs	Hunter, 1983
314	ground-water flow paths are shortened	Hunter, 1983
315	water from a confined aquifer enters repository	Hunter, 1983
316	water from the unconfined aquifer enters repository	Hunter, 1983
317	location of river channel changes	Hunter, 1983
318	location of river channel changes and flow through repository is altered	Hunter, 1983
319	flow channels close and reopen later	Hunter, 1983
320	meteorite impact	Hunter, 1989
321	climatic change	Hunter, 1989
322	glaciation	Hunter, 1989
323	leaching	Hunter, 1989
324	diffusion out of the repository	Hunter, 1989
325	dissolution	Hunter, 1989
326	dissolution other than leaching	Hunter, 1989
327	thermal effects	Hunter, 1989
328	seal performance	Hunter, 1989
329	subsidence	Hunter, 1989
330	exhumation	Hunter, 1989
331	drilling into repository	Hunter, 1989
332	effects of mining for resources	Hunter, 1989
333	sabotage	Hunter, 1989
334	warfare	Hunter, 1989
335	sedimentation	Hunter, 1989

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FEP ID	Initial FEP	Reference[1]
336	ground-water flow	Hunter, 1989
337	migration of brine aquifer	Hunter, 1989
338	migration of intracrystalline brine inclusions	Hunter, 1989
339	effects of brine pocket	Hunter, 1989
340	gas generation waste effect	Hunter, 1989
341	radiolysis waste effect	Hunter, 1989
342	waste/rock interaction	Hunter, 1989
343	breccia-pipe formation	Hunter, 1989
344	induced diapirism	Hunter, 1989
345	faulting	Hunter, 1989
346	Igneous intrusion	Hunter, 1989
347	nuclear criticality	Hunter, 1989
348	meteorite impact	IAEA 1983
349	climatic change	IAEA 1983
350	sea level change	IAEA 1983
351	glacial erosion	IAEA 1983
352	geochemical change	IAEA 1983
353	corrosion	IAEA 1983
354	transport agent introduction	IAEA 1983
355	fluid interactions	IAEA 1983
356	fluid migration	IAEA 1983
357	decay-product gas generation	IAEA 1983
358	faulty design	IAEA 1983
359	exploration bore-hole seal failure	IAEA 1983
360	thermal effects	IAEA 1983
361	canister movement	IAEA 1983
362	fluid pressure, density, viscosity changes	IAEA 1983
363	differential elastic response	IAEA 1983
364	material property changes	IAEA 1983
365	mechanical effects	IAEA 1983
366	non-elastic response	IAEA 1983

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FEP ID	Initial FEP	Reference[1]
367	shaft seal failure	IAEA 1983
368	geochemical change	IAEA 1983
369	diagenesis	IAEA 1983
370	gas or brine pockets	IAEA 1983
371	climate control	IAEA 1983
372	reservoirs	IAEA 1983
373	inadvertent future intrusion	IAEA 1983
374	undetected past intrusion	IAEA 1983
375	undiscovered boreholes	IAEA 1983
376	Intentional intrusion	IAEA 1983
377	archeological exhumation	IAEA 1983
378	irrigation	IAEA 1983
379	faulty operation	IAEA 1983
380	faulty waste emplacement	IAEA 1983
381	resource mining (mineral, water, hydrocarbon, geothermal, salt, etc)	IAEA 1983
382	exploratory drilling	IAEA 1983
383	mine shafts	IAEA 1983
384	sabotage	IAEA 1983
385	war	IAEA 1983
386	waste recovery	IAEA 1983
387	intentional artificial ground-water recharge or withdrawal	IAEA 1983
388	denudation	IAEA 1983
389	stream erosion	IAEA 1983
390	sedimentation	IAEA 1983
391	flooding	IAEA 1983
392	ground-water flow	IAEA 1983
393	brine pockets	IAEA 1983
394	large-scale alterations of hydrology	IAEA 1983
395	hydrology change	IAEA 1983
396	gas generation	IAEA 1983

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FEP ID	Initial FEP	Reference[1]
397	radiolysis	IAEA 1983
398	waste package-rock interactions	IAEA 1983
399	breccia pipes	IAEA 1983
400	diapirism	IAEA 1983
401	faulting/seismicity	IAEA 1983
402	faults, shear zones	IAEA 1983
403	local fracturing	IAEA 1983
404	intrusive	IAEA 1983
405	intrusive dikes	IAEA 1983
406	Isostatic	IAEA 1983
407	lava tubes	IAEA 1983
408	orogenic	IAEA 1983
409	uplift/subsidence	IAEA 1983
410	epeirogenic	IAEA 1983
411	magmatic activity	IAEA 1983
412	extrusive	IAEA 1983
413	nuclear criticality	IAEA 1983
414	chemical liquid waste disposal	IAEA 1983
415	meteorites	Koplik et al., 1982
416	climate modification	Koplik et al., 1982
417	climatic fluctuations	Koplik et al., 1982
418	glaciation	Koplik et al., 1982
419	corrosion	Koplik et al., 1982
420	biosphere alteration	Koplik et al., 1982
421	local fluid migration	Koplik et al., 1982
422	dissolutioning	Koplik et al., 1982
423	decay product gas generation	Koplik et al., 1982
424	Improper design of operation	Koplik et al., 1982
425	Thermal effects	Koplik et al., 1982
426	canister movement	Koplik et al., 1982
427	change in local state of stress	Koplik et al., 1982

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FEP ID	Initial FEP	Reference[1]
428	readjustment of rock along joints	Koplik et al., 1982
429	fluid pressure changes	Koplik et al., 1982
430	canister migration	Koplik et al., 1982
431	convection	Koplik et al., 1982
432	differential elastic response	Koplik et al., 1982
433	material property changes	Koplik et al., 1982
434	Mechanical effects	Koplik et al., 1982
435	nonelastic response	Koplik et al., 1982
436	stored energy	Koplik et al., 1982
437	shaft seal failure	Koplik et al., 1982
438	seal - rock interactions	Koplik et al., 1982
439	subsidence of canister	Koplik et al., 1982
440	geochemical alterations	Koplik et al., 1982
441	diagenesis	Koplik et al., 1982
442	gas or brine pockets	Koplik et al., 1982
443	reservoirs	Koplik et al., 1982
444	Inadvertent future intrusion	Koplik et al., 1982
445	Undetected past intrusion	Koplik et al., 1982
446	undiscovered boreholes	Koplik et al., 1982
447	Intentional intrusion	Koplik et al., 1982
448	archeological exhumation	Koplik et al., 1982
449	irrigation	Koplik et al., 1982
450	establishment of population center	Koplik et al., 1982
451	improper waste emplacement	Koplik et al., 1982
452	resource mining (salt, mineral, hydrocarbon, geothermal)	Koplik et al., 1982
453	mine shafts	Koplik et al., 1982
454	sabotage	Koplik et al., 1982
455	war	Koplik et al., 1982
456	waste recovery	Koplik et al., 1982
457	Perturbation of ground-water system	Koplik et al., 1982
458	intentional artificial ground-water recharge or withdrawal	Koplik et al., 1982

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FEP ID	Initial FEP	Reference[1]
459	weapons testing	Koplik et al., 1982
460	Denudation and stream erosion	Koplik et al., 1982
461	Sedimentation	Koplik et al., 1982
462	Flooding	Koplik et al., 1982
463	Modification of hydrologic regime	Koplik et al., 1982
464	gas generation	Koplik et al., 1982
465	Radiation effects	Koplik et al., 1982
466	radiolysis	Koplik et al., 1982
467	Chemical effects	Koplik et al., 1982
468	waste package - geology interactions	Koplik et al., 1982
469	breccia pipes	Koplik et al., 1982
470	diapirism	Koplik et al., 1982
471	far-field faulting	Koplik et al., 1982
472	near-field faulting	Koplik et al., 1982
473	faults, shear zones	Koplik et al., 1982
474	Static fracturing	Koplik et al., 1982
475	impact fracturing	Koplik et al., 1982
476	surficial fissuring	Koplik et al., 1982
477	local fracturing	Koplik et al., 1982
478	Igneous emplacement	Koplik et al., 1982
479	intrusive magmatic activity	Koplik et al., 1982
480	hydraulic fracturing	Koplik et al., 1982
481	isostasy	Koplik et al., 1982
482	lava tubes	Koplik et al., 1982
483	Orogenic diastrophism	Koplik et al., 1982
484	Epeirogenic displacement	Koplik et al., 1982
485	Magmatic activity	Koplik et al., 1982
486	extrusive magmatic activity	Koplik et al., 1982
487	criticality	Koplik et al., 1982
488	storage of hydrocarbons, compressed air, or hot water	Koplik et al., 1982
489	non-nuclear waste disposal	Koplik et al., 1982

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FEP ID	Initial FEP	Reference[1]
490	chemical liquid waste disposal	Koplik et al., 1982
491	Meteorite impact	Merrett and Gillespie, 1983
492	determination of meteorite impact frequencies	Merrett and Gillespie, 1983
493	probability of meteorite damage	Merrett and Gillespie, 1983
494	Glaciation	Merrett and Gillespie, 1983
495	glacial erosion	Merrett and Gillespie, 1983
496	fracture mechanics analysis	Merrett and Gillespie, 1983
497	vault-related events	Merrett and Gillespie, 1983
498	presence of a heat source	Merrett and Gillespie, 1983
499	excavation	Merrett and Gillespie, 1983
500	use of explosive devices	Merrett and Gillespie, 1983
501	drilling and mining	Merrett and Gillespie, 1983
502	Denudation and fluvial erosion	Merrett and Gillespie, 1983
503	denudation	Merrett and Gillespie, 1983
504	fluvial erosion	Merrett and Gillespie, 1983
505	alteration of hydrological conditions	Merrett and Gillespie, 1983
506	new fault formation	Merrett and Gillespie, 1983
507	rapid fault growth	Merrett and Gillespie, 1983
508	slow fault growth	Merrett and Gillespie, 1983
509	stress analysis	Merrett and Gillespie, 1983
510	glacially induced faulting	Merrett and Gillespie, 1983
511	subsidence and rebound	Merrett and Gillespie, 1983
512	Seismic activity	Merrett and Gillespie, 1983
513	jointed rock motion	Merrett and Gillespie, 1983
514	Volcanic activity	Merrett and Gillespie, 1983
515	hot-spot volcanic activity	Merrett and Gillespie, 1983
516	rift system volcanic activity	Merrett and Gillespie, 1983
517	Presence of a radioactive source	Merrett and Gillespie, 1983
518	Meteorite impact	NEA OECD, 2000
519	Climate change, Global	NEA OECD, 2000
520	Climate change, regional and local	NEA OECD, 2000

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FEP ID	**Initial FEP**	**Reference**[1]
521	Ecological response to climate changes	NEA OECD, 2000
522	Hydrological/hydrogeological response to climate changes	NEA OECD, 2000
523	Sea Level change	NEA OECD, 2000
524	Warm climate effects (tropical and desert)	NEA OECD, 2000
525	Glacial and ice sheet effects, local	NEA OECD, 2000
526	Periglacial effects	NEA OECD, 2000
527	Container materials and characteristics	NEA OECD, 2000
528	Atmospheric transport of contaminants	NEA OECD, 2000
529	Vegetation	NEA OECD, 2000
530	Animal populations	NEA OECD, 2000
531	Biological/biochemical processes and conditions (in geosphere)	NEA OECD, 2000
532	Biological/biochemical processes and conditions (in waste and EBS)	NEA OECD, 2000
533	Species evolution	NEA OECD, 2000
534	Animal, plant and microbe mediated transport of contaminants	NEA OECD, 2000
535	Colloids. contaminant interactions and transport with	NEA OECD, 2000
536	Contaminant transport path characteristics (in geosphere)	NEA OECD, 2000
537	Chemical/complexing agents, effects on contaminant speciation/transport	NEA OECD, 2000
538	Solid-mediated transport of contaminants	NEA OECD, 2000
539	Sorption/desorption processes, contaminant	NEA OECD, 2000
540	Speciation and solubility, contaminant	NEA OECD, 2000
541	Dissolution, precipitation, and crystallization, contaminant	NEA OECD, 2000
542	Noble gases	NEA OECD, 2000
543	Volatiles and potential for volatility	NEA OECD, 2000
544	Gas-mediated transport of contaminants	NEA OECD, 2000
545	Geological resources	NEA OECD, 2000
546	Geological units, other	NEA OECD, 2000
547	Host rock	NEA OECD, 2000
548	Repository assumptions	NEA OECD, 2000

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FEP ID	Initial FEP	Reference[1]
549	Thermal processes and conditions (in geosphere)	NEA OECD, 2000
550	Excavation disturbed zone, host rock	NEA OECD, 2000
551	Buffer/backfill materials and characteristics	NEA OECD, 2000
552	Other engineered features materials and characteristics	NEA OECD, 2000
553	Thermal processes and conditions (in wastes and EBS)	NEA OECD, 2000
554	Emplacement of wastes and backfilling	NEA OECD, 2000
555	Repository design	NEA OECD, 2000
556	Mechanical processes and conditions (in geosphere)	NEA OECD, 2000
557	Mechanical processes and conditions (in wastes and EBS)	NEA OECD, 2000
558	Seals. cavern/tunnel/shaft	NEA OECD, 2000
559	Closure and repository sealing	NEA OECD, 2000
560	Dose response assumptions	NEA OECD, 2000
561	Dosimetry	NEA OECD, 2000
562	Drinking water, foodstuffs and drugs, contaminant concentrations in	NEA OECD, 2000
563	Environmental media, contaminant concentrations in	NEA OECD, 2000
564	Impacts or concern	NEA OECD, 2000
565	Human characteristics (physiology, metabolism)	NEA OECD, 2000
566	Chemical/organic toxin stability	NEA OECD, 2000
567	Exposure modes	NEA OECD, 2000
568	Non-food products, contaminant concentrations in	NEA OECD, 2000
569	Nonradiological toxicity/effects	NEA OECD, 2000
570	Radiological toxicity/effects	NEA OECD, 2000
571	Radon and radon daughter exposure	NEA OECD, 2000
572	Diet and fluid Intake	NEA OECD, 2000
573	Food and water processing and preparation	NEA OECD, 2000
574	Food chains, uptake of contaminants in	NEA OECD, 2000
575	Chemical/geochemical processes and conditions (in geosphere)	NEA OECD, 2000
576	Chemical/geochemical processes and conditions (In wastes and	NEA OECD, 2000
577	Organics and potential for organic forms	NEA OECD, 2000

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FEP ID	Initial FEP	Reference[1]
578	Diagenesis	NEA OECD, 2000
579	Gas sources and effects (in geosphere)	NEA OECD, 2000
580	Human influences on climate	NEA OECD, 2000
581	Social and Institutional developments	NEA OECD, 2000
582	Excavation/construction	NEA OECD, 2000
583	Explosions and crashes	NEA OECD, 2000
584	Future human action assumptions	NEA OECD, 2000
585	Future human behavior (target group) assumptions	NEA OECD, 2000
586	Habits (non-diet related behavior)	NEA OECD, 2000
587	Leisure and other uses of environment	NEA OECD, 2000
588	Human response to climate changes	NEA OECD, 2000
589	Surface environment, human activities	NEA OECD, 2000
590	Technological developments	NEA OECD, 2000
591	Adults, children, Infants and other variations	NEA OECD, 2000
592	Human-action-mediated transport of contaminants	NEA OECD, 2000
593	Community characteristics	NEA OECD, 2000
594	Dwellings	NEA OECD, 2000
595	Motivation and knowledge issues (inadvertent/deliberate human actions)	NEA OECD, 2000
596	Administrative control , repository site	NEA OECD, 2000
597	Records and markers, repository	NEA OECD, 2000
598	Unintrusive site investigation	NEA OECD, 2000
599	Site Investigation	NEA OECD, 2000
600	Rural and agricultural land and water use (incl. fisheries)	NEA OECD, 2000
601	Urban and Industrial land and water use	NEA OECD, 2000
602	Wild and natural land and water use	NEA OECD, 2000
603	Monitoring of repository	NEA OECD, 2000
604	Remedial actions	NEA OECD, 2000
605	Schedule and planning	NEA OECD, 2000
606	Quality control	NEA OECD, 2000
607	Retrievability	NEA OECD, 2000

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FEP ID	Initial FEP	Reference[1]
608	Drilling activities (human intrusion)	NEA OECD, 2000
609	Mining and other underground activities (human intrusion)	NEA OECD, 2000
610	Accidents and unplanned events	NEA OECD, 2000
611	Water management (wells, reservoirs. dams)	NEA OECD, 2000
612	Coastal features	NEA OECD, 2000
613	Topography and morphology	NEA OECD, 2000
614	Erosion and deposition	NEA OECD, 2000
615	Erosion and sedimentation	NEA OECD, 2000
616	Hydraulic/hydrogeological processes and conditions (in geosphere)	NEA OECD, 2000
617	Hydraulic/hydrogeological processes and conditions (in wastes and EBS)	NEA OECD, 2000
618	Hydrological/hydrogeological response to geological changes	NEA OECD, 2000
619	Hydrothermal activity	NEA OECD, 2000
620	Marine features	NEA OECD, 2000
621	Soil and sediment	NEA OECD, 2000
622	Aquifers and water-bearing features, near surface	NEA OECD, 2000
623	Water-mediated transport of contaminants	NEA OECD, 2000
624	Hydrological regime and water balance (near-surface)	NEA OECD, 2000
625	Lakes, rivers, streams and springs	NEA OECD, 2000
626	Atmosphere	NEA OECD, 2000
627	Meteorology	NEA OECD, 2000
628	Model and data Issues	NEA OECD, 2000
629	Timescale of concern	NEA OECD, 2000
630	Regulatory requirements and exclusions	NEA OECD, 2000
631	Spatial domain or concern	NEA OECD, 2000
632	Ecological/biological microbial systems	NEA OECD, 2000
633	Microbial/biological/plant-mediated processes,	NEA OECD, 2000
634	Gas sources and effects (in wastes and EBS)	NEA OECD, 2000
635	Radioactive decay and in-growth	NEA OECD, 2000
636	Radiation effects (In wastes and EBS)	NEA OECD, 2000

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Table 1 (continued)

FEP ID	Initial FEP	Reference[1]
637	Inorganic solids/solutes	NEA OECD, 2000
638	Salt diapirism and dissolution	NEA OECD, 2000
639	Discontinuities, large scale (in geosphere)	NEA OECD, 2000
640	Metamorphism	NEA OECD, 2000
641	Deformation, elastic, plastic or brittle	NEA OECD, 2000
642	Seismicity	NEA OECD, 2000
643	Undetected features (In geosphere)	NEA OECD, 2000
644	Tectonic movements and orogeny	NEA OECD, 2000
645	Volcanic and magmatic activity	NEA OECD, 2000
646	Nuclear criticality	NEA OECD, 2000
647	Inventory, radionuclide and other material	NEA OECD, 2000
648	Waste form materials and characteristics	NEA OECD, 2000
649	Waste allocation	NEA OECD, 2000
650	meteorite impact	NEA, 1992
651	no ice age	NEA, 1992
652	sea-level rise/fall	NEA, 1992
653	ecological response to climatic change	NEA, 1992
654	glaciation (erosion/deposition, glacial loading, hydrogeological change)	NEA, 1992
655	periglacial effects (permafrost, high seasonality)	NEA, 1992
656	river flow and lake level changes	NEA, 1992
657	fracturing	NEA, 1992
658	embrittlement and cracking	NEA, 1992
659	metallic corrosion (pitting/uniform, internal and external agents, gas generation e.g. H2)	NEA, 1992
660	animal uptake	NEA, 1992
661	plant uptake	NEA, 1992
662	uptake by animal, plant, root	NEA, 1992
663	uptake by deep rooting species	NEA, 1992
664	soil and sediment bioturbation	NEA, 1992
665	plant and animal evolution	NEA, 1992
666	colloid formation, dissolution and transport	NEA, 1992

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Table 1 (continued)

FEP ID	Initial FEP	Reference[1]
667	accumulation in soils and organic debris	NEA, 1992
668	advection and dispersion	NEA, 1992
669	matrix diffusion	NEA, 1992
670	multiphase flow and gas driven flow	NEA, 1992
671	solubility limit	NEA, 1992
672	sorption (linear/non-linear, reversible/irreversible)	NEA, 1992
673	non-radioactive solute plume in geosphere (effect on redox, ph and sorption)	NEA, 1992
674	diffusion	NEA, 1992
675	mass, isotopic and species dilution	NEA, 1992
676	dissolution, precipitation, and crystallization	NEA, 1992
677	natural gas intrusion	NEA, 1992
678	gas flow	NEA, 1992
679	gas mediated transport	NEA, 1992
680	inadequate backfill or compaction voidage	NEA, 1992
681	dewatering of host rock	NEA, 1992
682	common cause failures	NEA, 1992
683	investigation borehole seal failure and degradation	NEA, 1992
684	stress field changes, settling, subsidence or caving	NEA, 1992
685	thermal effects (concrete hydration)	NEA, 1992
686	Thermal (nuclear and chemical)	NEA, 1992
687	canister or container movement	NEA, 1992
688	changes in in-situ stress field	NEA, 1992
689	subsidence / collapse	NEA, 1992
690	differential elastic response	NEA, 1992
691	material defects (e.g. early canister failure)	NEA, 1992
692	material property changes	NEA, 1992
693	Mechanical	NEA, 1992
694	non-elastic response	NEA, 1992
695	Design and construction	NEA, 1992
696	design modification	NEA, 1992

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FEP ID	Initial FEP	Reference[1]
697	shaft or access tunnel seal failure and degradation	NEA, 1992
698	altered soil or surface water chemistry	NEA, 1992
699	chemical transformations	NEA, 1992
700	chemical gradients (electrochemical effects and osmosis)	NEA, 1992
701	complexing agents	NEA, 1992
702	diagenesis	NEA, 1992
703	land slide	NEA, 1992
704	accidents during operation	NEA, 1992
705	agricultural and fisheries practice changes	NEA, 1992
706	anthropogenic climate changes (greenhouse effect)	NEA, 1992
707	abandonment of unsealed repository	NEA, 1992
708	poor closure	NEA, 1992
709	tunneling	NEA, 1992
710	underground construction	NEA, 1992
711	geothermal energy production	NEA, 1992
712	repository flooding during operation	NEA, 1992
713	co-disposal of reactive wastes (deliberate)	NEA, 1992
714	undetected past intrusions (boreholes, mining)	NEA, 1992
715	injection of liquid wastes	NEA, 1992
716	loss of records	NEA, 1992
717	archeological investigation	NEA, 1992
718	irrigation	NEA, 1992
719	demographic change, urban development	NEA, 1992
720	land use changes	NEA, 1992
721	post-closure monitoring	NEA, 1992
722	underground nuclear testing	NEA, 1992
723	effects of phased operation	NEA, 1992
724	Operation and closure	NEA, 1992
725	poor quality construction	NEA, 1992
726	radioactive waste disposal error	NEA, 1992
727	Post-closure surface activities	NEA, 1992

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FEP ID	Initial FEP	Reference[1]
728	exploitation drilling	NEA, 1992
729	exploratory drilling	NEA, 1992
730	resource mining	NEA, 1992
731	quarrying, near surface extraction	NEA, 1992
732	sabotage	NEA, 1992
733	malicious intrusion (sabotage, act of war)	NEA, 1992
734	recovery of repository materials	NEA, 1992
735	recovery of repository materials	NEA, 1992
736	ground-water abstraction	NEA, 1992
737	dams and reservoirs, built/drained	NEA, 1992
738	coastal erosion and estuarine development	NEA, 1992
739	denudation (eolian and fluvial)	NEA, 1992
740	chemical denudation and weathering	NEA, 1992
741	freshwater sediment transport and deposition	NEA, 1992
742	fracture mineralization and weathering	NEA, 1992
743	rock heterogeneity (permeability, mineralogy), affecting water and	NEA, 1992
744	river, stream, channel erosion (downcutting)	NEA, 1992
745	marine sediment transport and deposition	NEA, 1992
746	extremes of precipitation, snow melt and associated flooding	NEA, 1992
747	effects at saline-freshwater interface	NEA, 1992
748	ground-water conditions (saturated/unsaturated)	NEA, 1992
749	ground-water discharge (to surface water, springs, soils, wells, and marine)	NEA, 1992
750	ground-water flow (Darcy, non-Darcy, intergranular fracture,	NEA, 1992
751	recharge to ground water	NEA, 1992
752	saline or freshwater intrusion	NEA, 1992
753	natural thermal effects	NEA, 1992
754	induced hydrological changes (fluid pressure, density convection, viscosity)	NEA, 1992
755	site flooding	NEA, 1992

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FEP ID	Initial FEP	Reference[1]
756	rivers rechanneled	NEA, 1992
757	river meander	NEA, 1992
758	frost weathering	NEA, 1992
759	solar insolation	NEA, 1992
760	coastal surge, storms, and hurricanes	NEA, 1992
761	precipitation, temperature, soil, water balance	NEA, 1992
762	ecological change (ex. forest fire cycles)	NEA, 1992
763	microbial interactions	NEA, 1992
764	microbiological (effects on corrosion/degradation, solubility/complexation, gas generation, ex. CH.C02)	NEA, 1992
765	pedogenesis	NEA, 1992
766	gas effects (pressurization, disruption, explosion, fire)	NEA, 1992
767	radioactive decay and ingrowth (chain decay)	NEA, 1992
768	radiolysis	NEA, 1992
769	Radiological	NEA, 1992
770	heterogeneity of waste forms (chemical, physical)	NEA, 1992
771	cellulosic degradation	NEA, 1992
772	interactions of host materials and ground water with repository material (ex. concrete carbonation, sulphate attack)	NEA, 1992
773	interactions of waste and repository materials with host materials (electrochemical corrosive agents)	NEA, 1992
774	introduced complexing agents and cellulosics	NEA, 1992
775	induced chemical changes (solubility sorption, species equilibrium, mineralization)	NEA, 1992
776	diapirism	NEA, 1992
777	fault activation	NEA, 1992
778	fault generation	NEA, 1992
779	host rock fracture aperture changes	NEA, 1992
780	metamorphic activity	NEA, 1992
781	changes in the earth's magnetic field	NEA, 1992
782	uplift and subsidence (orogenic, isostatic)	NEA, 1992
783	seismicity	NEA, 1992

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FEP ID	Initial FEP	Reference[1]
784	plate movement/tectonic change	NEA, 1992
785	undetected features (faults, fracture networks, shear zones, brecciation, gas pockets)	NEA, 1992
786	magmatic activity (intrusive, extrusive)	NEA, 1992
787	nuclear criticality	NEA, 1992
788	inadvertent inclusion of undesirable materials	NEA, 1992
789	Recurrance of Lake Bonneville	Neptune
790	Wave action	Neptune
791	Animal burrowing	Neptune
792	Dust devils	Neptune
793	Barrier stability during inundation	Neptune
794	inhalation pathways	Neptune
795	human induced hydraulic fracturing	Neptune
796	natural hydraulic fracturing (hydrogeological)	Neptune
797	Sedimentation	Neptune
798	Inundation	Neptune
799	radon emanation	Neptune
800	natural hydraulic fracturing (tectonic/seismic/volcanic)	Neptune
801	Off-Site Residents: impacts on the site by people who might use the area but don't live on the site itself.	Neptune
802	On-Site Residents: water well with desalinization; construction-related activities like basements, footings, and utilities; enhanced infiltration from septic; altered plant/animal communities; effect of grading on infiltration; effect of buildings and pavement on evapotranspiration.	Neptune
803	Agricultural activities	Neptune
804	Explosions and Crashes related to plane crashes, bombs	Neptune
805	Accidental Intrusion, facility properties intact: mineral, oil and gas, geothermal or other resource exploration; water well with desalinization; construction-related activities	Neptune
806	Accidental Intrusion, facility properties altered due to prior volcanic or seismic event	Neptune
807	FEPs related to post-closure inhabitation of the area	Neptune
808	Deliberate Intrusion (purposeful waste retrieval; archeology; terrorism, etc)	Neptune

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FEP ID	Initial FEP	Reference[1]
809	FEPs related to post-closure intrusion by nonresidents who come looking for something, or to some kind of major accident like a plane crash either before or after closure	Neptune
810	meteorite	Prij et al. 1991
811	climatic variability	Prij et al. 1991
812	minor climatic changes	Prij et al. 1991
813	sea-level changes	Prij et al. 1991
814	ecological response to climate	Prij et al. 1991
815	glaciation	Prij et al. 1991
816	periglacial effects	Prij et al. 1991
817	canister defects	Prij et al. 1991
818	common cause (canister) failures	Prij et al. 1991
819	fracturing	Prij et al. 1991
820	embrittlement, cracking	Prij et al. 1991
821	metallic corrosion	Prij et al. 1991
822	bioturbation of soil sediment	Prij et al. 1991
823	radiocolloid formation	Prij et al. 1991
824	accumulation in soils, organic debris	Prij et al. 1991
825	transport of radionuclides	Prij et al. 1991
826	advection and dispersion	Prij et al. 1991
827	matrix diffusion	Prij et al. 1991
828	multiphase flow	Prij et al. 1991
829	leaching of nuclides	Prij et al. 1991
830	non-radioactive solute in geosphere	Prij et al. 1991
831	diffusion	Prij et al. 1991
832	dilution of mass	Prij et al. 1991
833	dissolution/precipitation reactions	Prij et al. 1991
834	natural gas intrusion	Prij et al. 1991
835	gas mediated transport	Prij et al. 1991
836	inadequate backfill compaction, voidage	Prij et al. 1991
837	convergence of openings	Prij et al. 1991
838	dewatering of host rock	Prij et al. 1991

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FEP ID	Initial FEP	Reference[1]
839	stress field changes	Prij et al. 1991
840	thermal effects	Prij et al. 1991
841	Thermal	Prij et al. 1991
842	degradation of buffer/backfill	Prij et al. 1991
843	canister or container movement	Prij et al. 1991
844	changes in in-situ stress field	Prij et al. 1991
845	readjustment of host rock along joints	Prij et al. 1991
846	heat production	Prij et al. 1991
847	fracture aperture changes	Prij et al. 1991
848	canister migration	Prij et al. 1991
849	dehydration of salt minerals	Prij et al. 1991
850	differential elastic response	Prij et al. 1991
851	material defects	Prij et al. 1991
852	swelling of backfill (clay)	Prij et al. 1991
853	swelling of corrosion products	Prij et al. 1991
854	material property changes	Prij et al. 1991
855	Mechanical	Prij et al. 1991
856	non-elastic response	Prij et al. 1991
857	release of stored energy	Prij et al. 1991
858	Design and construction	Prij et al. 1991
859	design modification	Prij et al. 1991
860	seal failure	Prij et al. 1991
861	subsidence, collapse	Prij et al. 1991
862	alteration of soil, surface water chemistry	Prij et al. 1991
863	Geochemical	Prij et al. 1991
864	chemical transformations	Prij et al. 1991
865	ionic strength	Prij et al. 1991
866	speciation equilibrium reactions	Prij et al. 1991
867	texture	Prij et al. 1991
868	acidity	Prij et al. 1991
869	adsorption and desorption reactions	Prij et al. 1991

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FEP ID	Initial FEP	Reference[1]
870	chemical equilibrium reactions	Prij et al. 1991
871	counter, competitive, and potential determining ions	Prij et al. 1991
872	physico-chemical characteristics influencing chemical equilibria	Prij et al. 1991
873	redox conditions	Prij et al. 1991
874	geochemical alterations	Prij et al. 1991
875	diagenesis	Prij et al. 1991
876	land slide	Prij et al. 1991
877	accidents during operation	Prij et al. 1991
878	agricultural developments and changes	Prij et al. 1991
879	anthropogenic climate changes (greenhouse effect)	Prij et al. 1991
880	abandonment of unsealed repository	Prij et al. 1991
881	poor closure	Prij et al. 1991
882	tunneling	Prij et al. 1991
883	underground construction	Prij et al. 1991
884	fisheries developments and changes	Prij et al. 1991
885	geothermal energy production	Prij et al. 1991
886	co-disposal of reactive wastes (deliberate)	Prij et al. 1991
887	Human Induced Phenomena	Prij et al. 1991
888	undetected past intrusions	Prij et al. 1991
889	injection of fluids	Prij et al. 1991
890	loss of records	Prij et al. 1991
891	archaeological investigation	Prij et al. 1991
892	irrigation	Prij et al. 1991
893	changes in land use	Prij et al. 1991
894	demographic developments and changes	Prij et al. 1991
895	urban developments and changes	Prij et al. 1991
896	post-closure monitoring	Prij et al. 1991
897	underground nuclear testing	Prij et al. 1991
898	Operation and closure	Prij et al. 1991
899	phased operation effects	Prij et al. 1991

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FEP ID	Initial FEP	Reference[1]
900	attempt of site Improvement	Prij et al. 1991
901	poor quality construction	Prij et al. 1991
902	improper waste emplacement	Prij et al. 1991
903	radioactive waste disposal error	Prij et al. 1991
904	Post-closure sub-surface activities	Prij et al. 1991
905	Post-closure subsurface activities (intrusion)	Prij et al. 1991
906	Post-closure surface activities	Prij et al. 1991
907	exploitation drilling	Prij et al. 1991
908	exploratory drilling	Prij et al. 1991
909	resource mining	Prij et al. 1991
910	quarrying, surface mining	Prij et al. 1991
911	sabotage	Prij et al. 1991
912	malicious intrusion, sabotage/war	Prij et al. 1991
913	ground-water abstraction/recharge	Prij et al. 1991
914	construction of dams/reservoirs	Prij et al. 1991
915	drainage of dams reservoirs	Prij et al. 1991
916	coastal erosion development of estuaries	Prij et al. 1991
917	denudation, erosion	Prij et al. 1991
918	channel erosion	Prij et al. 1991
919	chemical denudation	Prij et al. 1991
920	channeling and preferential pathways	Prij et al. 1991
921	effects on suberosion	Prij et al. 1991
922	sediment transport	Prij et al. 1991
923	solifluction	Prij et al. 1991
924	rock heterogeneity	Prij et al. 1991
925	subrosion	Prij et al. 1991
926	flooding of repository during operation	Prij et al. 1991
927	extreme precipitation	Prij et al. 1991
928	flooding of site	Prij et al. 1991
929	changes in ground-water system	Prij et al. 1991
930	ground-water conditions	Prij et al. 1991

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Table 1 (continued)

FEP ID	Initial FEP	Reference[1]
931	ground-water discharge	Prij et al. 1991
932	ground-water flow	Prij et al. 1991
933	ground-water recharge	Prij et al. 1991
934	saline-freshwater interface	Prij et al. 1991
935	brine migration	Prij et al. 1991
936	natural thermal effects	Prij et al. 1991
937	induced hydrological changes	Prij et al. 1991
938	changes in river regime, lake levels	Prij et al. 1991
939	intrusion of saline/fresh water	Prij et al. 1991
940	rechanneling of rivers	Prij et al. 1991
941	meandering of river	Prij et al. 1991
942	water table changes	Prij et al. 1991
943	frost weathering	Prij et al. 1991
944	solar insolation	Prij et al. 1991
945	coastal surge, storms	Prij et al. 1991
946	precipitation, temperature, soil, water balance	Prij et al. 1991
947	temperature	Prij et al. 1991
948	ecological response to sudden change (forest fires)	Prij et al. 1991
949	evolution	Prij et al. 1991
950	microbial interactions	Prij et al. 1991
951	microbiological effects	Prij et al. 1991
952	pedogenesis	Prij et al. 1991
953	gas generation, explosions	Prij et al. 1991
954	gas generation effects	Prij et al. 1991
955	radioactive decay/ingrowth	Prij et al. 1991
956	Radiological	Prij et al. 1991
957	radiolysis	Prij et al. 1991
958	heterogeneity of waste forms; chemical or physical	Prij et al. 1991
959	cellulosic degradation	Prij et al. 1991
960	electrochemical reactions	Prij et al. 1991
961	introduced complexing agents, cellulosics	Prij et al. 1991

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Table 1 (continued)

FEP ID	Initial FEP	Reference[1]
962	material interactions	Prij et al. 1991
963	redox potential, pH	Prij et al. 1991
964	induced chemical changes	Prij et al. 1991
965	diapirism, halokinesis	Prij et al. 1991
966	fault activation	Prij et al. 1991
967	fault generation	Prij et al. 1991
968	fracturing	Prij et al. 1991
969	metamorphic activity	Prij et al. 1991
970	changes in magnetic field	Prij et al. 1991
971	creep of rock	Prij et al. 1991
972	uplift and subsidence	Prij et al. 1991
973	seismicity	Prij et al. 1991
974	undetected geological features	Prij et al. 1991
975	plate tectonics	Prij et al. 1991
976	undetected features	Prij et al. 1991
977	magmatic activity	Prij et al. 1991
978	nuclear criticality	Prij et al. 1991
979	inadvertent inclusion of undesirable materials	Prij et al. 1991
980	radon emanation	Neptune
981	resuspension	Neptune

[1] References for Andersson et al. (1989), Burkholder (1980), Guzowski (1990), Hertzler and Atwood (1989), Hunter (1983), Hunter, (1989), IAEA (1983), Koplik et al. (1982), Merrett and Gillespie, NEA (1992) and Prij et al. (1991) were found in Guzowski and Newman (1993).

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Table 2. List of consolidated FEPs evaluated for inclusion in the conceptual site model and scenarios

Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs[1]**
Climate change	climate change	Climate change can have a large influence on site performance. Climate change includes natural and anthropogenic changes and its effects on hydrology (including lake effects), hydrogeology, glaciation, biota, and human behaviors.	2, 3, 4, 159, 221, 222, 252, 253, 254, 321, 349, 350, 416, 417, 519, 520, 521, 522, 523, 524, 651, 652, 653, 811, 812, 813, 814
	lake effects	A large lake could have detrimental effects on the repository. Lake effects include appearance/ disappearance of large lakes and associated phenomena (sedimentation, wave action, erosion/inundation, isostasy). This is covered within climate change scenarios. Regulations suggest consideration.	656, 789
	wave action	Wave action, including seiches, could influence site performance and is included in long-term scenarios. See lake effects and erosion/inundation.	224, 790
Containerization	containment degradation	A number of processes can contribute to degradation of waste containment. These are accounted for in release of the source term. It is expected that no credit will be given to containment. Regulations suggest consideration.	7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 352, 496, 527, 657, 658, 817, 818, 819, 820
	corrosion	Corrosion is one of the processes that would contribute to degradation of waste containment. Regulations suggest consideration.	18, 19, 20, 161, 353, 419, 659, 821
Contaminant Migration	biotically-induced transport	Plant uptake and burrow excavation are potential contaminant transport (CT) pathways. Modeling includes biotic (plant- and animal-mediated) processes leading to contaminant transport, and the evolution of these processes in response to climate change and other influences, including bioturbation, burrowing, root development, and contaminant uptake and translocation. Regulations suggest consideration.	21, 420, 529, 530, 531, 532, 533, 534, 661, 662, 663, 664, 665, 791, 822
	colloid transport	Colloid formation could be a CT pathway. This process will be considered in the geochemistry conceptual model.	22, 23, 24, 535, 666, 823

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Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs**[1]
	contaminant transport	CT is a large class of processes that govern the migration of contaminants in the environment, including transport media (water, air, soil) processes (advection-dispersion, diffusion, plant uptake, soil translocation) and partitioning between phases; much overlap with atmospheric, groundwater, surface water, and biotically-induced transport. Regulations suggest consideration.	25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 162, 163, 257, 301, 302, 303, 304, 305, 323, 354, 355, 356, 421, 536, 537, 538, 539, 540, 667, 668, 669, 670, 671, 672, 673, 824, 825, 826, 827, 828, 829, 830
	diffusion	Diffusion is a basic CT process that could affect performance. Diffusion occurs in gas and water phases.	36, 306, 324, 674, 831
	dilution	Dilution is a basic CT process that could affect performance. Dilution occurs when mixing with less concentrated water.	37, 675, 832
	dispersion	Dispersion is a basic CT process that could affect performance. Hydrodynamic dispersion is associated with water advection.	38
	dissolution	Dissolution will govern leaching of the waste form into water, limited by aqueous solubility.	39, 40, 164, 225, 258, 325, 326, 422, 541, 676, 833
	dust devils	Dust devils are common on the flats, and could disperse contaminants. These are included in atmospheric dispersion.	792
	gas transport	Radon produced in the waste is likely to be transported via gaseous diffusion. Transport in the gas phase includes gas generation in the waste, partitioning between air and water phases, diffusion in air and water, and radioactive decay and ingrowth.	42, 43, 44, 165, 166, 259, 357, 423, 542, 543, 544, 678, 679, 835
	infiltration	Infiltration through the cap materials, the waste, and unsaturated zone could be an important CT mechanism. This includes infiltration of meteoric water (precipitation minus abstractions) through the cap, into wastes, and potentially to the groundwater.	45, 260, 307
	local geology	This feature will control some aspects of CT and is included implicitly in other processes. Regulations suggest consideration.	545, 546, 547

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Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs**[1]
	preferential pathways	Preferential pathways could contribute to CT. Their presence is accounted for in the definition of advective and diffusive processes. Regulations suggest consideration.	46
Engineered Features	compaction error	Inadequate compaction could result in subsidence. This overlaps with subsidence and closure failure.	680, 836
	engineered features	Many engineered features are intended to improve performance. This large collection of features is intended to promote containment and inhibit migration of contaminants. Regulations suggest consideration.	48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 167, 168, 169, 170, 226, 227, 228, 261, 308, 309, 327, 359, 360, 361, 362, 363, 425, 426, 427, 428, 429, 430, 431, 432, 497, 498, 548, 549, 550, 551, 552, 553, 554, 555, 681, 682, 683, 684, 685, 686, 687, 688, 689,690
	material properties	Material properties are an essential feature of any model, and include density, porosity, hydraulic conductivity, permeability, texture, tortuosity, etc. of waste, backfill, cap materials, and naturally occurring materials.	60, 61, 62, 171, 364, 433, 692, 852, 853, 854
	repository design	Respository design clearly influences its performance. This is accounted for implicitly in the modeling of the repository. Regulations suggest consideration.	695, 696, 858, 859
	source release	Source release is an essential part of the model, and can result from many mechanisms, including containment failure, leaching, radon emanation, plant uptake, and translocation by burrowing animals.	128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 196, 291, 342, 398, 467, 468, 637, 770, 771, 772, 773, 774, 775, 958, 959, 960, 961, 962, 963, 964

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Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs[1]**
	subsidence of repository	Subsidence can compromise performance, leading to failure of the cap, and enhanced infiltration. Regulations suggest consideration.	310, 311, 329, 439, 861
	waste	Waste form and inventory are essential parts of the model. Inventory and source release includes initial inventory of radionuclides and its physical and chemical form, container performance, matrix performance, leaching, and other release mechanisms.	517, 647, 648, 649
Exposure	animal ingestion	Human ingestion of livestock and game exposed to contaminants is an exposure pathway, and is implemented as part of the human exposure model, as ingestion of fodder and feed by livestock, and ingestion of livestock by humans, and similar pathways for game. Regulations suggest consideration.	660
	dosimetry	Dosimetry hints at human dose response, which is an integral part of PA. Physiological dose response will be estimated in the PA model. Dosimetry as a science is not a FEP, *per se.* Regulations suggest consideration.	560, 561
	exposure media	Exposure media are a fundamental part of exposure pathways, and include foodstuffs, drinking water, other environmental media. These are included in the human exposure model. Regulations suggest consideration.	562, 563
	human behavior	Behavior is part of human exposure pathway. Future human behaviors include activities and their frequency and duration, distinct from food and water ingestion. Regulations suggest consideration.	584, 585, 586, 587, 588
	human exposure	Human exposure, in terms of dose and toxicity, is considered in the model, and includes exposure pathways (ingestion, inhalation, etc.) and physiological effects from radionuclides and toxic contaminants. Regulations suggest consideration.	68, 564, 565, 566, 567, 568, 569, 570, 571, 801, 802
	ingestion pathways	Ingestion of food, water, and soils are modeled human exposure pathways. These include human exposures due to ingestion of water and foodstuffs, and transport pathways (e.g. food chains) that lead to foodstuffs. Regulations suggest consideration.	572, 573, 574

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Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs**[1]
	inhalation pathways	Inhalation of gases and fine particles are modeled human exposure pathways. Regulations suggest consideration.	794
Geochemical	geochemical effects	Geochemical processes control CT in waste sources, water, and geologic media. These include chemical sorption and partitioning between phases, aqueous solubility, precipitation, chemical stability, complexing, changes in water chemistry (redox potential, pH, Eh), fluid interactions, halokinesis, diagenesis, speciation, cellulosic degradation effects, interactions with clays and other host materials, effects of corrosion products, effects of cementitious materials, and leaching.	69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 174, 264, 368, 440, 575, 576, 577, 698, 699, 700, 701, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874
Human Processes	anthropogenic climate change	This is addressed as part of climate change in general.	85, 580, 706, 879
	community development	Development of communities and other human habitation overlaps with land use and habitation, and is considered in the human exposure assessment, albeit unlikely. See inhabitation, land use. Regulations suggest consideration.	581
	excavation	Excavation includes construction of basements and other construction, and is included as part of the human intrusion scenarios.	330, 499, 582, 709, 710, 882, 883
	explosions	Human-caused explosions include bombs, plane crashes, and conventional weapons training.	230, 500, 583, 804
	human-induced processes	Human-induced processes are limited to repository design, inadvertent human intrusion, or human-induced climate change. Engineered features include repository design and new technological developments. Intentional intrusion is not considered. Anthropogenic climate change is considered under climate change.	90, 91, 92, 177, 271, 272, 372, 443, 589, 590, 712, 713, 886
	human-induced transport	Human activities that could contribute to release are considered. Humans can induce contaminant transport through a variety of activities. See inadvertent human intrusion.	273, 274, 591, 592, 795, 887
	inadvertent human intrusion	Inadvertent human intrusion into the waste is considered in the development of exposure pathways. Regulations suggest consideration.	178, 179, 231, 275, 276, 277, 373, 374, 375, 444, 445, 446, 714, 805, 806, 888

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Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs[1]**
	inhabitation	Inhabitation on or near the site, including the establishment of surface or underground dwellings, communities, or cities, is extremely unlikely. See community development, land use. Regulations suggest consideration.	93, 94, 593, 594, 807
	institutional control	Institutional control affects human exposures, and includes records of site knowledge, markers, barriers, and security, and the loss thereof. Regulations suggest consideration.	95, 595, 596, 597, 716, 890
	land use	Land use in general could affect exposure scenarios. Land use changes are related to demographics, including development of agricultural, industrial, urban, or wild land uses. Regulations suggest consideration.	183, 450, 600, 601, 602, 719, 720, 893, 894, 895
	post-closure subsurface activities	Subsurface human activities are covered to the extent that they are inadvertent. This could include intrusion, construction, investigation, drilling, or mining. Regulations suggest consideration.	727, 904, 905, 906
Hydrogeological	denudation	Denudation could expose wastes, and is combined with erosion and inundation. Regulations suggest consideration.	192, 388, 460, 502, 503, 739, 917
	erosion	Erosion of the repository resulting from pluvial, fluvial, or aeolian processes can result from extreme precipitation, changes in surface water channels, and weathering. Regulations suggest consideration.	110, 238, 284, 389, 504, 613, 740, 918, 919, 920, 921
	erosional transport	Erosional (sediment) transport could be a CT mechanism. Sediments may move during erosion; includes solifluction. Regulations suggest consideration.	111, 239, 614, 615, 741, 742, 922, 923
	hydrogeological effects	Hydrogeological and groundwater hydraulics changes may occur in response to geological changes, including hydrothermal activity. This is generally covered under groundwater transport. Regulations suggest consideration.	112, 616, 617, 618, 619, 743, 744, 796, 924
	sedimentation	Sedimentation would occur on a lake bottom, and could affect performance. This includes sedimentation/aggradation onto the repository.	113, 193, 285, 335, 390, 461, 621, 797

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Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs**[1]
Hydrology	groundwater transport	Groundwater transport includes waterborne contaminant transport (CT) in the unsaturated and saturated zones, and is a principal CT mechanism. Groundwater flow and transport mechanisms include advection-dispersion, diffusion, fluid migration, waterborne contaminant transport, changes in the flow system, recharge and discharge, water table movements, and brine interactions.	114, 115, 116, 117, 118, 286, 312, 313, 314, 315, 316, 336, 337, 338, 339, 392, 393, 622, 623, 747, 748, 749, 750, 751, 752, 929, 930, 931, 932, 933, 934, 935, 942
	hydrological effects	Hydrological processes are considered under the topics of surface water and groundwater. Regulations suggest consideration.	463, 505, 624, 753, 754, 936, 937
	inundation	Inundation by a large lake or reservoir is likely to affect the site in the long term. (See also: wave action, and lake effects). Regulations suggest consideration.	755, 798, 938, 939
Meteorology	frost weathering	Weathering from frost cycles is included in cap degradation modeling.	758, 943
	meteorology	Meteorology is considered indirectly; meteorology as a science is not a FEP, *per se*, but contributes to other processes, such as precipitation and atmospheric dispersion, which are covered elsewhere. Regulations suggest consideration.	626, 627, 761, 946, 947
	resuspension	Resuspension will affect site performance, allowing particulates from surface soils to be redistributed by atmospheric dispersion.	981
	atmospheric dispersion	Atmospheric dispersion is a potential CT pathway and is modeled. See also: dust devils. Regulations suggest consideration.	256, 528
	tornado	Tornados are possible in the area.	289
Model Settings	model parameterization	Parameterization is a fundamental part of modeling, though is not a FEP, *per se*.	628
	period of performance	Definition of a period of performance is a fundamental part of PA modeling, though is not a FEP, *per se*.	629
	regulatory requirements	Regulatory requirements drive much of the modeling in PA, though is not a FEP, *per se*.	630
	spatial domain	Definition of a spatial domain is a fundamental part of modeling, though is not a FEP, *per se*.	631

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Table 2 (continued)

Neptune Subgroup	**Normalized FEP (accepted)**	**Discussion**	**Representative ~~1~~ FEP IDs[1]**
Other Natural Processes	ecological changes	Changes in the types and abundance of plants and animals could affect performance. Changes in the ecology can be associated with catastrophic events (e.g. fire, inundation), evolution, or climate change.	762, 948, 949
	gas generation	Uranium wastes are expected to produce radon which will affect site performance in terms of doses. See also gas transport.	122, 123, 340, 396, 464, 634, 766, 953, 954
	pedogenesis	Soils are likely to develop on the cap and may affect performance.	765, 952
	radioactive decay and in-growth	Radioactive decay and ingrowth processes are essential to the model.	635, 767, 799, 955
	radon emanation	Radon emanation directly affects the mass of radon released into the environment, and hence site performance.	980
	reconcentration	Possible reconcentration of radiological materials during transport is accounted for in the CT modeling.	127
Tectonic/ Seismic/ Volcanic	geophysical effects	Geophysical changes to the engineered features of the site are accounted for in degradation. Geophysical effects include pressure, stress, density, viscosity, deformation, magnetics, creep, and elasticity.	141, 142, 143, 509, 641, 781, 970, 971

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~~T~~[1] The Representative FEP IDs correspond to the FEP IDs given in Table 1.

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Table 3. List of FEPs dismissed from further consideration.

Table 3 (continued)

Neptune Subgroup	**Normalized FEP (dismissed)**	**Discussion**	**Representative ~~1~~ FEP IDs**[1]
Celestial	meteorite impact	The occurrence and consequences of a direct hit by a meteorite are out of the scope of this model.	1, 158, 219, 220, 251, 320, 348, 415, 491, 492, 493, 518, 650, 810
Climate change	glacial effects	Glacial effects include presence of continental glaciers and resulting isostatic effects, glacial erosion, and periglacial effects. Glaciers in the basin are not modeled. Return of a large lake is expected should a glacial epoch return and is covered within climate change scenarios.	5, 160, 223, 255, 322, 351, 418, 494, 495, 525, 526, 654, 655, 815, 816
	permafrost	The effects of permafrost are bounded by those of cap degradation, which considers more damaging freeze/thaw cycles. See frost weathering.	6, 300
Contaminant Migration	gas intrusion	No mechanism for intrusion of naturally-produced gases into the repository has been identified.	41, 677, 834
Engineered Features	convergence of openings	This FEP applies to mined repositories only.	837
	design error	Errors in design could compromise performance but are not included in the modeling. Design error is distinct from construction or operational error.	47, 358, 424
	material defects	Material defects are covered by degradation, and include material defects in source containment, closure cap, and other engineered materials.	691, 851
	mechanical effects	Mechanical effects are covered implicitly by degradation, and include changes in mechanical properties and conditions, including failure.	63, 64, 65, 172, 262, 365, 366, 434, 435, 556, 557, 693, 694, 855, 856
	release of stored energy	No significant energy is stored within the wastes.	66, 436, 857
	repository seals	Regulations suggest consideration, but, the sealing of the repository shafts, boreholes, and construction and failure of such is applicable only to mined repositories.	67, 173, 229, 263, 328, 367, 437, 558, 559, 697, 860

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Table 3 (continued)

Neptune Subgroup	**Normalized FEP (dismissed)**	**Discussion**	**Representative ~~1~~ FEP IDs**[1]
Exposure	agriculture	Agriculture includes establishment, evolution, and abandonment of agriculture and aquaculture at and near the site. Regulations suggest consideration, however, none of these are expected to occur because of the high salinity of soils and groundwater at the site.	705, 803, 878
Geological	diagenesis	Diagenesis in local lacustrine sediments could include the formation of interstitial evaporites, but is not expected to change site performance.	83, 175, 265, 369, 441, 578, 702, 875
	gas or brine pockets	No gas or brine pockets have been identified below the site.	176, 370, 442, 579
	landslide	Regulations suggest consideration, but landslides are not expected to occur in the flat lacustrine basin. Mass wasting of the site itself is covered under erosion.	266, 703, 876
	local subsidence	Geological subsidence in the area is unlikely to seriously affect performance, and is not expected in the basin of lacustrine sediments.	267
Human Processes	accidents during operations	Regulations suggest consideration, but operational performance is not within the scope of the PA model.	84, 704, 877
	climate control	No climate control at the facility is assumed. Climate control is a feature of certain mined repositories.	268, 371
	closure failure	Regulations suggest consideration; however, poor closure includes abandonment or other failure to close the facility as planned, and is not modeled.	86, 87, 707, 708, 880, 881
	fire	The waste is not combustible or explosive. Fires in the waste itself or following explosions are distinct from wildfire.	269, 270
	fisheries	Regulations suggest consideration, but development of fisheries is not credible at the site.	884
	geothermal energy production	No geothermal resources are identified at the site.	89, 711, 885
	injection wells	Given the regional history, the construction of injection wells nearby for disposal of liquid wastes is possible. The effect of drilling such wells in the vicinity would be negligible, however.	232, 715, 889

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Table 3 (continued)

Neptune Subgroup	**Normalized FEP (dismissed)**	**Discussion**	**Representative ~~1~~ FEP IDs[1]**
	intentional intrusion	Intentional intruders are not protected and are not modeled as receptors. Intentional intrusion includes exhumation of waste, sabotage, terrorism, or archeological research.	96, 180, 181, 278, 376, 377, 447, 448, 717, 808, 891
	investigation	Site investigation is considered intentional, and receptors are not covered.	598, 599, 809
	irrigation	Regulations suggest consideration, and irrigation could affect site performance, but will not occur since there is no suitable water source.	182, 233, 378, 449, 718, 892
	monitoring	Monitoring of the site is required, but persons performing the activity are not protected since it is intentional and informed. Monitoring activities will not affect the performance of the site.	97, 603, 721, 896
	nuclear testing	Regulations suggest consideration; however, testing of nuclear devices underground, at the ground surface, or in the atmosphere is considered intentional disruption of the site and is not covered.	98, 722, 897
	operational effects	Operations could affect performance, and include normal site operation, closure, and later attempts at site improvement. Regulations suggest consideration; however, operations are not part of the PA.	99, 604, 605, 723, 724, 898, 899, 900
	operational error	Covered under operational effects. Operational errors include poor quality site construction, waste emplacement, and site closure. Regulations suggest consideration, however, operations are not part of the PA.	100, 184, 279, 379, 380, 451, 725, 726, 901, 902, 903
	quality control	Quality control is important to site operations, but is not a FEP that lends itself to modeling.	606
	resource extraction	Regulations suggest consideration. Resource extraction is a type of intentional intrusion, including drilling, mining, or quarrying into the repository, or in such a way as to affect performance, in search of resources such as petroleum, natural gas, salt, rock, or geothermal resources. See intentional intrusion.	101, 102, 103, 185, 186, 234, 235, 280, 331, 332, 381, 382, 383, 452, 453, 501, 608, 609, 728, 729, 730, 731, 907, 908, 909, 910
	sabotage	Sabotage is by its nature intentional. See intentional intrusion.	104, 187, 333, 384, 454, 732, 733, 911, 912

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Table 3 (continued)

Neptune Subgroup	Normalized FEP (dismissed)	Discussion	Representative ~~1~~ FEP IDs[1]
	unplanned events	This category is too vague to be considered explicitly; unplanned events are generally subsumed by other FEPs.	610
	war	Intrusion or disruption as part of an act of war would be intentional. See intentional intrusion.	105, 188, 334, 385, 455
	waste recovery	Regulations suggest consideration, but waste recovery, retrieval, or mining are considered intentional acts. See intentional intrusion.	106, 189, 386, 456, 607.734, 735
	water resource management	Water resource activities include construction of dams, reservoirs, and wells, and could affect the site as water is extracted or retained. Regulations suggest consideration; however, this is not specifically modeled, as it is bounded by the large lake scenario.	107, 108, 109, 190, 236, 237, 281, 282, 387, 457, 458, 611, 736, 737, 913, 914, 915
	weapons testing	Any nuclear and conventional weapons testing would be done with cognizance of the site, and is intentional. See also explosions and intentional intrusion.	191, 283, 459
Hydrogeological	subrosion	No subsurface erosion has been reported in the vicinity.	925
Hydrology	flooding	Regulations suggest consideration; however, temporary flooding of the site due to extreme precipitation is not plausible due to site topography in the midst of the flats. This is distinct from inundation by the return of a large lake, which is included.	194, 240, 391, 462, 746, 926, 927, 928
	surface water transport	Surface water transport includes formation and changes in rivers, lakes, and streams, and transport of dissolved and suspended solids, and sediments. Such effects are not anticipated at the facility. This is distinct from inundation by the return of a large lake, which is included.	119, 241, 287, 317, 318, 319, 394, 395, 625, 756, 757, 940, 941
Marine	coastal processes	Coastal processes will not apply at the site, since no sea or ocean is expected in relevant time frames. However, see wave action.	612, 738, 760, 916, 945
	hurricanes	No hurricanes occur in the area.	242, 288
	insolation	Insolation (the amount of sunshine on the site) has no direct effect on site performance. See ecological changes.	759, 944

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Table 3 (continued)

Neptune Subgroup	**Normalized FEP (dismissed)**	**Discussion**	**Representative ~~1~~ FEP IDs[1]**
	marine effects	Marine processes will not apply at the site, since no sea or ocean is expected in relevant time frames. Marine processes include sea-level change. See also coastal processes and tsunami.	620, 745
	tsunami	No tsunami will occur at the site. See coastal processes and marine effects.	243
Natural Processes	microbial effects	Microbial action is not expected to affect performance. Microbial processes include corrosion, changes in chemistry, and dissolution of glasses, but biotically-induced transport is limited to macrobiological processes.	120, 632, 633, 763, 764, 950, 951
	radiological effects	Regulations suggest consideration. Radiological processes such as radiolysis are a concern for waste containment in some geological repositories, but are not modeled here, since waste containment is not given credit.	124, 125, 126, 195, 341, 397, 465, 466, 636, 768, 769, 956, 957
	wildfire	Occasional wildfire (brush fire, forest fire, either local or widespread) is not likely to affect site performance in the long run, since this is a natural part of plant community dynamics.	290
Source Release	electrochemical effects	Electrochemical effects are not a relevant process at the site. Electrochemical reactions are a concern for the SKB repository.	121
	explosions	Explosive gases are not present in the repository.	88
Tectonic/ Seismic/ Volcanic	breccia pipes	Regulations suggest consideration, and the formation of breccia pipes or mud volcanoes could affect performance, but is considered highly unlikely.	197, 343, 399, 469
	diapirism	Salt deposits in the strata below the site will not result in the formation of diapirs.	198, 244, 292, 344, 400, 470, 638, 776, 965
	discontinuities	No major geological discontinuities are envisioned at the site.	639
	earthquake	Earthquakes, either from natural or man-made causes, would not change the performance of this shallow unconsolidated site.	138, 293

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Table 3 (continued)

Neptune Subgroup	**Normalized FEP (dismissed)**	**Discussion**	**Representative ~~1~~ FEP IDs**[1]
	faulting	Faulting is unlikely to significantly affect performance of this shallow unconsolidated site and is not explicitly modeled. Geologic faulting includes all type of faults, shear zones, diastrophism, existing and future. See also see fracturing.	139, 199, 200, 201, 245, 294, 345, 401, 402, 471, 472, 473, 506, 507, 508, 777, 778, 966, 967
	fracturing	Tectonic fracturing will not affect unconsolidated site performance.	202, 203, 204, 205, 246, 403, 474, 475, 476, 477, 779, 968
	geological intrusion	Magmatic and intrusive igneous activity has not been identified in the vicinity of the site. Geological intrusion includes dikes, intrusive and magmatic activity, and metamorphism due to such activity. This is distinct from breccia pipes (mud volcanoes) and human intrusion.	140, 206, 207, 295, 346, 404, 405, 478, 479, 640, 780, 969
	hydraulic fracturing	Hydraulic fracturing is performed in solid rock, and has no applicaton at the site. Hydraulic fracturing ("hydrofracking") is induced by humans to enhance resource recovery or liquid waste disposal by injection.	208, 480
	intrusion into accumulation zone in the biosphere	No accumulation zone in the biosphere has been identified at the site.	144
	isostatic effects	Isostatic changes could influence lake levels, which are accounted for elsewhere. Isostasy includes that caused by tectonics, large bodies of water, and by continental glaciers.	209, 406, 481, 510, 511
	lava tubes	No lava tubes exist at the site or are expected in the future.	210, 407, 482
	orogeny	No significant orogeny is expected in relevant time frames. Orogeny (mountain-building) caused by tectonic movements or regional uplift.	211, 247, 296, 408, 483
	regional subsidence	Regional subsidence could influence lake levels, which are accounted for elsewhere.	145, 409, 782, 972
	seismic effects	Regulations suggest consideration, but effects of seismic activity (see also earthquakes) would be insignificant for shallow land burial.	248, 512, 513, 642, 783, 973

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Table 3 (continued)

Neptune Subgroup	Normalized FEP (dismissed)	Discussion	Representative ~~1~~ FEP IDs[1]
	tectonic effects	Tectonic effects could influence lake levels, which are accounted for elsewhere.	146, 147, 148, 149, 212, 213, 410, 484, 643, 644, 784, 785, 974, 975, 976
	volcanism	No significant volcanism is expected in relevant time frames.	150, 214, 249, 250, 411, 412, 485, 486, 514, 515, 516, 645, 786, 800, 977
Waste	nuclear criticality	Nuclear criticality, while a concern for repositories of used nuclear fuel, is not a concern at this LLW site.	151, 152, 215, 297, 347, 413, 487, 646, 787, 978
	other waste	The current analysis is constrained to examine depleted uranium wastes only, including associated "contaminant" waste. This rather vague reference to "other waste" will be addressed as the scope of wastes under consideration expands.	153, 154, 155, 156, 157, 216, 217, 218, 298, 299, 414, 488, 489, 490, 788, 979

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[1] ~~T~~ The Representative FEP IDs correspond to the FEP IDs given in Table 1.

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