Safety Framework for Disposal of Heat-Generating Waste in Salt: Features, Events, and Processes (FEPs) Classification

Fuel Cycle Research & Development

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Used Fuel Disposition

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Technical Review (TR)	**Peer Review (PR)**
Review Documentation Provided	**Review Documentation Provided**
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☐ Signed TR Concurrence Sheet or,	☐ Signed PR Concurrence Sheet or,
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Robert MacKinnon — Robert MacKinnon [signature]

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ACRONYMS

DOE	U.S. Department of Energy
DRZ	disturbed rock zone
FEP	feature, event, and process
FY	fiscal year
HLW	high-level radioactive waste
IAEA	International Atomic Energy Agency
NE	Office of Nuclear Energy
NEA	Nuclear Energy Agency
PA	performance assessment
R&D	research and development
SRDI	Salt Research and Development Investigations
UFD	Office of Used Nuclear Fuel Disposition
UNF	used nuclear fuel

SAFETY FRAMEWORK FOR DISPOSAL OF HEAT-GENERATING WASTE IN SALT: FEATURES, EVENTS, AND PROCESSES (FEPS) CLASSIFICATION

1. INTRODUCTION

The U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) Office of Used Nuclear Fuel Disposition (UFD) is conducting research and development (R&D) on generic deep geologic disposal systems (i.e., repositories) for high-activity nuclear wastes that exist today or that could be generated under future fuel cycles. The term high-activity waste (U.S. Nuclear Waste Technical Review Board 2011) refers collectively to both used nuclear fuel (UNF) from nuclear reactors and high-level radioactive waste (HLW) from reprocessing of UNF, and from other sources.

In Fiscal Year (FY) 2012, DOE-NE together with the DOE Office of Environmental Management (DOE-EM) initiated an R&D effort for Salt Research and Development Investigations (SRDI), focused on gaining a further understanding of mined geologic disposal in salt (McMahon 2012). The primary SRDI activities undertaken in FY2012 and continued in FY2013 were:

- Activity 1: Existing Salt Data Compilation and Assessment
- Activity 2: Test Planning for Re-Entry into the North Experimental Area of the Waste Isolation Pilot Plant (WIPP)
- Activity 3: Thermal, Mechanical, Hydrologic, and Chemical Laboratory Studies Related to Salt
- Activity 4: Modeling Studies Related to Salt
- Activity 5: International Collaboration
- Activity 6: Salt Instrumentation Development and Test Methodologies

In support of SRDI Activity 4, an annotated outline of a safety framework for geologic disposal of heat-generating waste at a generic salt site was produced in FY2012 (Freeze et al. (2012). The safety framework provides a structure for the advancement of a safety case for disposal in salt. An overview of the safety framework as it relates to the elements of a safety case is presented in Section 1.1.

This report expands on the annotated outline of the safety framework by presenting a classification structure for the features, events, and processes (FEPs) that describe a generic salt repository. The FEP classification structure is represented using a FEP matrix, where the axes of the matrix have a direct correlation to relevant performance assessment elements of the safety framework and the safety case. This correlation between FEP classification and the safety case elements supports an integrated management strategy and performance assessment model implementation that can be used to prioritize SRDI R&D activities via a risk-informed approach. An overview of the FEP analysis is presented in Section 1.2. The FEP classification matrix approach for a generic salt repository is described in Section 2.

This report addresses the following milestone:

- *Level 3 Milestone, Quality Rigor Level (QRL)3* – Safety Framework for Disposal of Heat-Generating Waste in Salt (M3FT-13SN08180325)

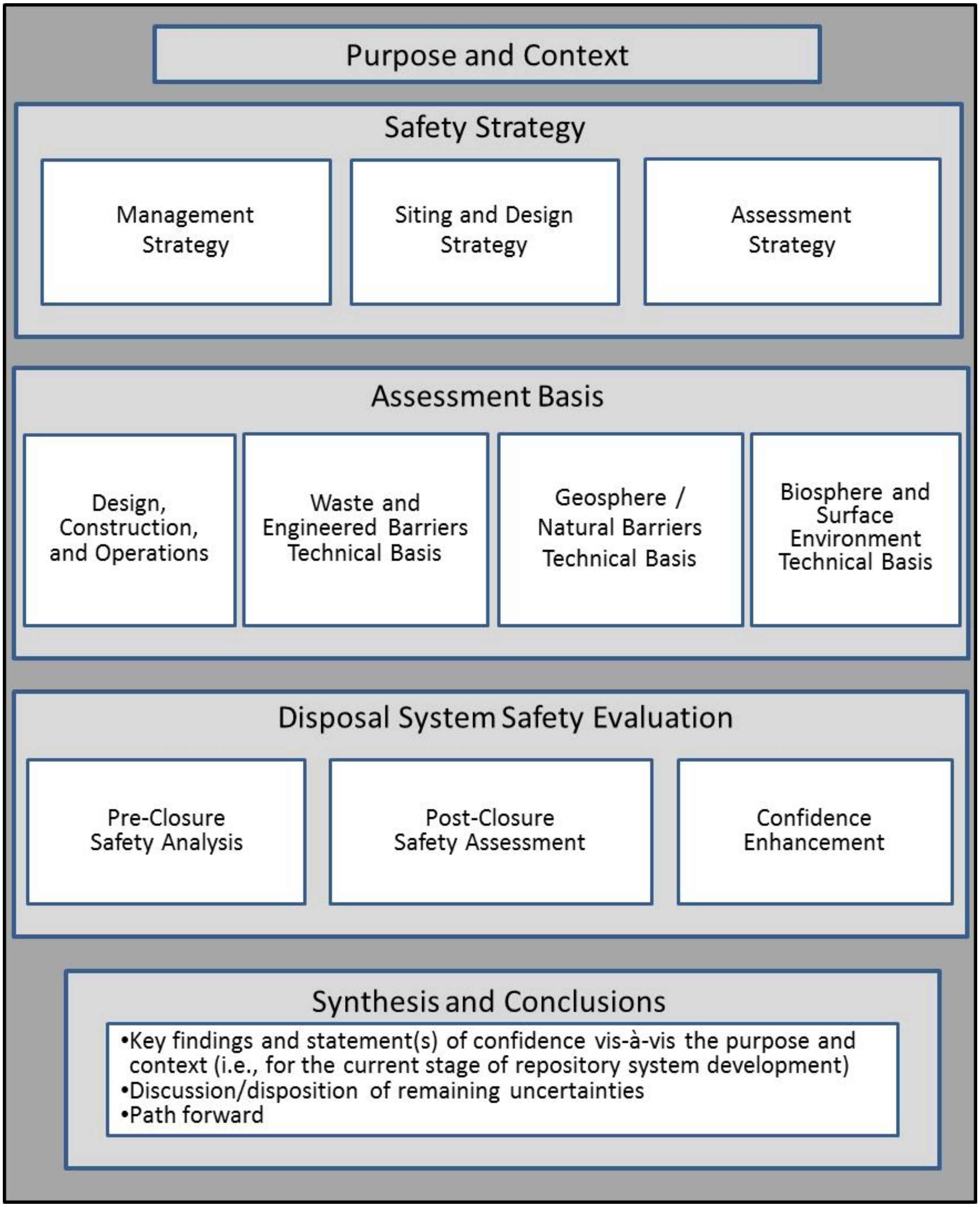
1.1 Safety Framework and Safety Case Overview

The formal concept of a safety case for the long-term disposal of UNF and HLW in an engineered facility located in a deep geologic formation was first introduced by the Nuclear Energy Agency (NEA) (NEA 1999a). Initial discussion and documentation on the topic continued in NEA (2002), NEA (2004), and IAEA (2006). More recently, there have been a number of international symposia, conferences, working groups, and summary papers devoted to understanding, developing, and/or summarizing the nature, purpose, context, and elements of safety cases (e.g., NEA 2008; NEA 2009; IAEA 2011; Schneider et al. 2011; Van Luik et al. 2011; and NEA 2013). In these recent summary and overview reports, there is notable convergence in the understanding and development of safety case documents published by national and international organizations. From these documents, Freeze et al. (2012, Section 1.1) compiled the following definitions:

> *A <u>safety case</u> is an integrated collection of qualitative and quantitative arguments, evidence, and analyses that substantiate the safety, and the level of confidence in the safety, of a geologic repository. Two of its major roles are as a management tool to guide the work of the implementer (e.g., DOE) through the various phases of repository development and to communicate the understanding of safety to a broad audience of stakeholders (National Research Council 2003). With regard to the former, because of various technical uncertainties associated with a complex one-of-a-kind repository project, the safety understanding and basis evolves through time. The safety case assists in organizing and synthesizing existing knowledge and prioritizing the future R&D work during repository planning and development, in order to reduce uncertainties and enhance the confidence in safety.*

> *A <u>safety framework</u> is not as detailed or complete as a safety case. The safety framework for salt disposal follows the outline of the elements of a safety case, identifies the types of information that will be required to satisfy the elements of the safety case, and anticipates where currently available generic information may exist. The development of a salt safety framework for salt disposal is consistent with the current UFD approach to generic repository R&D, and it provides an outline to organize the other SRDI activities in accordance with the safety case elements, thereby indicating where there are gaps in the documentation and research.*

The following major elements of the salt safety framework, which map to the general elements of a safety case, are shown schematically in Figure 1-1. The safety framework structure can be used as a management tool to integrate and prioritize other SRDI testing and modeling activities via a risk-informed approach, and as a communication tool to inform stakeholders of SRDI results.



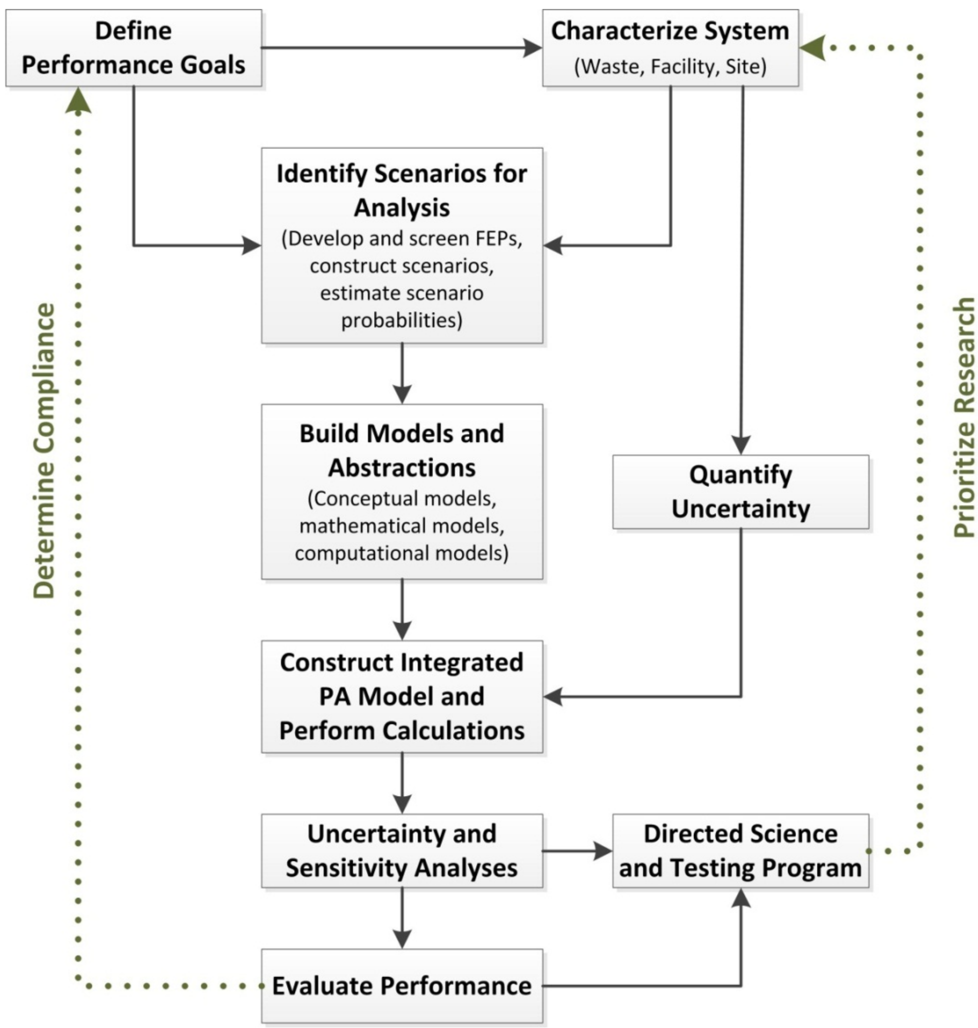
Modified from Freeze et al. (2012, Figure 1-1) and NEA (2004, Figure 1)

Figure 1-1. Major Elements of the Salt Safety Case

1.2 FEP Analysis Overview

Within the safety framework structure (Figure 1-1), FEP analysis is part of the Post-Closure Safety Assessment element. Post-closure safety assessments (also referred to as performance assessments (PAs)) pre-date the concept of a safety case. The historical context of safety assessment is described in NEA (1991) and NEA (1997); in addition, the role of safety assessment is discussed in the safety case reference documents identified in Section 1.1. For long-term geologic disposal, safety assessment generally refers to the quantitative analysis of post-closure disposal system performance (i.e., the period after the facility closure and beyond the time when active control of the facility can be relied on).

In a safety case, the post-closure safety assessment is supported by the Safety Strategy (specifically, the Assessment Strategy) and the Assessment Basis. As described in Freeze et al. (2012, Section 3.3), the assessment strategy can be formalized in terms of a safety assessment or PA methodology. The PA methodology consists of nine steps, which are progressively updated and repeated during the various phases of repository lifecycle (Meacham et al. 2011, Section 1.2.2). Figure 1-2 shows the sequential and iterative nature of these nine steps. Details of the general application of each of the steps are provided in Meacham et al. (2011, Section 1.2.2).



Source: Meacham et al. (2011, Figure 2)

Figure 1-2. PA Methodology

As shown in Figure 1-2, FEP analysis is part of the scenario development step of the PA methodology, which in turn informs the construction of models and the uncertainty and sensitivity analyses. Formal FEP analysis includes: (1) FEP identification – the development and classification of a comprehensive list of FEPs that cover the entire range of phenomena that are potentially relevant to the long-term performance of a salt disposal system, and (2) FEP screening – the specification of a subset of important FEPs that individually, or in combination with other FEPs, may have a measurable or observable effect on long-term performance. These important FEPs must be included in the post-closure PA model. The exclusion of a FEP from the PA model (e.g., by low probability, by low consequence, or by inconsistency with regulation) must be supported by a defensible rationale. In the context of a safety framework, the included FEPs are indicative of technical areas where R&D focus may be necessary. R&D may also be necessary to provide robust, defensible screening rationales for excluded FEPs.

FEP identification for a range of generic disposal systems is documented in Freeze et al. (2010) and Freeze et al. (2011). The modification of these generic FEPs and a preliminary screening relative to the salt disposal reference case is documented in Sevougian et al. (2012, Section 3.1.2).

This report describes the development of a FEP classification matrix, where the axes of the matrix have a direct correlation to relevant performance assessment elements of the safety framework and the safety case. The FEP classification matrix is used to organize the salt repository FEPs by feature and by process/event. The FEP classification matrix approach for a generic salt repository is described in Section 2.

2. SALT REPOSITORY FEP CLASSIFICATION MATRIX

A preliminary set of 208 FEPs potentially relevant to the disposal of UNF and HLW in a generic salt disposal system are listed in Sevougian et al. (2012, Appendix A). The salt repository FEPs derive from a list of 208 UFD FEPs developed by Freeze et al. (2011, Appendix A) for a generic disposal system in any one of four different disposal concepts: mined crystalline/granite, mined shale/clay, mined salt, and deep borehole crystalline. The UFD FEPs in Freeze et al. (2011) were developed from several comprehensive FEP lists and other relevant information (NEA 1999b, Appendix D; NEA 2006; SNL 2008).

2.1 FEP Numbering and Categorization Scheme

The salt repository FEPs (and the UFD FEPs) are categorized using a hierarchical numbering scheme that is very similar to the NEA classification scheme (NEA 1999b, Section 3). The numbering and categorization hierarchy is shown schematically in Figure 2-1.

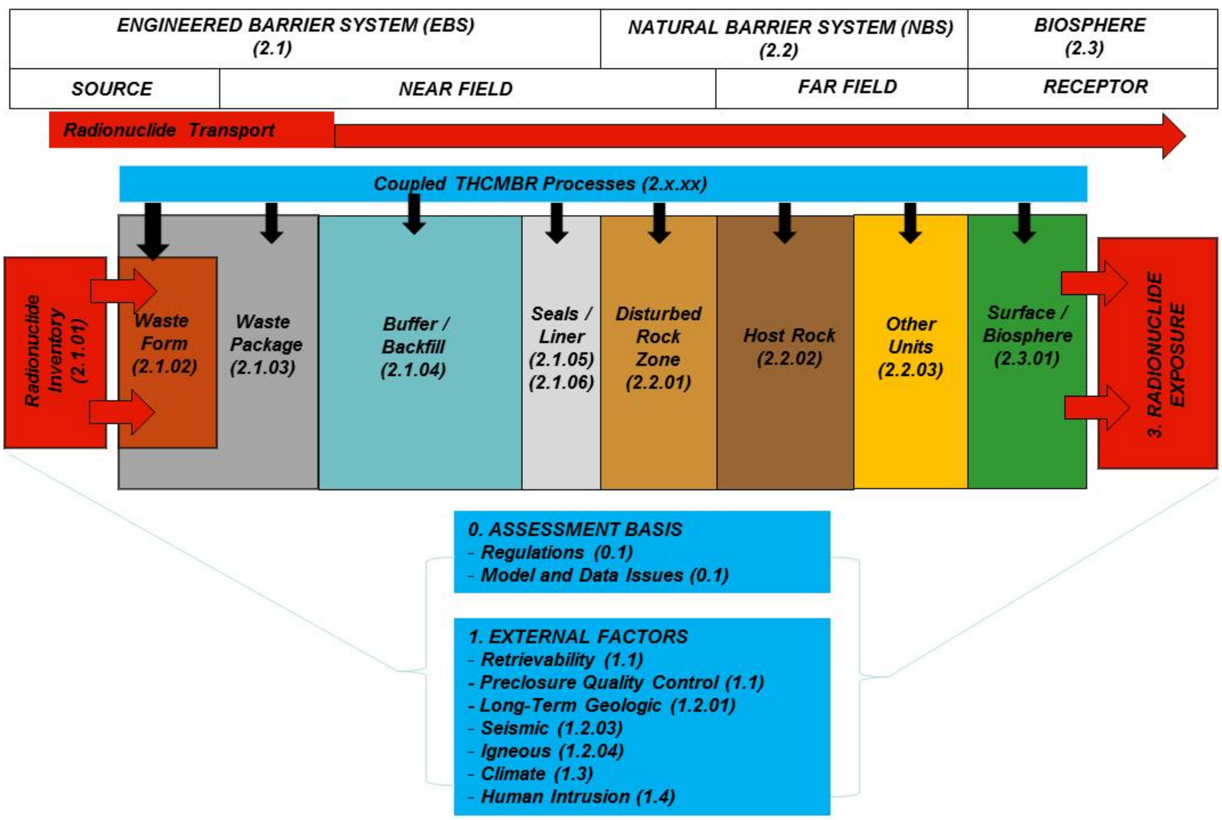


Figure 2-1. Hierarchical FEP Numbering and Categorization Scheme

The hierarchical classification levels are organized around the common regions and features of a disposal system: the Engineered Barrier System (EBS) which includes the wastes (e.g., inventory and waste forms) and engineered features (e.g., waste container/package, buffer/backfill, and seals); the Natural Barrier System (NBS) or geosphere which includes the disturbed rock zone (DRZ), host rock, and other geological units; and the Biosphere which includes the surface environment and receptor characteristics. In addition to the region/feature-based categories, there are also categories for the Assessment Basis and External Factors.

The classification hierarchy is established using the FEP numbering scheme. The first four digits of a FEP number correspond to hierarchical classification levels:

- 4 Layers (entries having the form X.0.00.00). These are:

  0 = Assessment Basis,
  1 = External Factors,
  2 = Disposal System Factors, and
  3= Radionuclide/Contaminant Factors.

- 12 Categories (entries having the form X.X.00.00). Examples of Categories under Disposal System Factors (2.X.00.00) are:

  2.1 = Wastes and Engineered Features,
  2.2 = Geologic Environment,
  2.3 = Surface Environment.

- 43 Headings (entries having the form X.X.XX.00 or X.X.XX.50). Examples of Headings under Disposal System Factors – Wastes and Engineered Features (2.1.XX.00) are:

  2.1.01= Inventory,
  2.1.02 = Waste Form,
  2.1.03 = Waste Container,
  2.1.04 = Buffer/Backfill,
  2.1.05 = Seals,
  2.1.06 = Other EBS Materials,
  2.1.07 = Mechanical Processes,
  2.1.08 = Hydrologic Processes,
  2.1.09 = Chemical Processes - Chemistry,
  2.1.09 = Chemical Processes - Transport,
  2.1.10 = Biological Processes,
  2.1.11 = Thermal Processes,
  2.1.12 = Gas Sources and Effects,
  2.1.13 = Radiation Effects,
  2.1.14 = Nuclear Criticality.

These 59 classification entries provide an organization structure for the 208 FEPs, which all have UFD FEP Numbers in the form X.X.XX.XX. The first four digits of a FEP number serve to group related FEPs by their Layer, Category, and Heading. However, at the lowest classification level (Heading), there can be some redundancies. For example, the Heading entries shown above for Disposal System Factors – Wastes and Engineered Features consist of a mixture of feature-based Headings (e.g., 2.1.01 through 2.1.06) and thermal-hydrologic-mechanical-chemical-biological-radiological (THCMBR) process-based Headings (e.g., 2.1.07 through 2.1.14). Because an individual FEP is typically a process (or event) acting upon a feature, many FEPs can be mapped to more than one Heading in this NEA-based classification scheme (e.g., an Individual FEP can be often be mapped to both a feature-based Heading and to a process-based Heading). Therefore, this organizational structure makes it difficult to find a unique "home" for all FEPs, and can result in related FEPs not all being grouped under the same Heading.

2.2 FEP Classification Matrix Approach

As described in Section 2.1, the NEA-based numbering and categorization scheme can be used to organize a FEP list, but redundancies in the classification entries (i.e., the Headings) make it difficult to completely group related FEPs and therefore it can be difficult to find all related FEPs within the FEP list. To overcome this shortcoming, a FEP classification matrix approach was developed to help organize the salt repository FEPs. The FEP matrix approach is refined from an earlier application (SNL 2008, Section

6.1.3). The FEP matrix, shown in Figure 2-2, provides a two-dimensional organizational structure that consists of a Features axis that defines the “rows” and a Processes/Events axis that defines the “columns”.

The Features axis is organized to generally correspond to the direction of flow and transport, from the waste to the receptor. Features are organized in hierarchical categories. At the top level are: Waste and Engineered Features (e.g., the Engineered Barrier System (EBS)), Geosphere Features (e.g., the Natural Barrier System (NBS)), Surface Features (e.g., the Biosphere), and System Features. Surface Features include FEPs that are relevant to the calculation of dose to the receptor, which may include radionuclide movement above the subsurface. System Features include FEPs that are potentially relevant to the repository system as a whole. As shown in Figure 2-2, there are lower-level categories below each of the top-level categories. For example, under Waste and Engineered Features are: Waste Form and Cladding, Waste Package and Internals, Buffer/Backfill, Emplacement Drifts/Tunnels (i.e., the open air regions that may be resent in non-backfilled open-mode designs), and Seals/Plugs. Below each of these sub-categories, a further level of detail may also be specified (e.g., under Waste Form there may be a need for a distinction between SNF and HLW and commercial and defense waste). It should be noted that the hierarchical feature categories are fairly generic at the top level, but may become disposal option specific at the sub-levels. For example, the sub-categories below the Host Rock and below the Other Geologic Units are specific to a salt repository.

The Processes and Events axis contains categories for FEPs that can act upon a Feature. A description of each of the Processes and Events categories is provided below. Two categories require some clarification:

- **Characteristics** are used to describe the properties of the features that need to be evaluated. The characteristics are not typically FEPs in the sense that they cannot be screened in or out, but the characteristic information (and changes to that information) influences the screening of the other FEPs. For example, the initial radionuclide inventory is considered a characteristic of the waste form.
- **Thermal** processes (conduction, radiation, convection) are generally treated in a coupled fashion with the process affected by thermal conditions. For example, the processes are referred to as thermal-mechanical, thermal-hydrologic, or thermal-chemical to indicate the principal couplings considered. The convention used to describe coupled processes places the principal causing process first and the affected process second. For example, thermal-chemical processes are those in which the thermal environment affects the behavior of the chemical environment. Generally, the reverse coupling (in this example, the effect of chemistry change on the thermal environment) is significantly weaker than the forward coupling. There is also an independent thermal process category, but past experience suggests it is usually difficult to isolate the thermal aspects of most FEPs.

Characteristics, Processes, and Events / Features	Characteristics	Processes											Events					
		Mechanical and Thermal-Mechanical	Hydrological and Thermal-Hydrologic	Chemical and Thermal-Chemical	Biological and Thermal-Biological	Transport and Thermal-Transport	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities (Long Timescale)	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities (Short Timescale)	Other
Waste and Engineered Features																		
Waste Form and Cladding																		
• Commercial SNF & Cladding																		
• Commercial HLW Glass																		
• Naval SNF & Cladding																		
• Defense SNF & Cladding																		
• Defense HLW																		
• Other																		
Waste Package and Internals																		
• Commercial SNF																		
• Commercial HLW																		
• Naval SNF																		
• Defense SNF																		
• Defense HLW																		
• Other Package Types																		
Buffer/Backfill																		
• Waste Package Buffer																		
• Tunnel/Drift/Room Backfill																		
Emplacement Tunnels/Drifts																		
• Open Excavations																		
• Tunnel/Drift Support																		
• Liners																		
• Other																		
Seals/Plugs																		
• Drift/Panel Closures																		
• Shaft Seals																		
• Plugged Boreholes																		
Geosphere Features																		
Host Rock (Repository Horizon)																		
• Bedded or Domal Salt																		
• Excavation Disturbed Zone																		
• Interbeds & Seams																		
Other Geologic Units																		
• Aquifer(s)																		
• Unsaturated Zone																		
• Pressurized Brine Pocket(s)																		
Surface Features																		
Biosphere																		
• Natural Surface and Near-Surface Environment																		
• Flora and Fauna																		
• Humans																		
• Food & Drinking Water																		
• Dwellings & Man-made Surface Features/Materials																		
System Features																		
Repository System																		
• Assessment Basis																		
• Preclosure/Operational																		
• Other Global																		

Figure 2-2. FEP Matrix

A brief description of the Processes follows:

- **Mechanical** processes include drift degradation and a range of mechanical processes that affect the degradation of engineered features. These mechanical processes include salt creep, rockfall, drift collapse, stress corrosion cracking, hydrogen embrittlement, buckling, floor heave, metamorphism, and diagenesis, among others. Mechanical processes also include processes that change rock properties such as porosity. **Thermal-mechanical** processes include thermal stresses and their corresponding effects on rock mass strength and degradation.
- **Hydrologic** flow processes include precipitation, infiltration, runoff, unsaturated zone flow, flow diversion, capillarity, matrix imbibition, evaporation, condensation, and saturated zone flow. **Thermal-hydrologic** processes include evaporation, condensation, vapor flow, and temperature-dependent property changes.
- **Chemical** processes include those processes that affect the degradation mechanisms of engineered features. These chemical processes include such detailed processes as dissolution, precipitation, reduction and oxidation, salt deliquescence, general corrosion, localized (or crevice) corrosion, alteration, and solubility. **Thermal-chemical** processes include evaporation, mineral precipitation, dissolution, and effects on thermal-chemical properties.
- **Biological** (and microbiological) processes include the potential effects of microorganisms on other processes relevant to performance, such as microbial effects on chemical processes. **Thermal-biological** processes include temperature-dependent effects.
- **Transport** includes such processes as advection, diffusion, dispersion, matrix diffusion, retardation, and colloid stability and filtration. These processes may occur within the EBS, NBS, and/or Biosphere. **Thermal-transport** processes include temperature-dependent effects. Transport processes are typically strongly dependent on the other THMCBR processes and couplings.
- **Thermal** processes include only those broad-based temperature dependencies that are not coupled to other THCMBR processes.
- **Radiological** processes include the potential effects of ionizing radiation from the decay of radioactive materials on other processes potentially relevant to performance, such as chemistry. Specific radiological processes include radiolysis. As in the case of thermal effects, the radiological processes are generally addressed through their coupling with other processes that in turn could potentially affect repository performance. Radiological processes also include radiological exposure to the receptor and the resulting doses.
- **Long-Term Geologic** processes include tectonic activity, metamorphism, diapirism, subsidence, and dissolution.
- **Climatic** processes include natural effects that may produce changes in the regional and local climate.
- **Human Activities (Long Timescale)** includes human-initiated effects on the climate and the surface and subsurface THCMBR environment.
- **Other** is reserved for processes that do not fit into any of the other categories. Examples include processes related to the calculation of the dose to the receptor such as ingestion, inhalation, and exposure.

A brief description of the Events follows:

- **Nuclear Criticality** events include initiators of sequences of events or processes that could lead to configurations that have potential for criticality in the EBS or NBS. For a criticality event to occur, the appropriate combination of materials (neutron moderators, neutron absorbers, fissile materials, or isotopes) and geometric configurations favorable to criticality must exist. During design, criticality analyses are performed to demonstrate that the initial emplaced configuration of the waste form remains subcritical, even under flooded conditions. For a configuration to have potential for criticality, all of the following conditions must occur: (1) sufficient mechanical or corrosive damage to the waste package outer corrosion barrier to cause a breach, (2) presence of a moderator, i.e., water, (3) separation of fissionable material from the neutron absorber material or an absorber material selection error during the canister fabrication process, and (4) the accumulation or presence of a critical mass of fissionable material.
- **Early Failure** events include phenomena that lead to the failure of a feature or component at a time significantly faster the design basis. An example is the through-wall penetration of a waste package due to manufacturing- or handling-induced defects, at a time earlier than would be predicted by mechanistic degradation models for a defect-free waste package. Another example is the early failure of a shaft seal.
- **Seismic** events include seismic activity that produces vibratory ground motion or fault displacement which affects the waste packages, the EBS, and/or the natural system pathways.
- **Igneous** events include igneous intrusion intersecting the repository, volcanic eruption from a volcanic vent that intersects the repository, and/or volcanic disturbance to the natural system pathways. Igneous intrusion considers the possibility that magma, in the form of a dike, could intrude into the EBS, destroying waste packages, and exposing the waste forms for potential mobilization of radionuclides. Volcanic eruption considers that a volcanic conduit (or conduits) intersects the repository, destroys waste packages, and erupts at the land surface. The volcanic eruption disperses volcanic tephra and entrained waste under atmospheric conditions, and deposits the contaminated tephra on land surfaces where the contaminated tephra becomes subject to redistribution by soil and near surface hydrogeologic processes.
- **Human Activities (Short Timescale)** includes human intrusion events. Human intrusion is commonly addressed by a stylized calculation (typically specified by regulation) that simulates a future drilling operation in which an intruder drills a land-surface borehole that directly intersects a waste package causing a release of radionuclides subsequently transported into the natural system or up the borehole to the surface.
- **Other** is reserved for events that do not fit into any of the other categories. Examples include events such as meteor or comet impacts, and explosion or crashes.

To demonstrate the applicability of the FEP matrix approach, the 208 salt repository FEPs from Sevougian et al. (2012, Appendix A) were mapped to the salt repository FEP matrix shown in Figure 2-2. The mapping is shown in Table 2-1. To provide mapping to the sub-categories, some of the 208 FEPs needed to be sub-divided. This typically occurred when an original FEP was broad-based and applied to multiple features. For example, FEPs for flow and transport typically applied to most if not all the components of the engineered barriers and geosphere, and were therefore sub-divided into multiple FEPs – one for each feature. The new FEPs retained the same numbering scheme as the original FEPs - when an original FEP was sub-divided into two or more new FEPs, an “A”, “B” or “C”, was appended to the existing FEP number.

Given the numerous FEP sub-divisions, a revised salt repository FEP list is presented in Table 2-2. The FEPs in Table 2-2 are listed in order of the FEP matrix features, rather than in order of FEP number, and are color-coded. A light yellow background means that a FEP has retained its FEP number, with no modification. A light red background means a FEP has been sub-divided into multiple parts. A light blue background denotes a new FEP that was created to address a FEP matrix box.

2.3 Conclusions and Future Work

Section 2.2 describes the initial development and application of a FEP classification matrix to facilitate the grouping of salt repository FEPs.

The FEP classification matrix provides an organizational structure that groups all related FEPs in a single matrix box, row, or column. In addition, the categories along the Features axis of the matrix (e.g., Waste and Engineered Features, Geosphere Features, Surface Features, and System Features) have a direct correspondence with the Assessment Basis elements of the safety framework shown in Figure 1-1 (e.g., Waste and Engineered Barriers, Geosphere/Natural Barriers, Biosphere and Surface Environment, and Design, Construction, and Operations). This correspondence facilitates integration of the FEP analysis process with the development of the safety case.

Eventually, it would be useful to incorporate the FEP matrix and the individual FEPs into a relational database to promote easy searching for FEPs and associated issues. The FEP matrix categories can also be mapped to safety case elements through a database.

Table 2-1. FEP Matrix with Mapping of Salt Repository FEPs

Characteristics, Processes, and Events / Features		Processes											Events					
	Characteristics	Mechanical and Thermal-Mechanical	Hydrological and Thermal-Hydrologic	Chemical and Thermal-Chemical	Biological and Thermal-Biological	Transport and Thermal-Transport	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities (Long Timescale)	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities (Short Timescale)	Other
Waste and Engineered Features																		
Waste Form and Cladding	2.1.01.01 2.1.01.02	2.1.01.04a 2.1.11.06a	2.1.08.02a 2.1.08.08a	2.1.01.04b 2.1.02.03 2.1.02.05 2.1.09.13a	2.1.10.01a	2.1.09.51a 2.1.09.52a 2.1.09.53a 2.1.09.54a 2.1.09.55a 2.1.09.56a 2.1.09.57a 2.1.09.58a 2.1.09.59a	2.1.11.01 2.1.11.02a	2.1.13.02a 2.1.13.03a										
• Commercial SNF & Cladding	2.1.02.00a 2.1.02.00e	2.1.02.06a 2.1.07.06		2.1.02.01 2.1.02.06b														
• Commercial HLW Glass	2.1.02.00b	2.1.07.07		2.1.02.02 2.1.02.04														
• Naval SNF & Cladding	2.1.02.00a 2.1.02.00e	2.1.02.06a 2.1.07.06		2.1.02.01 2.1.02.06b														
• Defense SNF & Cladding	2.1.02.00a 2.1.02.00e	2.1.02.06a 2.1.07.06		2.1.02.01 2.1.02.06b														
• Defense HLW	2.1.02.00b	2.1.07.07		2.1.02.02 2.1.02.04														
• Other	2.1.02.00c 2.1.02.00d	2.1.07.07a 2.1.07.07b		2.1.02.07 2.1.02.08														
Waste Package and Internals	2.1.01.03a 2.1.03.00a 2.1.03.00b 2.1.09.02a	2.1.07.05 2.1.11.06a 2.1.11.07	2.1.08.02b 2.1.08.07a 2.1.08.08b 2.1.11.10a 2.1.11.11a 2.1.12.01b	2.1.03.02 2.1.03.03 2.1.03.04 2.1.03.05 2.1.03.06 2.1.03.07 2.1.03.08 2.1.09.02b 2.1.09.05 2.1.09.08a 2.1.09.11a 2.1.09.13b 2.1.11.13a 2.1.12.01c	2.1.10.01b 2.1.11.13b	2.1.09.51b 2.1.09.52b 2.1.09.53b 2.1.09.54b 2.1.09.55b 2.1.09.56b 2.1.09.57b 2.1.09.58b 2.1.09.59b 2.1.09.60a 2.1.09.61a 2.1.09.63a 2.1.11.14a	2.1.11.02b	2.1.13.01a 2.1.13.02b 2.1.13.03b					2.1.14.01a	2.1.03.01a	1.2.03.01a	1.2.04.01a	1.4.02.01a 1.4.11.01a	
• Commercial SNF																		
• Commercial HLW																		
• Naval																		
• Defense SNF																		
• Defense HLW																		
• Other Packages																		

Characteristics, Processes, and Events / Features		Processes											Events					
	Characteristics	Mechanical and Thermal-Mechanical	Hydrological and Thermal-Hydrologic	Chemical and Thermal-Chemical	Biological and Thermal-Biological	Transport and Thermal-Transport	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities (Long Timescale)	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities (Short Timescale)	Other
Buffer/Backfill	2.1.04.00a 2.1.04.00b	2.1.04.01a 2.1.07.01a	2.1.04.01b 2.1.08.03 2.1.08.07b 2.1.08.08c	2.1.04.01c 2.1.09.06 2.1.09.13c 2.1.11.13c	2.1.09.13c 2.1.11.13d	2.1.09.51c 2.1.09.52c 2.1.09.53c 2.1.09.54c 2.1.09.55c 2.1.09.56c 2.1.09.57c 2.1.09.58c 2.1.09.59c 2.1.09.60b 2.1.09.61b 2.1.11.14b	2.1.04.01d	2.1.13.02c					2.1.14.02a	2.1.03.01b	1.2.03.01b	1.2.04.01b	1.4.02.01b 1.4.11.01b	
• Waste Package Buffer		2.1.11.09a																
• Tunnel/Drift/Room Backfill		2.1.07.03 2.1.07.04 2.1.11.08		2.1.09.03			2.1.11.02c 2.1.11.03											
Emplacement Tunnels/Drifts and Mine Workings	2.1.04.00c	2.1.07.01b 2.1.07.02 2.1.07.08a 2.1.07.09 2.1.07.10 2.1.11.09B 2.1.12.01d	2.1.08.06 2.1.08.08d 2.1.08.09a 2.1.11.10b 2.1.11.11b 2.1.11.12 2.1.12.01e 2.1.12.02 2.1.12.03 2.1.12.04	2.1.09.01 2.1.09.04 2.1.09.09 2.1.09.11b 2.1.09.12 2.1.09.13d 2.1.11.13e 2.1.12.01f	2.1.10.01d 2.1.11.13f	2.1.09.51d 2.1.09.52d 2.1.09.53d 2.1.09.54d 2.1.09.55d 2.1.09.56d 2.1.09.57d 2.1.09.58d 2.1.09.59d 2.1.09.60c 2.1.09.61c 2.1.09.63b 2.1.11.14c.	2.1.11.02d 2.1.11.04 2.1.11.05	2.1.13.01b 2.1.11.04 2.1.11.05					2.1.14.02b	2.1.03.01c	1.2.03.01c	1.2.04.01c	1.4.02.01c 1.4.11.01c	
• Open Excavations			2.1.08.07c	2.1.09.10														
• Tunnel/Drift Support	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Liners	2.1.04.00d 2.1.06.01		2.1.08.05	2.1.06.01a 2.1.09.07		2.1.09.62a												
• Other	2.1.04.00d 2.1.06.01			2.1.09.07 2.1.09.08b														
Seals/Plugs	2.1.05.00a 2.1.05.00b	2.1.07.08b 2.1.09.08c 2.1.11.09c	2.1.08.04 2.1.09.08c 2.1.11.11c	2.1.05.01 2.1.09.08c 2.1.11.13g	2.1.11.13h	2.1.09.62b 2.1.11.14d							2.1.14.02c	2.1.03.01d	1.2.03.01d	1.2.03.01d	1.4.02.01d 1.4.11.01d	
• Drift/Panel Closures	2.1.04.00e		2.1.08.09b 2.1.11.10c															
• Shaft Seals			2.1.08.09b 2.1.11.10c															
• Plugged Boreholes																		

Features \ Characteristics, Processes, and Events		Processes											Events					
	Characteristics	Mechanical and Thermal-Mechanical	Hydrological and Thermal-Hydrologic	Chemical and Thermal-Chemical	Biological and Thermal-Biological	Transport and Thermal-Transport	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities (Long Timescale)	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities (Short Timescale)	Other
Geosphere Features																		
Host Rock (Repository Horizon)	2.1.01.03b 2.2.02.01a 2.2.05.03a	2.2.07.01 2.2.11.06a	2.2.08.01 2.2.08.03a 2.2.08.04 2.2.08.05 2.2.11.01a 2.2.11.02a 2.2.11.03a 2.2.12.02a	2.2.09.01 2.2.09.03 2.2.09.05 2.2.11.04a 2.2.11.07a 2.2.12.01a	2.2.10.01 2.2.11.04b 2.2.12.01b	2.2.09.51 2.2.09.52 2.2.09.53 2.2.09.55 2.2.09.57 2.2.09.59 2.2.09.61 2.2.09.62a 2.2.09.63a 2.2.09.64 2.2.11.05a 2.2.12.03a			1.2.01.01a 1.2.01.02a 1.2.01.03a 1.2.01.04a 1.2.01.05a 1.2.01.06a	1.3.01.01a 1.3.04.01a 1.3.05.01a	1.4.01.01a		2.2.14.01a					
• Bedded or Domal Salt	2.2.02.01 2.2.05.01a 2.2.05.02a																	
• Excavation Disturbed Zone	2.2.01.00a	2.2.01.01b 2.2.01.01d	2.2.01.01c 2.2.08.06	2.2.01.01a 2.2.01.01e														
• Interbeds & Seams	2.2.02.01 2.2.05.01a 2.2.05.02a																	
Other Geologic Units (non-Repository Horizon)	2.2.03.01 2.2.05.01b 2.2.05.02b 2.2.05.03b	2.2.07.02 2.2.11.06b	2.2.08.02 2.2.08.03b 2.2.08.07 2.2.08.08 2.2.11.01b 2.2.11.02b 2.2.11.03b 2.2.12.02b	2.2.09.02 2.2.09.04 2.2.09.06 2.2.11.04b 2.2.11.07b 2.2.12.01c	2.2.10.02 2.2.11.04c 2.2.12.01d	2.2.09.52 2.2.09.54 2.2.09.56 2.2.09.58 2.2.09.60 2.2.09.62b 2.2.09.63b 2.2.09.65 2.2.11.05b 2.2.12.03b			1.2.01.01b 1.2.01.02b 1.2.01.03b 1.2.01.04b 1.2.01.05b 1.2.01.06b	1.3.01.01b 1.3.04.01b 1.3.05.01b	1.4.01.01b		2.2.14.01b		1.2.03.02b	1.2.04.02b	1.4.02.01d 1.4.11.01d	
• Aquifer(s)			2.2.08.08 2.2.08.09															
• Unsaturated Zone			2.2.08.08 2.2.08.09															
• Pressurized Brine Pocket(s)																		

Features / Characteristics, Processes, and Events		Processes											Events					
	Characteristics	Mechanical and Thermal-Mechanical	Hydrological and Thermal-Hydrologic	Chemical and Thermal-Chemical	Biological and Thermal-Biological	Transport and Thermal-Transport	Thermal	Radiological	Long-Term Geologic	Climatic	Human Activities (Long Timescale)	Other	Nuclear Criticality	Early Failure	Seismic	Igneous	Human Activities (Short Timescale)	Other
Surface Features																		
Biosphere				2.3.09.02 2.3.09.03	2.3.10.01		2.3.11.01	3.3.01.01		1.3.01.01c 1.3.04.01c 1.3.05.01c		3.3.06.01 3.3.06.02 3.3.06.03			1.2.03.03a	1.2.04.03a	1.4.11.01d	
• Natural Surface and Near-Surface Environment (soils, sediments, surface waters, atmosphere, etc.)	2.3.01.01 2.3.02.01 2.3.04.01	2.3.07.01 2.3.07.02	2.3.08.01 2.3.08.02 2.3.08.03	2.3.09.01		2.3.09.51 2.3.09.52 2.3.09.53 2.3.09.54 2.3.09.55					2.4.08.01 2.4.08.02	3.3.01.03 3.3.04.03						
• Flora and Fauna	2.3.05.01	2.3.07.03																
• Humans	2.4.01.01 2.4.01.02										1.4.01.01c 2.4.04.01							
• Food & Drinking Water												3.3.01.02 3.3.04.01 3.3.04.02						
• Dwellings and other Man-made Surface Features/Materials												3.3.01.03 3.3.04.03						
System Features																		
Repository System																		
• Assessment Basis	0.1.02.01 0.1.03.01 0.1.09.01 0.1.10.01 0.1.10.02																	
• Preclosure/Operational	1.1.08.01 1.1.10.01	1.1.13.01 1.1.02.02	1.1.01.01 1.1.02.03	1.1.02.01														
• Other Global	1.5.01.02 1.5.03.01	1.5.01.01																

Table 2-2. Generic Salt Repository FEP List Consistent with FEP Matrix

UFD FEP Number	Description	Type or Associated Processes
2.0.00.00	**2. DISPOSAL SYSTEM FEATURES**	
2.1.00.00	**2.1 WASTE AND ENGINEERED FEATURES**	
2.1.02.00	**WASTE FORM & CLADDING (SNF Waste Forms/Cladding, HLW Glass/Other, Other Waste Forms)**	
	Physical-Chemical Characteristics	
2.1.01.01	Waste Inventory - Radionuclides - Non-Radionuclides	- Composition - Enrichment / Burn-up
2.1.01.02	Radioactive Decay and Ingrowth	- Decay chains - Decay products - Neutron activation
2.1.02.00A	SNF Physical Properties and Composition	Characteristics for the intact and degraded states
2.1.02.00B	HLW Physical Properties and Composition	Characteristics for the intact and degraded states
2.1.02.00C	Properties and Composition of TRU and Class C wastes	Characteristics for the intact and degraded states
2.1.02.00D	Properties and Composition of Other Waste Forms	Characteristics for the intact and degraded states
2.1.02.00E	Cladding Physical Properties	Characteristics for the intact and degraded states
	Mechanical and Thermal-Mechanical Processes	
2.1.01.04A	Interactions Between Co-Located Waste	
2.1.02.06A	SNF Cladding Degradation and Failure	- Unzipping - Creep - Internal Pressure - Mechanical Impact
2.1.07.06	Mechanical Impact on SNF Waste Form	- Drift collapse - Swelling corrosion products
2.1.07.07	Mechanical Impact on HLW Waste Form	- Drift collapse - Swelling corrosion products
2.1.07.07A	Mechanical Impact on TRU and Class C wastes	- Drift collapse - Swelling corrosion products
2.1.07.07B	Mechanical Impact on Other Waste Forms	- Drift collapse - Swelling corrosion products
2.1.11.06A	Thermal-Mechanical Effects on Waste Form	- Mechanical loads from room closure due to salt creep - Alteration - Cracking - Thermal expansion / stress
	Hydrological and Thermal-Hydrological Processes	
2.1.08.02A	Flow In and Through the Waste Forms	- Saturated / Unsaturated flow - Movement as thin films or droplets
2.1.08.08A	Capillary Effects in Waste Form	- Wicking - Capillary barrier - Osmotic binding
	Chemical and Thermal-Chemical Processes	

UFD FEP Number	Description	Type or Associated Processes
2.1.01.04B	Interactions Between Co-Located Waste	
2.1.02.01	SNF (Commercial, DOE) Degradation - Alteration / Phase Separation - Dissolution / Leaching - Radionuclide Release	Degradation is dependent on: - Composition - Geometry / Structure - Enrichment / Burn-up - Surface Area - Gap and Grain Fraction - Damaged Area - THC Conditions
2.1.02.02	HLW (Glass, Ceramic, Metal) Degradation - Alteration / Phase Separation - Dissolution / Leaching - Cracking (in UFD, App A list) - Radionuclide Release	Degradation is dependent on: - Composition - Geometry / Structure - Surface Area - Damaged / Cracked Area - THC Conditions
2.1.02.03	Degradation of Organic/Cellulosic Materials in Waste	- Nitrification - Sulfidization - Methanogenesis
2.1.02.04	HLW (Glass, Ceramic, Metal) Recrystallization	
2.1.02.05	Pyrophoricity or Flammable Gas from SNF or HLW	
2.1.02.06B	SNF Cladding Degradation and Failure	- Initial damage - General Corrosion - Microbially Influenced Corrosion - Localized Corrosion - Enhanced Corrosion (silica, fluoride) - Stress Corrosion Cracking - Hydride Cracking
2.1.02.07	TRU and Class C Waste Degradation	
2.1.02.08	Degradation of Other Waste Forms	- Special Pu waste forms
2.1.09.13A	Radionuclide Speciation and Solubility in Waste Form	- Dissolved concentration limits - Limited dissolution due to inclusion in secondary phase - Enhanced dissolution due to alpha recoil - Complexation with organic ligands - Formation of various types of colloids
	Biological and Thermal-Biological Processes	
2.1.10.01A	Microbial Activity in Waste Form	- Effects on corrosion - Formation of complexants, microbial colloids, and biofilms - Gas generation by biodegradation - Biomass production - Bioaccumulation
	Transport and Thermal-Transport Processes	
2.1.09.51A	Advection of Dissolved Radionuclides in Waste Form	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation

UFD FEP Number	Description	Type or Associated Processes
2.1.09.52A	Diffusion of Dissolved Radionuclides in Waste Form	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation
2.1.09.53A	Sorption of Dissolved Radionuclides in Waste Form	- Surface complexation properties - Flow pathways and velocity - Saturation
2.1.09.54A	Complexation in Waste Form	- Formation of organic complexants (humates, fulvates, organic waste) - Enhanced transport of radionuclides associated with organic complexants
2.1.09.55A	Formation of Colloids in Waste Form	- Formation of intrinsic colloids - Formation of pseudo colloids (host rock fragments, waste form fragments, corrosion products, microbes, and humics) - Formation of co-precipitated colloids - Sorption/attachment of radionuclides to colloids (clay, silica, waste form, FeOx, microbes)
2.1.09.56A	Stability of Colloids in Waste Form	- Chemical stability of attachment (dependent on water chemistry) - Mechanical stability of colloid (dependent on colloid size, gravitational settling)
2.1.09.57A	Advection of Colloids in Waste Form	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation - Colloid concentration
2.1.09.58A	Diffusion of Colloids in Waste Form	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation - Colloid concentration
2.1.09.59A	Sorption of Colloids in Waste Form	- Surface complexation properties - Flow pathways and velocity - Saturation - Colloid concentration
	Thermal Processes	
2.1.11.01	Heat Generation in Waste Form	- Radionuclide decay
2.1.11.02A	Exothermic Reactions in Waste Form	- Oxidation of SNF - Hydration of concrete -
	Radiological Processes	
2.1.13.02A	Radiation Damage to Waste Form	- He generation from … - Enhanced waste form degradation - Enhanced waste package degradation - Enhanced backfill degradation - Enhanced degradation of other EBS components (liner/rock reinforcement materials, seals, waste support structure)
2.1.13.03A	Radiological Mutation of Microbes in Waste Form	
2.1.03.00	**WASTE PACKAGE (SNF Package/Container/Internals, HLW Package/Container/Internals, Other)**	
	Physical-Chemical Characteristics	

UFD FEP Number	Description	Type or Associated Processes
2.1.03.00A	Waste Package Design - SNF Waste Packages - HLW Waste Packages - TRU/Class C Waste Packages - Other Waste Packages	Characteristics
2.1.03.00B	Physical Properties of Waste Package Internals - SNF Rod Assemblies - HLW Clad and Assembly - Other Waste Assemblies	Characteristics: Mechanical, hydrologic, chemical, and transport properties in the intact and degraded states
2.1.01.03A	Heterogeneity of Waste Inventory - Waste Package Scale	- Composition - Enrichment / Burn-up - Damaged Area
2.1.09.02A	Chemical Characteristics of Water Flowing Into Waste Packages	- Water composition (radionuclides, dissolved species, …) - Initial void chemistry (air / gas) - Water chemistry (pH, ionic strength, pCO2, ..) - Reduction-oxidation potential - Influent chemistry (from tunnels and/or backfill)
	Mechanical and Thermal-Mechanical Processes	
2.1.07.05	Mechanical Impact on Waste Packages	- Rockfall / Drift collapse - Waste package movement - Rubble or backfill loads - Internal gas pressure - Swelling corrosion products - Lifting or sinking of containers
2.1.12.01A	Gas Generation in Waste Package	- Pressurization of the waste package internals - Mechanical damage to the waste package from gas pressure
2.1.11.06B	Thermal-Mechanical Effects on In-Package Components	- Mechanical loads from room closure due to salt creep - Alteration - Cracking - Thermal expansion / stress
2.1.11.07	Thermal-Mechanical Effects on Waste Packages	- Mechanical loads from room closure due to salt creep - Thermal sensitization/phase changes - Cracking - Thermal expansion / stress / creep
	Hydrological and Thermal-Hydrological Processes	
2.1.08.02B	Flow In and Through Waste Packages	- Saturated / Unsaturated flow - Movement as thin films or droplets
2.1.08.07A	Condensation Forms on Waste Packages	- Heat transfer (spatial and temporal distribution of temperature and relative humidity) - Dripping - Moisture movement
2.1.08.08B	Capillary Effects in Waste Package	- Wicking - Capillary barrier - Osmotic binding
2.1.12.01B	Gas Generation in Waste Package	- Vaporization of water - Influence of gas pressure on advective flows toward and away from the waste package
2.1.11.10A	Thermal Effects on Flow in Waste Package	- Altered influx/seepage - Altered saturation / relative humidity (dry-out, resaturation) - Condensation
2.1.11.11A	Thermally-Driven Flow (Convection) in Waste Package	- Convection
	Chemical and Thermal-Chemical Processes	

UFD FEP Number	Description	Type or Associated Processes
2.1.03.02	General Corrosion of Waste Packages	- Dry-air oxidation - Humid-air corrosion - Aqueous phase corrosion - Passive film formation and stability
2.1.03.03	Stress Corrosion Cracking (SCC) of Waste Packages	- Crack initiation, growth and propagation - Stress distribution around cracks
2.1.03.04	Localized Corrosion of Waste Packages	- Pitting - Crevice corrosion - Salt deliquescence
2.1.03.05	Hydride Cracking of Waste Packages	- Hydrogen diffusion through metal matrix - Crack initiation and growth in metal hydride phases
2.1.03.06	Microbially Influenced Corrosion (MIC) of Waste Packages	- Viable colonies of halophilic bacteria - EBS environments promoting and sustaining microbial colonies
2.1.03.07	Internal Corrosion of Waste Packages Prior to Breach	
2.1.03.08	Evolution of Flow Pathways in Waste Packages	- Evolution of physical form of waste package - Plugging of cracks in waste packages
2.1.09.02B	Chemical Characteristics of Water in Waste Packages	- Reduction-oxidation potential - Reaction kinetics - Evolution of water chemistry / interaction with waste packages
2.1.09.05	Chemical Interaction of Water with Corrosion Products - In Waste Packages	- Corrosion product formation and composition (waste form, waste package internals, waste package) - Evolution of water chemistry in waste packages
2.1.09.08A	Chemical Interaction of Water with Other Components In Waste Packages	
2.1.09.11A	Electrochemical Effects in Waste Package	- Enhanced metal corrosion
2.1.09.13B	Radionuclide Speciation and Solubility in Waste Package	- Dissolved concentration limits - Limited dissolution due to inclusion in secondary phase - Enhanced dissolution due to alpha recoil - Complexation with organic ligands - Formation of colloids
2.1.12.01C	Gas Generation in Waste Package	- H_2 generation from waste package corrosion
2.1.11.13A	Thermal Effects on Chemistry in Waste Package	
	Biological and Thermal-Biological Processes	
2.1.10.01B	Microbial Activity in Waste Package	- Effects on corrosion - Formation of complexants - Formation of microbial colloids - Formation of biofilms - Gas generation by biodegradation - Biomass production - Bioaccumulation - CO_2, CH_4, and H_2S generation from microbial degradation
2.1.11.13B	Thermal Effects on Microbial Activity in Waste Package	
	Transport and Thermal-Transport Processes	

UFD FEP Number	Description	Type or Associated Processes
2.1.09.51B	Advection of Dissolved Radionuclides in Waste Package	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation
2.1.09.52B	Diffusion of Dissolved Radionuclides in Waste Package	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation
2.1.09.53B	Sorption of Dissolved Radionuclides in Waste Package	- Surface complexation properties - Flow pathways and velocity - Saturation
2.1.09.54B	Complexation in Waste Package	- Formation of organic complexants (humates, fulvates, organic waste) - Enhanced transport of radionuclides associated with organic complexants
2.1.09.55B	Formation of Colloids in Waste Package	- Formation of intrinsic colloids - Formation of pseudo colloids (host rock fragments, waste form fragments, corrosion products, microbes, and humics) - Formation of co-precipitated colloids - Sorption/attachment of radionuclides to colloids (clay, silica, waste form, FeOx, microbes)
2.1.09.56B	Stability of Colloids in Waste Package	- Chemical stability of attachment (dependent on water chemistry) - Mechanical stability of colloid (dependent on colloid size, gravitational settling)
2.1.09.57B	Advection of Colloids in Waste Package	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation - Colloid concentration
2.1.09.58B	Diffusion of Colloids in Waste Package	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation - Colloid concentration
2.1.09.59B	Sorption of Colloids in Waste Package	- Surface complexation properties - Flow pathways and velocity - Saturation - Colloid concentration
2.1.09.60A	Sorption of Colloids at Air-Water Interface in Waste Package	- Colloid trapping at the air-water interface in unsaturated porous media
2.1.09.61A	Filtration of Colloids in Waste Packages	- Physical filtration or trapping (dependent on flow pathways, colloid size) - Electrostatic filtration
2.1.09.63A	Radionuclide Release from the Waste Package - Dissolved - Colloidal - Gas Phase - Complexed with organic ligands	- Spatial and temporal distribution of releases to the host rock (due to varying flow pathways and velocities, varying component degradation rates, varying transport properties)
2.1.11.14A	Thermal Effects on Transport in Waste Package	- Thermal diffusion (Soret effect) - Thermal osmosis
	Thermal Processes	
2.1.11.02B	Exothermic Reactions in Waste Packages	- Oxidation of SNF - Hydration of concrete

UFD FEP Number	Description	Type or Associated Processes
	Radiological Processes	
2.1.13.01A	Radiolysis In Waste Package	- Gas generation - Altered water chemistry - H_2 generation from radiolysis
2.1.13.02B	Radiation Damage to Waste Package	- He generation from waste from alpha decay - Enhanced waste form degradation - Enhanced waste package degradation - Enhanced backfill degradation - Enhanced degradation of other EBS components (liner/rock reinforcement materials, seals, waste support structure)
2.1.13.03B	Radiological Mutation of Microbes in Waste Package	
	Nuclear Criticality	
2.1.14.01A	Criticality In-Package	- Formation of critical configuration
	Early Failure	
2.1.03.01	Early Failure of Waste Packages	- Manufacturing defects - Improper sealing - Constructability and fabrication technology (in UFD, App A list)
1.2.03.00	**Seismic**	
1.2.03.01A	Seismic Activity Impacts Waste Packages	- Mechanical damage to waste package from ground motion, rockfall, drift collapse, fault displacement
1.2.04.00	**Igneous**	
1.2.04.01A	Igneous Activity Impacts Waste Package	- Mechanical damage to waste package (from igneous intrusion) - Chemical interaction with magmatic volatiles - Transport of radionuclides (in magma, pyroclasts, vents)
1.4.00.00	**Human Activities (Short Time Scale)**	
1.4.02.01A	Human Intrusion into Waste Package - Deliberate - Inadvertent	- Drilling (resource exploration, …) - Mining / tunneling - Unintrusive site investigation (airborne, surface-based, …)
1.4.11.01A	Explosions and Crashes from Human Activities	- War - Sabotage - Testing - Resource exploration / exploitation - Aircraft
	BUFFER/BACKFILL (Waste Package Buffer, Tunnel/Room Backfill)	
	Physical-Chemical Characteristics	
2.1.04.00A	Repository Design - Use of a buffer material around the waste package - Use of backfill around the packages and/or in the drifts - Use of ground support or drift liners	Characteristics:

UFD FEP Number	Description	Type or Associated Processes
2.1.04.00B	Buffer and Backfill Composition and Physical Properties	Characteristics: Mechanical, hydrologic, chemical, and transport properties of buffer and backfill materials in the intact and degraded states
	Mechanical and Thermal-Mechanical Processes	
2.1.04.01A	Evolution and Degradation of Buffer and Backfill	- Compaction from creep closure of drifts - Thermal expansion / Degradation - Swelling/Drying of clays
2.1.07.01A	Rockfall	- Dynamic loading (block size and velocity) on backfill
2.1.07.03	Mechanical Effects of Backfill	- Backfill may consolidate during room closure process - Static and dynamic loading on EBS structures - Restricts displacement of EBS components during ground motion and fault displacement - Protects EBS components from rockfall/drift collapse caused by ground motion and fault displacement
2.1.07.04	Mechanical Impact on Backfill	- Rockfall / Drift collapse - Hydrostatic pressure of drift walls on any backfill present - Internal gas pressure
2.1.11.08	Thermal-Mechanical Effects on Backfill	- Mechanical loads from room closure due to salt creep - Alteration - Cracking - Thermal expansion / stress
2.1.11.09A	Thermal-Mechanical Effects on Buffers	- Mechanical loads from room closure due to salt creep - Alteration - Cracking - Thermal expansion / stress
	Hydrological and Thermal-Hydrological Processes	
2.1.04.01B	Evolution and Degradation of Buffer and Backfill	- Evolution of backfill flow pathways - Erosion / dissolution - Thermal expansion / Degradation - Swelling/Drying of clays
2.1.08.03	Flow In and Through the Buffer and Backfill	- Saturated / Unsaturated flow - Fracture / Matrix flow
2.1.08.07B	Condensation Forms within Buffer or Backfill	- Heat transfer (spatial and temporal distribution of temperature and relative humidity) - Dripping - Moisture movement
2.1.08.08C	Capillary Effects in Buffers and Backfill	- Wicking - Capillary barrier - Osmotic binding
	Chemical and Thermal-Chemical Processes	
2.1.04.01C	Evolution and Degradation of Buffer and Backfill	- Alteration - Erosion / Dissolution
2.1.09.03	Chemical Characteristics of Water in Backfill	- Water composition (radionuclides, dissolved species, …) - Water chemistry (pH, ionic strength, pCO2, ..) - Reduction-oxidation potential - Reaction kinetics - Influent chemistry (from tunnels and/or waste package) - Evolution of water chemistry / interaction with backfill

UFD FEP Number	Description	Type or Associated Processes
2.1.09.06	Chemical Interaction of Water with Buffer and Backfill - On Waste Packages - In Backfill - In Tunnels	- Backfill composition and evolution (bentonite, crushed rock, ...) - Evolution of water chemistry in backfill, and in tunnels - Enhanced degradation of waste packages (crevice formation)
2.1.09.13C	Radionuclide Speciation and Solubility in Buffer and Backfill	- Dissolved concentration limits - Limited dissolution due to inclusion in secondary phase - Enhanced dissolution due to alpha recoil - Complexation with organic ligands - Formation of various types of colloids
2.1.11.13C	Thermal Effects on Chemistry in Buffer and Backfill	-
	Biological and Thermal-Biological Processes	
2.1.10.01C	Microbial Activity in Buffer and Backfill	- Effects on corrosion - Formation of complexants - Formation of microbial colloids - Formation of biofilms - Gas generation by biodegradation - Biomass production - Bioaccumulation
2.1.11.13D	Thermal Effects on Microbial Activity in Buffer and Backfill	
	Transport and Thermal-Transport Processes	
2.1.09.51C	Advection of Dissolved Radionuclides in Buffer/Backfill	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation
2.1.09.52C	Diffusion of Dissolved Radionuclides in Buffer/Backfill	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation
2.1.09.53C	Sorption of Dissolved Radionuclides in Buffer/Backfill	- Surface complexation properties - Flow pathways and velocity - Saturation
2.1.09.54C	Complexation in Buffer/Backfill	- Formation of organic complexants (humates, fulvates, organic waste) - Enhanced transport of radionuclides associated with organic complexants
2.1.09.55C	Formation of Colloids in Buffer/Backfill	- Formation of intrinsic colloids - Formation of pseudo colloids (host rock fragments, waste form fragments, corrosion products, microbes, and humics) - Formation of co-precipitated colloids - Sorption/attachment of radionuclides to colloids (clay, silica, waste form, FeOx, microbes)
2.1.09.56C	Stability of Colloids in Buffer/Backfill	- Chemical stability of attachment (dependent on water chemistry) - Mechanical stability of colloid (dependent on colloid size, gravitational settling)
2.1.09.57C	Advection of Colloids in Buffer/Backfill	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation - Colloid concentration

UFD FEP Number	Description	Type or Associated Processes
2.1.09.58C	Diffusion of Colloids in Buffer/Backfill	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation - Colloid concentration
2.1.09.59C	Sorption of Colloids in Buffer/Backfill	- Surface complexation properties - Flow pathways and velocity - Saturation - Colloid concentration
2.1.09.60B	Sorption of Colloids at Air-Water Interface in Buffer/Backfill	- Colloid trapping at the air-water interface in unsaturated porous media
2.1.09.61B	Filtration of Colloids in Buffer/Backfill	- Physical filtration or trapping (dependent on flow pathways, colloid size) - Electrostatic filtration
2.1.11.14B	Thermal Effects on Transport in Emplacement Drifts	- Thermal diffusion (Soret effect) - Thermal osmosis
	Thermal Processes	
2.1.04.01D	Evolution and Degradation of Buffer and Backfill	- Thermal expansion / Degradation
2.1.11.02C	Exothermic Reactions in Buffer/Backfill	- Oxidation of SNF - Hydration of concrete
2.1.11.03	Effects of Backfill on Thermal Environment in Emplacement Drifts	- Thermal conductivity of backfill - Thermal blanket - Condensation
	Radiological Processes	
2.1.13.02C	Radiation Damage to Buffer/Backfill	- Enhanced waste form degradation - Enhanced waste package degradation - Enhanced backfill degradation - Enhanced degradation of other EBS components (liner/rock reinforcement materials, seals, waste support structure)
	Nuclear Criticality	
2.1.14.02A	Criticality in Buffer/Backfill	- Formation of critical configuration
1.2.03.00	**Seismic**	
1.2.03.01B	Seismic Activity Impacts Buffer/Backfill	- Mechanical damage to EBS (liners, rock bolts and wire mesh, drift reinforcements materials, and EDZ) from ground motion, rockfall, drift collapse, fault displacement
1.2.04.00	**Igneous**	
1.2.04.01B	Igneous Activity Impacts Buffer/Backfill	- Mechanical damage to EBS (from igneous intrusion) - Chemical interaction with magmatic volatiles - Transport of radionuclides (in magma, pyroclasts, vents)
1.4.00.00	**Human Activities (Short Time Scale)**	
1.4.02.01B	Human Intrusion into Buffer/Backfill - Deliberate - Inadvertent	- Drilling (resource exploration, …) - Mining / tunneling - Unintrusive site investigation (airborne, surface-based, …)
1.4.11.01B	Explosions and Crashes from Human Activities	- War - Sabotage - Testing - Resource exploration / exploitation - Aircraft

UFD FEP Number	Description	Type or Associated Processes
2.1.04.00	**EMPLACEMENT DRIFTS & MINE WORKINGS (Open Excavations, Ground Support, Drift Liners, Waste Package Support Materials, Other)**	
	Physical-Chemical Characteristics	
2.1.04.00C	Repository Design - Use of ground support, drift liners, and waste package supporting structures/materials	Characteristics:
2.1.04.00D	Properties of Ground Support, Drift Liners, and Waste Package Support Materials	Characteristics: Mechanical, hydrologic, chemical, and transport properties of drift support systems or drift liners in the intact and degraded states
2.1.06.01	Degradation of Ground Support/Drift Liner Materials	- Alteration / Degradation / Cracking - Corrosion - Erosion / Dissolution / Spalling
	Mechanical and Thermal-Mechanical Processes	
2.1.07.01B	Rockfall	- Dynamic loading (block size and velocity) on ground support, and drift liners
2.1.07.02	Drift Collapse (For a salt repository, this FEP could be combined with the Rockfall FEP).	- Alteration of seepage - Alteration of EBS flow pathways - Alteration of EBS thermal environment
2.1.07.08A	Mechanical Impact on Liner / Rock Reinforcement Materials and Waste Package Support Materials	- Rockfall / Drift collapse - Movement - Hydrostatic pressure - Swelling corrosion products - Lifting or sinking of containers
2.1.07.09	Mechanical Effects at EBS Component Interfaces	- Component-to-component contact (static or dynamic) - Volume changes (in UFD, App A list) - Thermal expansion
2.1.07.10	Mechanical Degradation of Emplacement Drifts	- Roof buckling and floor heave - Initial damage from excavation / construction - Consolidation of EBS components - Degradation of waste package support structure and drift support structure - Alteration of EBS flow pathways
2.1.12.01D	Gas Generation in Emplacement Drifts	- Repository Pressurization - Influence of gas pressure on room closure
2.1.11.09B	Thermal-Mechanical Effects on Other EBS Components - Drift Liner / Ground Support Materials - Waste Package Support Structure	- Mechanical loads from room closure due to salt creep - Alteration - Cracking - Thermal expansion / stress
	Hydrological and Thermal-Hydrological Processes	

UFD FEP Number	Description	Type or Associated Processes
2.1.08.05	Flow Through Ground Support/Drift Liner/Rock Reinforcement Materials in Emplacement Drifts	- Saturated / Unsaturated flow - Flow pathways along rock bolts - Fracture / Matrix flow
2.1.08.06	Alteration and Evolution of Flow Pathways in Emplacement Drifts	- Drift collapse - Degradation/consolidation of EBS components - Plugging of flow pathways - Formation of corrosion products - Water ponding
2.1.08.07C	Condensation Forms On Tunnel Roof/Walls	- Heat transfer (spatial and temporal distribution of temperature and relative humidity) - Dripping - Moisture movement
2.1.08.08D	Capillary Effects in the Emplacement Drifts	- Wicking - Capillary barrier - Osmotic binding
2.1.08.09A	Influx/Seepage Into the Emplacement Drifts	- Water influx rate (spatial and temporal distribution)
2.1.12.02	Effects of Gas on Flow Through the Emplacement Drifts	- Two-phase flow - Gas bubbles
2.1.12.03	Gas Transport in Emplacement Drifts	- Gas phase transport - Gas phase release from EBS
2.1.12.04	Gas Explosions in Emplacement Drifts	
2.1.12.01E	Gas Generation in Emplacement Drifts	- Repository pressurization - Vaporization of water - Influence of gas pressure on advective flows toward and away from the emplacement drifts
2.1.11.10B	Thermal Effects on Flow in Emplacement Drifts	- Altered influx/seepage - Altered saturation / relative humidity (dry-out, resaturation) - Condensation
2.1.11.11B	Thermally-Driven Flow (Convection) in Emplacement Drifts	- Convection
2.1.11.12	Thermally-Driven Buoyant Flow / Heat Pipes in Emplacement Drifts	- Vapor flow
	Chemical and Thermal-Chemical Processes	
2.1.06.01A	Degradation of Ground Support/Drift Liner Materials	- Alteration / Degradation / Cracking - Corrosion - Erosion / Dissolution / Spalling
2.1.09.01	Chemistry of Water Flowing into the Emplacement Drifts	- Chemistry of influent water (spatial and temporal distribution)

UFD FEP Number	Description	Type or Associated Processes
2.1.09.04	Chemical Characteristics of Water in Tunnels	- Water composition (radionuclides, dissolved species, …) - Initial void chemistry (air/gas) (in UDF, App A List) - Water chemistry (pH, ionic strength, pCO2, ..) - Reduction-oxidation potential - Reaction kinetics - Influent chemistry (from near-field host rock) - Initial chemistry (from construction / emplacement) - Evolution of water chemistry / interaction with seals, liner/rock reinforcement materials, waste package support materials
2.1.09.07	Chemical Interaction of Water with Package Support Structures/Ground Support/Drift Liners/Rock Reinforcement and Cementitious Materials in Emplacement Drifts	- Liner composition and evolution (concrete, metal, ...) - Rock reinforcement material composition and evolution (grout, rock bolts, mesh, ...) - Other cementitious materials composition and evolution - Evolution of water chemistry in backfill, and in tunnels
2.1.09.08B	Chemical Interaction of Water with Other EBS Components in Emplacement Drifts	- Waste Package Support composition and evolution (concrete, metal, ...) - Other EBS components (other metals (copper), ...) - Evolution of water chemistry in backfill, and in tunnels
2.1.09.09	Chemical Effects at EBS Component Interfaces	- Component-to-component contact (chemical reactions) - Consolidation of EBS components - Barrier degradation at interfaces (in UDF, App A List)
2.1.09.10	Chemical Effects of Waste-Rock Contact	- Waste-to-host rock contact (chemical reactions) - Component-to-host rock contact (chemical reactions)
2.1.09.11B	Electrochemical Effects in Emplacement Drifts	- Enhanced metal corrosion
2.1.09.12	Chemical Effects of Drift Collapse	- Evolution of water chemistry in backfill and in tunnels (from altered seepage, from altered thermal-hydrology)
2.1.09.13 D	Radionuclide Speciation and Solubility in Emplacement Drifts	- Dissolved concentration limits - Limited dissolution due to inclusion in secondary phase - Enhanced dissolution due to alpha recoil - Complexation with organic ligands - Formation of various types of colloids
2.1.12.01F	Gas Generation in Emplacement Drifts	- H_2 generation from corrosion of iron-based alloys
2.1.11.13E	Thermal Effects on Chemistry in Emplacement Drifts	
	Biological and Thermal-Biological Processes	
2.1.10.01D	Microbial Activity in Emplacement Drifts	- Effects on corrosion - Formation of complexants - Formation of microbial colloids - Formation of biofilms - Gas generation by biodegradation - Biomass production - Bioaccumulation - CO_2, CH_4, and H_2S generation from microbial degradation
2.1.11.13F	Thermal Effects on Microbial Activity in Emplacement Drifts	
	Transport and Thermal-Transport Processes	
2.1.09.51D	Advection of Dissolved Radionuclides in Emplacement Drifts	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation

UFD FEP Number	Description	Type or Associated Processes
2.1.09.52D	Diffusion of Dissolved Radionuclides in Emplacement Drifts	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation
2.1.09.53D	Sorption of Dissolved Radionuclides in Emplacement Drifts	- Surface complexation properties - Flow pathways and velocity - Saturation
2.1.09.54D	Complexation in Emplacement Drifts	- Formation of organic complexants (humates, fulvates, organic waste) - Enhanced transport of radionuclides associated with organic complexants
2.1.09.55D	Formation of Colloids in Emplacement Drifts	- Formation of intrinsic colloids - Formation of pseudo colloids (host rock fragments, waste form fragments, corrosion products, microbes, and humics) - Formation of co-precipitated colloids - Sorption/attachment of radionuclides to colloids (clay, silica, waste form, FeOx, microbes)
2.1.09.56D	Stability of Colloids in Emplacement Drifts	- Chemical stability of attachment (dependent on water chemistry) - Mechanical stability of colloid (dependent on colloid size, gravitational settling)
2.1.09.57D	Advection of Colloids in Emplacement Drifts	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation - Colloid concentration
2.1.09.58D	Diffusion of Colloids in Emplacement Drifts	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation - Colloid concentration
2.1.09.59D	Sorption of Colloids in Emplacement Drifts	- Surface complexation properties - Flow pathways and velocity - Saturation - Colloid concentration
2.1.09.60C	Sorption of Colloids at Air-Water Interface in Emplacement Drifts	- Colloid trapping at the air-water interface in unsaturated porous media
2.1.09.61C	Filtration of Colloids in Emplacement Drifts	- Physical filtration or trapping (dependent on flow pathways, colloid size) - Electrostatic filtration
2.1.09.62A	Radionuclide Transport Through Drift Liners and Ground Support	- Advection - Dispersion - Diffusion - Sorption

UFD FEP Number	Description	Type or Associated Processes
2.1.09.63B	Radionuclide Release from Emplacement Drifts - Dissolved - Colloidal - Gas Phase	- Spatial and temporal distribution of releases to the host rock (due to varying flow pathways and velocities, varying component degradation rates, varying transport properties)
2.1.11.14C	Thermal Effects on Transport in Emplacement Drifts	- Thermal diffusion (Soret effect) - Thermal osmosis
	Thermal Processes	
2.1.11.02D	Exothermic Reactions in Emplacement Drifts	- Oxidation of SNF - Hydration of concrete
2.1.11.04	Effects of Drift Collapse on Thermal Environment in Emplacement Drifts	- Thermal conductivity of rubble - Thermal blanket - Condensation
2.1.11.05	Effects of Influx (Seepage) on Thermal Environment in Emplacement Drifts	- Temperature and relative humidity (spatial and temporal distribution)
	Radiological Processes	
2.1.13.01B	Radiolysis In Emplacement Drifts	- Gas generation - Altered water chemistry - H_2 generation from radiolysis
2.1.13.02D	Radiation Damage to Drift Supports/Liners in Emplacement Drifts	- Enhanced waste form degradation - Enhanced waste package degradation - Enhanced backfill degradation - Enhanced degradation of other EBS components (liner/rock reinforcement materials, seals, waste support structure)
2.1.13.03C	Radiological Mutation of Microbes in Emplacement Drifts	
	Nuclear Criticality	
2.1.14.02 B	Criticality in Emplacement Drifts	- Formation of critical configuration
1.2.03.00	**Seismic**	
1.2.03.01C	Seismic Activity Impacts Emplacement Drifts and Internal Components	- Mechanical damage to EBS (liners, rock bolts and wire mesh, drift reinforcements materials, and EDZ) from ground motion, rockfall, drift collapse, fault displacement
1.2.04.00	**Igneous**	
1.2.04.01C	Igneous Activity Impacts Emplacement Drifts and Internal Components	- Mechanical damage to EBS (from igneous intrusion) - Chemical interaction with magmatic volatiles - Transport of radionuclides (in magma, pyroclasts, vents)
1.4.00.00	**Human Activities (Short Time Scale)**	
1.4.02.01C	Human Intrusion into the Emplacement Drifts - Deliberate - Inadvertent	- Drilling (resource exploration, …) - Mining / tunneling - Unintrusive site investigation (airborne, surface-based, …)
1.4.11.01C	Explosions and Crashes from Human Activities	- War - Sabotage - Testing - Resource exploration / exploitation - Aircraft
2.1.05.00	**SEALS/PLUGS (Drift/Panel Closures, Shaft Seals, Plugged Boreholes)**	

UFD FEP Number	Description	Type or Associated Processes
	Physical-Chemical Characteristics	
2.1.04.00E	Properties of Drift and Panel Closures	Characteristics: Mechanical, hydrologic, chemical, and transport properties of drift support systems or drift liners in the intact and degraded states
2.1.05.00A	Design of the Shaft Seals, Panel Closures, and Borehole Plugs	Characteristics
2.1.05.00B	Composition and Physical Properties of the Shaft Seals, Panel Closures, and Borehole Plugs	Characteristics: Mechanical, hydrologic, chemical, and transport properties of buffer and backfill materials in the intact and degraded states
	Mechanical and Thermal-Mechanical Processes	
2.1.07.08B	Mechanical Impact on Shaft Seals, Panel Closures, and Borehole Plugs	- Rockfall - Movement - Hydrostatic pressure - Swelling corrosion products
2.1.11.09C	Thermal-Mechanical Effects on Shaft Seals, Panel Closures, and Borehole Plugs	- Mechanical loads from salt creep - Alteration - Cracking - Thermal expansion / stress
	Hydrological Processes	
2.1.08.04	Flow Through Shaft Seals, Panel Closures, and Borehole Plugs	- Saturated / Unsaturated flow - Fracture / Matrix flow - Gas transport (in UFD, Appendix A list)
2.1.08.09B	Influx/Seepage Through Panel Closures and Shaft Seals	- Water influx rate (spatial and temporal distribution)
2.1.11.10C	Thermal Effects on Flow Through Shaft Seals and Panel Closures	- Altered influx/seepage - Altered saturation / relative humidity (dry-out, resaturation) - Condensation
2.1.11.11C	Thermally-Driven Flow (Convection) through Shaft Seals, Panel Closures, and Borehole Plugs	- Convection
	Chemical and Thermal-Chemical Processes	
2.1.05.01	Degradation of Shaft Seals, Panel Closures, and Borehole Plugs	- Alteration / Degradation / Cracking - Erosion / Dissolution - Asphalt seals: degradation as function of temperature and degassing (in UFD, App A list)

UFD FEP Number	Description	Type or Associated Processes
2.1.09.08C	Chemical Interaction of Water with Shaft Seals, Panel Closures, and Borehole Plugs	- Panel closures and seal composition and evolution
2.1.11.13G	Thermal Effects on Chemistry in Shaft Seals, Panel Closures and Borehole Plugs	
	Biological and Thermal-Biological Processes	
2.1.11.13H	Thermal Effects on Microbial Activity in Shaft Seals, Panel Closures, and Borehole Plugs	
	Transport and Thermal-Transport Processes	
2.1.09.62B	Radionuclide Transport Through Shaft Seals, Panel Closures, and Borehole Plugs	- Advection - Dispersion - Diffusion - Sorption
2.1.11.14D	Thermal Effects on Transport through Shaft Seals, Panel Closures, and Borehole Plugs	- Thermal diffusion (Soret effect) - Thermal osmosis
	Nuclear Criticality	
2.1.14.02 C	Criticality in Shaft Seals, Panel Closures, or Borehole Plugs	- Formation of critical configuration
1.2.03.00	**Seismic**	
1.2.03.01D	Seismic Activity Impacts Shaft Seals, Panel Closures, or Borehole Plugs	- Mechanical damage to seals, closures, or plugs from ground motion, rockfall, drift collapse, or fault displacement
1.2.04.00	**Igneous**	
1.2.04.01D	Igneous Activity Impacts Shaft Seals, Panel Closures, or Borehole Plugs	- Mechanical damage to EBS (from igneous intrusion) - Chemical interaction with magmatic volatiles - Transport of radionuclides (in magma, pyroclasts, vents)
1.4.00.00	**Human Activities (Short Time Scale)**	
1.4.02.01D	Human Intrusion into Shaft Seals, Panel Closures, or Borehole Plugs - Deliberate - Inadvertent	- Drilling (resource exploration, …) - Mining / tunneling - Unintrusive site investigation (airborne, surface-based, …)
1.4.11.01D	Explosions and Crashes from Human Activities	- War - Sabotage - Testing - Resource exploration / exploitation - Aircraft
2.2.00.00	**GEOSPHERE FEATURES**	
2.2.02.00	**HOST ROCK (REPOSITORY HORIZON)**	
	Physical-Chemical Characteristics	
2.2.01.00A	Composition and physical properties of the EDZ	Characteristics: Mechanical and hydrologic properties of the evolving EDZ
2.1.01.03B	Heterogeneity of Waste Inventory - Repository Scale	- Composition - Enrichment / Burn-up - Damaged Area

UFD FEP Number	Description	Type or Associated Processes
2.2.02.01	Stratigraphy and Properties of Host Rock	- Rock units - Thickness, lateral extent, heterogeneities, discontinuities, contacts - Physical properties - Flow pathways
2.2.05.01A	Fractures in Host Rock	- Rock properties - Hydrologic properties
2.2.05.02A	Faults in Host Rock	- Rock properties - Hydrologic properties
2.2.05.03A	Alteration and Evolution of Flow Pathways in Host Rock	- Changes In rock properties - Changes in faults - Changes in fractures - Changes in flow pathways, aquifers, and aquitards, including potential for plugging and dissolution - Changes in saturation
2.2.02.01A	Chemistry of Water Flowing into the Host Rock	- Chemistry of influent water (spatial and temporal distribution)
	Mechanical and Thermal-Mechanical Processes	
2.2.01.01B	Evolution of EDZ	- Mechanical loads from room closure due to salt creep - Formation of fractures and separations along interbeds and clay seams due to floor heave and roof fall
2.2.01.01D	Thermal-Mechanical Effects on EDZ	- Thermal-mechanical effects, particularly healing of fractures in the EDZ - Thermal expansion / stress
2.2.07.01	Mechanical Effects on Host Rock	- From subsidence due to repository-related excavations - From salt creep - From healing of the EDZ - From dissolution of halite - From solution mining of other strata - From fracturing caused by gas pressurization
2.2.11.06A	Thermal-Mechanical Effects on Host Rock	- Temperature dependence of mechanical processes, particularly salt creep - Thermal expansion / stress - Altered properties of fractures, faults, rock matrix
	Hydrological and Thermal-Hydrological Processes	
2.2.01.01C	Flow Through EDZ	- Saturated / Unsaturated flow - Fracture / Matrix flow - Gas transport - Flow pathways
2.2.08.01	Flow Through the Host Rock	- Saturated flow - Fracture flow / matrix imbibition (probably not applicable to salt) - Unsaturated flow (fingering, capillarity, episodicity, perched water) - Preferential flow pathways - Density and thermal effects on flow - Flow pathways out of Host Rock
2.2.08.03A	Effects of Recharge on Geosphere Flow in the Host Rock	- Infiltration rate - Water table rise/decline - Effect of climate change
2.2.08.04	Effects of Repository Excavation on Flow Through the Host Rock	- Saturated flow (flow sink) - Unsaturated flow (capillary diversion, drift shadow) - Influx/Seepage into EBS (film flow, enhanced seepage)
2.2.08.05	Condensation Forms in Host Rock	- Condensation cap - Shedding

UFD FEP Number	Description	Type or Associated Processes
2.2.08.06	Flow Through EDZ	- Saturated / Unsaturated flow - Fracture / Matrix flow
2.2.12.02A	Effects of Gas on Flow Through the Host Rock	- Altered gradients and/or flow pathways - Vapor/air flow - Two-phase flow - Gas bubbles - Natural Gas Intrusion from formations beneath repository (N32)
2.2.11.01A	Thermal Effects on Flow in Host Rock - Repository-Induced - Natural Geothermal	- Altered saturation / relative humidity (dry-out, resaturation) - Altered gradients, density, and/or flow pathways - Vapor flow - Condensation
2.2.11.02A	Thermally-Driven Flow (Convection) in Host Rock	- Convection
2.2.11.03A	Thermally-Driven Buoyant Flow / Heat Pipes in Host Rock	- Vapor flow
	Chemical and Thermal-Chemical Processes	
2.2.01.01A	Chemistry in the EDZ	- Chemical characteristics of groundwater in EDZ - Radionuclide speciation and solubility in EDZ
2.2.01.01E	Thermal-Chemical Effects on EDZ	- Thermal-chemical alteration, including diffusion of sulfates from the host rock into the disposal rooms (affects gas generation)
2.2.09.01	Chemical Characteristics of Groundwater in Host Rock	- Water composition (radionuclides, dissolved species, …) - Water chemistry (temperature, pH, Eh, ionic strength …) - Reduction-oxidation potential - Reaction kinetics - Interaction with EBS
2.2.09.03	Chemical Interactions and Evolution of Groundwater in Host Rock	- Host rock composition and evolution (granite, clay, salt ...) - Evolution of water chemistry in host rock - Chemical effects on density - Interaction with EBS - Reaction kinetics - Mineral dissolution/precipitation - Redissolution of precipitates after dry-out
2.2.09.05	Radionuclide Speciation and Solubility in Host Rock	- Dissolved concentration limits
2.2.11.04A	Thermal Effects on Chemistry and Microbial Activity in Host Rock	- Mineral precipitation / dissolution - Altered solubility
2.2.11.07A	Thermal-Chemical Alteration of Host Rock	- Mineral precipitation / dissolution - Altered properties of fractures, faults, rock matrix - Alteration of minerals / volume changes - Formation of near-field chemically altered zone (rind)
2.2.12.01A	Gas Generation in Host Rock	- Degassing (clathrates, deep gases) - Vaporization of water
	Biological and Thermal-Biological Processes	
2.2.10.01	Microbial Activity in Host Rock	- Formation of complexants - Formation and stability of microbial colloids - Biodegradation - Bioaccumulation

UFD FEP Number	Description	Type or Associated Processes
2.2.11.04B	Thermal Effects on Chemistry and Microbial Activity in Host Rock	- Mineral precipitation / dissolution - Altered solubility
2.2.12.01B	Gas Generation in Host Rock	- Microbial degradation of organics
	Transport and Thermal-Transport Processes	
2.2.09.51	Advection of Dissolved Radionuclides in Host Rock	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Matrix diffusion - Saturation
2.2.09.53	Diffusion of Dissolved Radionuclides in Host Rock	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation
2.2.09.55	Sorption of Dissolved Radionuclides in Host Rock	- Surface complexation properties - Flow pathways and velocity - Saturation
2.2.09.57	Complexation in Host Rock	- Presence of organic complexants (humates, fulvates, carbonates, …) - Enhanced transport of radionuclides associated with organic complexants
2.2.09.59	Colloidal Transport in Host Rock	- Flow pathways and velocity - Saturation - Advection - Dispersion - Diffusion - Sorption - Colloid concentration
2.2.09.61	Radionuclide Transport Through EDZ	- Advection - Dispersion - Diffusion - Sorption
2.2.09.62A	Dilution of Radionuclides in Groundwater in Host Rock	- Mixing with uncontaminated groundwater - Mixing at withdrawal well
2.2.09.63A	Dilution of Radionuclides with Stable Isotopes in Host Rock	- Mixing with stable and/or naturally occurring isotopes of the same element
2.2.09.64	Radionuclide Release from Host Rock - Dissolved - Colloidal - Gas Phase	- Spatial and temporal distribution of releases to the Other Geologic Units or to the Biosphere (due to varying flow pathways and velocities, varying transport properties)
2.2.11.05A	Thermal Effects on Transport in Host Rock	- Thermal diffusion (Soret effect) - Thermal osmosis
2.2.12.03A	Gas Transport in Host Rock	- Gas phase transport - Gas phase release from Host Rock

UFD FEP Number	Description	Type or Associated Processes
1.2.01.00	**Long-Term Geologic Processes**	
1.2.01.01A	Tectonic Activity – Large Scale Impacts the Host Rock	- Uplift - Folding
1.2.01.02A	Subsidence Impacts Host Rock	
1.2.01.03A	Metamorphism Impacts Host Rock	- Structural changes due to natural heating and/or pressure
1.2.01.04A	Diagenesis Impacts Host Rock	- Mineral alteration due to natural processes
1.2.01.05A	Diapirism Impacts Host Rock	- Plastic flow of rocks under lithostatic loading - Salt / evaporates - Clay
1.2.01.06A	Large-Scale Dissolution of the Host Rock	
	Climatic	
1.3.01.01A	Climate Change - Natural	- Variations in precipitation and temperature - Long-term global (sea level, …) - Short-term regional and local - Seasonal local (flooding, storms, …)
1.3.04.01A	Periglacial Effects	- Permafrost - Seasonal freeze/thaw
1.3.05.01A	Glacial and Ice Sheet Effects	- Glaciation - Isostatic depression - Melt water
	Human Activities (Long Time Scale)	
1.4.01.01A	Human Influences on Climate - Intentional - Accidental	- Variations in precipitation and temperature - Global, regional, and/or local - Greenhouse gases, ozone layer failure
2.2.14.00	**Nuclear Criticality**	
2.2.14.01A	Criticality in the Host Rock	- Formation of critical configuration
1.2.03.00	**Seismic**	
1.2.03.02A	Seismic Activity Impacts the Host Rock	- Altered flow pathways and properties - Altered stress regimes (faults, fractures) - Regional tectonics, regional uplift, and regional subsidence - Changes in fault/fracture properties
1.2.04.00	**Igneous**	
1.2.04.02A	Igneous Activity Impacts the Host Rock	- Altered flow pathways and properties - Altered stress regimes (faults, fractures) - Igneous intrusions - Altered thermal and chemical conditions
1.4.00.00	**Human Activities (Short Time Scale)**	
1.4.02.01C	Human Intrusion - Deliberate - Inadvertent	- Drilling (resource exploration, …) - Mining / tunneling - Unintrusive site investigation (airborne, surface-based, …)
1.4.11.01C	Explosions and Crashes from Human Activities	- War - Sabotage - Testing - Resource exploration / exploitation - Aircraft
2.2.03.00	**OTHER GEOLOGIC UNITS (NON-HOST STRATA)**	

UFD FEP Number	Description	Type or Associated Processes
	Physical-Chemical Characteristics	
2.2.03.01	Stratigraphy and Properties of Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Rock units - Thickness, lateral extent, heterogeneities, discontinuities, contacts - Physical properties - Flow pathways - Brine reservoirs
2.2.05.01B	Fractures in Non-Host Rock	- Rock properties - Hydrologic properties
2.2.05.02B	Faults in Non-Host Rock	- Rock properties - Hydrologic properties
2.2.05.03B	Alteration and Evolution of Flow Pathways in Non-Host Rock	- Changes In rock properties - Changes in faults - Changes in fractures - Changes in flow pathways, aquifers, and aquitards, including potential for plugging and dissolution - Changes in saturation
	Mechanical and Thermal-Mechanical Processes	
2.2.07.02	Mechanical Effects on Other Geologic Units	- From subsidence due to repository-related excavations - From solution mining of other strata - Chemical precipitation / dissolution - Stress regimes
2.2.11.06B	Thermal-Mechanical Effects on Non-Host Rock	- Thermal expansion / compression - Altered properties of fractures, faults, rock matrix
	Hydrological and Thermal-Hydrological Processes	
2.2.08.02	Flow Through the Other Geologic Units - Confining units - Aquifers	- Saturated flow - Fracture flow / matrix imbibition - Unsaturated flow (fingering, capillarity, episodicity, perched water) - Preferential flow pathways - Density and thermal effects on flow - Saline or freshwater intrusions - Flow pathways out of Other Geologic Units
2.2.08.03B	Effects of Recharge on Geosphere Flow in Other Geologic Units	- Infiltration rate - Water table rise/decline - Effect of climate change
2.2.08.07	Mineralogic Dehydration	- Dehydration reactions release water and may lead to volume changes
2.2.08.08	Groundwater Discharge to Biosphere Boundary	- Surface discharge (water table, capillary rise, surface water) - Flow across regulatory boundary
2.2.08.09	Groundwater Discharge to Well	- Human use (drinking water, bathing water, industrial) - Agricultural use (irrigation, animal watering)
2.2.12.02B	Effects of Gas on Flow Through the Non-Host Rock	- Altered gradients and/or flow pathways - Vapor/air flow - Two-phase flow - Gas bubbles - Natural Gas Intrusion from formations beneath repository (N32)
2.2.11.01B	Thermal Effects on Flow in Non-Host Rock - Repository-Induced - Natural Geothermal	- Altered saturation / relative humidity (dry-out, resaturation) - Altered gradients, density, and/or flow pathways - Vapor flow - Condensation
2.2.11.02B	Thermally-Driven Flow (Convection) in Non-Host Rock	- Convection

UFD FEP Number	Description	Type or Associated Processes
2.2.11.03B	Thermally-Driven Buoyant Flow / Heat Pipes in Non-Host Rock	- Vapor flow
	Chemical and Thermal-Chemical Processes	
2.2.09.02	Chemical Characteristics of Groundwater in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Water composition (radionuclides, dissolved species, …) - Water chemistry (temperature, pH, Eh, ionic strength …) - Reduction-oxidation potential - Reaction kinetics - Saline or freshwater intrusion - Interaction with other geologic units
2.2.09.04	Chemical Interactions and Evolution of Groundwater in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Host rock composition and evolution (granite, clay, salt ...) - Evolution of water chemistry in host rock - Chemical effects on density - Reaction kinetics - Mineral dissolution/precipitation - Recharge chemistry
2.2.09.06	Radionuclide Speciation and Solubility in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Dissolved concentration limits
2.2.11.04B	Thermal Effects on Chemistry and Microbial Activity in Non-Host Rock	- Mineral precipitation / dissolution - Altered solubility
2.2.11.07B	Thermal-Chemical Alteration of Non-Host Rock	- Mineral precipitation / dissolution - Altered properties of fractures, faults, rock matrix - Alteration of minerals / volume changes - Formation of near-field chemically altered zone (rind)
2.2.12.01C	Gas Generation in Non-Host Rock	- Degassing (clathrates, deep gases) - Vaporization of water
	Biological and Thermal-Biological Processes	
2.2.10.02	Microbial Activity in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Formation of complexants - Formation and stability of microbial colloids - Biodegradation - Bioaccumulation
2.2.11.04C	Thermal Effects on Chemistry and Microbial Activity in Non-Host Rock	- Mineral precipitation / dissolution - Altered solubility
2.2.12.01D	Gas Generation in Non-Host Rock	- Microbial degradation of organics
	Transport and Thermal-Transport Processes	
2.2.09.52	Advection of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Matrix diffusion - Saturation
2.2.09.54	Diffusion of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Gradients (concentration, chemical potential) - Diffusive properties (diffusion coefficients) - Flow pathways and velocity - Saturation
2.2.09.56	Sorption of Dissolved Radionuclides in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Surface complexation properties - Flow pathways and velocity - Saturation

UFD FEP Number	Description	Type or Associated Processes
2.2.09.58	Complexation in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Presence of organic complexants (humates, fulvates, carbonates, …) - Enhanced transport of radionuclides associated with organic complexants
2.2.09.60	Colloidal Transport in Other Geologic Units (Non-Host-Rock) - Confining units - Aquifers	- Flow pathways and velocity - Saturation - Advection - Dispersion - Diffusion - Sorption - Colloid concentration
2.2.09.62B	Dilution of Radionuclides in Groundwater in Other Geologic Units	- Mixing with uncontaminated groundwater - Mixing at withdrawal well
2.2.09.63B	Dilution of Radionuclides with Stable Isotopes in Other Geologic Units	- Mixing with stable and/or naturally occurring isotopes of the same element
2.2.09.65	Radionuclide Release from Other Geologic Units - Dissolved - Colloidal - Gas Phase	- Spatial and temporal distribution of releases to the Biosphere (due to varying flow pathways and velocities, varying transport properties)
2.2.12.03B	Gas Transport in Non-Host Rock	- Gas phase transport - Gas phase release from Non-Host Rock
2.2.11.05B	Thermal Effects on Transport in Non-Host Rock	- Thermal diffusion (Soret effect) - Thermal osmosis
1.2.01.00	**Long-Term Geologic Processes**	
1.2.01.01B	Tectonic Activity – Large Scale Impacts the Non-Host Rock	- Uplift - Folding
1.2.01.02B	Subsidence Impacts the Non-Host Rock	
1.2.01.03B	Metamorphism Impacts the Non-Host Rock	- Structural changes due to natural heating and/or pressure
1.2.01.04B	Diagenesis Impacts the Non-Host Rock	- Mineral alteration due to natural processes
1.2.01.05B	Diapirism Impacts the Non-Host Rock	- Plastic flow of rocks under lithostatic loading - Salt / evaporates - Clay
1.2.01.06B	Large-Scale Dissolution of the Non-Host Rock	
	Climatic	
1.3.01.01B	Climate Change - Natural	- Variations in precipitation and temperature - Long-term global (sea level, …) - Short-term regional and local - Seasonal local (flooding, storms, …)
1.3.04.01B	Periglacial Effects	- Permafrost - Seasonal freeze/thaw
1.3.05.01B	Glacial and Ice Sheet Effects	- Glaciation - Isostatic depression - Melt water
	Human Activities (Long Time Scale)	
1.4.01.01B	Human Influences on Climate - Intentional - Accidental	- Variations in precipitation and temperature - Global, regional, and/or local - Greenhouse gases, ozone layer failure

UFD FEP Number	Description	Type or Associated Processes
	Nuclear Criticality	
2.2.14.01B	Criticality in Non-Host Rock	- Formation of critical configuration
1.2.03.00	**Seismic**	
1.2.03.02B	Seismic Activity Impacts Non-Host Rock	- Altered flow pathways and properties - Altered stress regimes (faults, fractures) - Regional tectonics, regional uplift, and regional subsidence - Changes in fault/fracture properties
1.2.04.00	**Igneous**	
1.2.04.02B	Igneous Activity Impacts Non-Host Rock	- Altered flow pathways and properties - Altered stress regimes (faults, fractures) - Igneous intrusions - Altered thermal and chemical conditions
1.4.00.00	**Human Activities (Short Time Scale)**	
1.4.02.01D	Human Intrusion - Deliberate - Inadvertent	- Drilling (resource exploration, …) - Mining / tunneling - Unintrusive site investigation (airborne, surface-based, …)
1.4.11.01D	Explosions and Crashes from Human Activities	- War - Sabotage - Testing - Resource exploration / exploitation - Aircraft
2.3.00.00	**SURFACE FEATURES**	
	BIOSPHERE	
2.3.01.00	**Physical-Chemical Characteristics**	
2.3.01.01	Topography and Surface Morphology	- Recharge and discharge areas
2.3.02.01	Surficial Soil Type	- Physical and chemical attributes
2.3.04.01	Surface Water	- Lakes, rivers, springs - Dams, reservoirs, canals, pipelines - Coastal and marine features - Water management activities
2.3.05.01	Biosphere Characteristics	- Climate - Soils - Flora and fauna - Microbes - Evolution of biosphere (natural, anthropogenic – e.g., acid rain)
2.4.01.01	Human Characteristics	- Physiology - Metabolism - Adults, children

UFD FEP Number	Description	Type or Associated Processes
2.4.01.02	Human Evolution	- Changing human characteristics - Sensitization to radiation - Changing lifestyle
2.3.07.00	**Mechanical and Thermal-Mechanical Processes**	
2.3.07.01	Erosion	- Mechanical weathering (N41) - Denudation - Subsidence - Aeolian or fluvial erosion (N43, N44) - Mass wasting (erosion)(N45)
2.3.07.02	Deposition	- Mechanical or chemical weathering - Aeolian or fluvial deposition (N46, N47) - Lacustrine deposition (N48) - Mass wasting (i.e., landslides)(N49)
2.3.07.03	Animal Intrusion into Repository	- Burrowing animals can affect structure of surface sediments (N70)
2.3.08.00	**Hydrological and Thermal-Hydrological Processes**	
2.3.08.01	Precipitation	- Spatial and temporal distribution [see also Climate Change in 1.3.01.01] [contributes to Infiltration in 2.3.08.03]
2.3.08.02	Surface Runoff and Evapotranspiration	- Runoff, impoundments, flooding, increased recharge - Evaporation - Condensation - Transpiration (root uptake)
2.3.08.03	Infiltration and Recharge	- Spatial and temporal distribution - Effect on hydraulic gradient - Effect on water table elevation
2.3.09.00	**Chemical and Thermal-Chemical Processes**	
2.3.09.01	Chemical Characteristics of Soil and Surface Water	- Altered recharge chemistry (natural) - Altered recharge chemistry (anthropogenic – e.g., acid rain) - Chemical weathering (N42) [contributes to Chemical Evolution of Groundwater in 2.2.09.04]
2.3.09.02	Radionuclide Speciation and Solubility in Biosphere	- Dissolved concentration limits
2.3.09.03	Radionuclide Alteration in Biosphere	- Altered physical and chemical properties - Isotopic dilution
2.3.10.00	**Biological and Thermal-Biological Processes**	
2.3.10.01	Microbial Activity in Biosphere	- Effect on biosphere characteristics - Effect on transport through biosphere
2.3.09.50	**Transport and Thermal-Transport Processes**	
2.3.09.51	Atmospheric Transport Through Biosphere	- Radionuclide transport in air, gas, vapor, particulates, aerosols - Processes include: wind, plowing, degassing, precipitation

UFD FEP Number	Description	Type or Associated Processes
2.3.09.52	Surface Water Transport Through Biosphere	- Radionuclide transport and mixing in surface water - Processes include: lake mixing, river flow, spring discharge, overland flow, irrigation, aeration, sedimentation, dilution
2.3.09.53	Soil and Sediment Transport Through Biosphere	- Radionuclide transport in or on soil and sediments - Processes include: fluvial (runoff, river flow), eolian (wind), saltation, glaciation, bioturbation (animals)
2.3.09.54	Radionuclide Accumulation in Soils	- Leaching/evaporation from discharge (well, groundwater upwelling) - Deposition from atmosphere or water (irrigation, runoff)
2.3.09.55	Recycling of Accumulated Radionuclides from Soils to Groundwater	
2.3.11.00	**Thermal Processes**	
2.3.11.01	Effects of Repository Heat on Biosphere	
3.3.01.00	**Radiological Processes**	
3.3.01.01	Radionuclides in Biosphere Media	- Soil - Surface Water - Air - Plant Uptake - Animal (Livestock, Fish) Uptake - Bioaccumulation
	Climatic	
1.3.01.01C	Climate Change - Natural	- Variations in precipitation and temperature - Long-term global (sea level, …) - Short-term regional and local - Seasonal local (flooding, storms, …)
1.3.04.01C	Periglacial Effects	- Permafrost - Seasonal freeze/thaw
1.3.05.01C	Glacial and Ice Sheet Effects	- Glaciation - Isostatic depression - Melt water
	Human Activities (Long Time Scale)	
1.4.01.01C	Human Influences on Climate - Intentional - Accidental	- Variations in precipitation and temperature - Global, regional, and/or local - Greenhouse gases, ozone layer failure
2.4.04.01	Human Lifestyle	- Diet and fluid intake (food, water, tobacco/drugs, etc.) - Dwellings - Household activities - Leisure activities
2.4.08.01	Land and Water Use	- Agricultural (irrigation, plowing, fertilization, crop storage, greenhouses, hydroponics) - Farms and Fisheries (feed, water, soil) - Urban / Industrial (development, energy production, earthworks, population density) - Natural / Wild (grasslands, forests, bush, surface water)
2.4.08.02	Evolution of Land and Water Use	- New practices (agricultural, farming, fisheries) - Technological developments - Social developments (new/expanded communities)
	Other (3.3.04.00, Exposure Modes, and 3.3.06.00, Toxic Effects)	

UFD FEP Number	Description	Type or Associated Processes
3.3.01.02	Radionuclides in Food Products	- Diet and fluid sources (location, degree of contamination, dilution with uncontaminated sources) - Foodstuff and fluid processing and preparation (water filtration, cooking techniques)
3.3.01.03	Radionuclides in Non-Food Products	- Dwellings (location, building materials and sources, fuel sources) - Household products (clothing and sources, furniture and sources, tobacco, pets) - Biosphere media
3.3.04.01	Ingestion	- Food products - Soil, surface water
3.3.04.02	Inhalation	- Gases and vapors - Suspended particulates (dust, smoke, pollen)
3.3.04.03	External Exposure	- Non-Food products - Soil, surface water
3.3.06.01	Radiation Doses	- Exposure rates (ingestion, inhalation, external exposure) - Dose conversion factors - Gases and vapors - Suspended particulates (dust, smoke, pollen)
3.3.06.02	Radiological Toxicity and Effects	- Human health effects from radiation doses
3.3.06.03	Non-Radiological Toxicity and Effects	- Human health effects from non-radiological toxicity
1.2.03.00	**Seismic**	
1.2.03.03A	Seismic Activity Impacts Surface Environment	- Altered surface characteristics - Altered surface transport pathways - Altered recharge - Regional uplift or subsidence - Surface faulting (N11 is subsurface only)
1.2.04.00	**Igneous**	
1.2.04.03A	Igneous Activity Impacts Surface Environment	- Altered surface characteristics - Altered surface transport pathways - Altered recharge - Ashfall and ash redistribution
1.4.00.00	**Human Activities (Short Time Scale)**	
1.4.11.01D	Explosions and Crashes from Human Activities	- War - Sabotage - Testing - Resource exploration / exploitation - Aircraft
1.0.00.00	**REPOSITORY SYSTEM FEATURES**	
0.0.00.00	**ASSESSMENT BASIS**	
0.1.02.01	Timescales of Concern	
0.1.03.01	Spatial Domain of Concern	
0.1.09.01	Regulatory Requirements and Exclusions	

UFD FEP Number	Description	Type or Associated Processes
0.1.10.01	Model Issues	- Conceptual model - Mathematical implementation - Geometry and dimensionality - Process coupling - Boundary and initial conditions
0.1.10.02	Data Issues	- Parameterization and values - Correlations - Uncertainty
1.1.00.00	**PRECLOSURE/OPERATIONAL**	
	Physical-Chemical Characteristics	
1.1.08.01	Deviations from Design and Inadequate Quality Control	- Error in waste emplacement (waste forms, waste packages, waste package support materials) - Error in EBS component emplacement (backfill, seals, liner) - Inadequate excavation / construction (planning, schedule, implementation) - Aborted/incomplete closure of repository - Material and/or component defects
1.1.10.01	Control of Repository Site	- Active controls (controlled area) - Retention of records - Passive controls (markers)
	Mechanical and Thermal-Mechanical Processes	
1.1.13.01	Retrievability	
1.1.02.02	Mechanical Effects from Preclosure Operations - In EBS - In EDZ - In Host Rock	- Creation of excavation-disturbed zone (EDZ) - Stress relief - Boring and blasting effects - Rock reinforcement effects (drillholes) - Accidents and unplanned events - Enhanced flow pathways
	Hydrological and Thermal-Hydrological Processes	
1.1.01.01	Open Boreholes	- Site investigation boreholes (open, improperly sealed) - Preclosure and postclosure monitoring boreholes - Enhanced flow pathways from EBS
1.1.02.03	Thermal-Hydrologic Effects from Preclosure Operations - In EBS - In EDZ - In Host Rock	- Site flooding - Preclosure ventilation - Accidents and unplanned events
	Chemical and Thermal-Chemical Processes	
1.1.02.01	Chemical Effects from Preclosure Operations - In EBS - In EDZ - In Host Rock	- Water contaminants (explosives residue, diesel, organics, etc.) - Water chemistry different than host rock (e.g., oxidizing) - Undesirable materials left - Accidents and unplanned events
1.5.00.00	**OTHER GLOBAL**	
	Other Events	
1.5.01.01	Meteorite Impact	- Cratering, host rock removal - Exhumation of waste - Alteration of flow pathways

UFD FEP Number	Description	Type or Associated Processes
1.5.01.02	Extraterrestrial Events	- Solar systems (supernova) - Celestial activity (sun - solar flares, gamma-ray bursters; moon – earth tides) - Alien life forms
1.5.03.01	Earth Planetary Changes	- Changes in earth's magnetic field - Changes in earth's gravitational field (tides) - Changes in ocean currents

NOTE: text in red indicates changes identified in, or subsequent to, Sevougian et al. (2012, Appendix A)

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