Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

We put science to work.™

Savannah River National Laboratory®

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

Safety Functions and Features, Events and Processes for the E-Area Performance Assessment

R. R. Seitz

February 2020

SRNL-STI-2020-00039, Revision 0

SRNL.DOE.GOV

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

Keywords: *Performance Assessment*

Retention: *Permanent*

Safety Functions and Features, Events and Processes for the E-Area Performance Assessment

R. R. Seitz

February 2020

Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

Savannah River National Laboratory®
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

REVIEWS AND APPROVALS

AUTHORS:

____

R. R. Seitz, Inspection Experts, Inc. Date

TECHNICAL REVIEW:

____

B. T. Butcher, Environmental Modeling, SRNL Date

APPROVAL:

____

D. A. Crowley, Manager Date
Environmental Modeling, SRNL

____

A. P. Fellinger, Director, Environmental Restoration Technology, SRNL Date

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

CIG	Component-In-Grout
CLSM	Controlled Low-Strength Material
DOE	Department of Energy
DSA	Documented Safety Analysis
EBS	Engineered Barrier System
ELLWF	E-Area Low-Level Waste Facility
ET	Engineered Trench
FEPs	Features, Events and Processes
FFA	Federal Facility Agreement
FY	Fiscal Year
GCL	Geosynthetic Clay Liner
HDPE	High-Density Polyethylene
IAEA	International Atomic Energy Agency
ILV	Intermediate-Level Vault
ISAM	Improvement of Safety Assessment Methodologies
Kd	Sorption Coefficient
LAWV	Low-Activity Waste Vault
LLW	Low-Level Waste
LLWF	Low-Level Waste Facility
LUCAP	Land Use Control Assurance Plan
LUCIP	Land Use Controls Implementation Plan
LVZ	Lower Vadose Zone
NRCDA	Naval Reactor Component Disposal Area
PA	Performance Assessment
POA	Point of Assessment
RCRA	Resource Conservation and Recovery Act
SRS	Savannah River Site
ST	Slit Trench
TBD	To Be Determined
UVZ	Upper Vadose Zone
VZ	Vadose Zone

1.0 Introduction

The DOE Technical Standard, "Disposal Authorization Statement and Tank Closure Documentation," (DOE 2017) recommends the use of safety functions and features, events and processes (FEPs) to support development of conceptual models and identification of scenarios to be considered in a performance assessment (PA). The FEP process provides a means to describe how a PA considers and addresses the factors that could influence the performance of key barriers. Understanding the roles of barriers in terms of limiting migration helps to focus on how changes in the system could lead to a situation where those roles cannot be fulfilled and there is the potential for compromised performance.

The FEPs screening and review process was used to identify FEPs that are relevant for the E-Area Low-Level Waste Facility (LLWF) and specifically those FEPs that could have a detrimental impact on the effectiveness of a given safety function. For this PA, a default list of FEPs developed at the International Atomic Energy Agency (IAEA 2004) and an approach implemented for PAs at the Hanford and Idaho sites (Mehta et al. 2016, DOE-ID 2019) are used to identify processes and events that could influence the effectiveness of a given safety function for the E-Area LLWF (e.g., subsidence can impact the safety function of the cover system and lead to increased infiltration). The Hanford and Idaho PAs represent two of the most recent applications of this approach. The PA evaluates the potential impacts of changes in performance of different features of the system and demonstrates that the safety functions represent multiple and redundant barriers. Barrier analyses, assuming a safety function is not present, also test the robustness of the system in the event of the loss of one or more safety functions. Such evaluations also support a qualitative illustration of the concept of defense in depth.

The safety concept for closure of the E-Area LLWF (generically referred to as "E-Area") encompasses a variety of different features (i.e., administrative controls, natural site features, and engineered barriers) that reduce the potential impacts on human health and the environment from the residual waste that will remain after closure. These features can be represented as a collection of safety functions acting independently and as a system to provide for overall safety. In some applications, there have been attempts to assign numerical expectations to specific safety functions, but that is not the intent in this case. The concept of safety functions is used more qualitatively in two ways for this PA:

1. To illustrate the robustness of the E-Area design, operational practices and closure approach by documenting features that are and are not credited in different modeling cases.
2. To identify the roles of the different features and potential processes and events that could compromise the performance of safety features and need to be considered when developing the modeling approach.

This report addresses both safety functions and FEPs for the E-Area PA.

2.0 Safety Functions

The first part of this task involved identifying safety functions that are relevant for the E-Area PA. The resulting table of safety functions is provided in Appendix A. Each safety function includes a general description, a list of FEPs relevant for that function, and those FEPs considered potentially deleterious. The last two columns in the table summarize how the safety function was considered in the E-Area PA and in any sensitivity and uncertainty analyses. The effectiveness of these safety functions is evaluated as part of the demonstration of a reasonable expectation of meeting the performance objectives and measures. Defense-in-depth is also addressed by considering potential impacts if any of the safety functions are lost or degraded through time or disruptive events. In many cases, the significance of deleterious FEPs relative to the conclusions of the analysis is addressed as more of a bounding approach by ignoring or taking minimal credit for the effectiveness of a given safety function either in the base case or in a barrier analysis. The table helps to highlight these types of deliberate biases.

2.1 Contextual Safety Functions

Although there is often a focus on technical safety functions, it is important to recognize a number of safety functions that are provided by administrative or contextual requirements. These are not quantitatively addressed in this PA. For example, the all pathways dose performance objective (25 mrem/yr) is set at a fraction of the overall public dose limit (factor of four less than 100 mrem/yr). Furthermore, the performance objective is well below the average annual dose in the United States (roughly a factor of 25 less than 630 mrem/yr). Thus, significant safety margins are already built into the overall performance requirements.

A second key aspect of the safety concept for E-Area is associated with the administrative requirement in DOE O 458.1 Chg 3, "Radiation Protection of the Public and the Environment," (DOE 2013) for continuing land ownership by the U.S. Department of Energy. It is noteworthy that all the technical calculations that are presented in this PA are predicated on the loss of Safety Functions IC1 (institutional control) and IC2 (societal memory) in Appendix A. That is, loss of institutional control and loss of societal memory of the activities at the Savannah River Site (SRS) are both assumed to occur 100 years after closure. In the likely case that either or both of these safety functions remain effective, any exposure scenarios considered at 100 years are not credible.

DOE M 435.1-1 Chg 2, "Radioactive Waste Management Manual," (DOE 2011a) also introduces an administrative safety function related to the assumed location of a receptor (i.e., the point of compliance or point of assessment) and the habits of the receptor (i.e., a more highly exposed individual). Assuming the first two safety functions (institutional control and societal memory) are lost, DOE M 435.1-1 Chg 2 generically expects that a groundwater well will be installed 100 m (328 ft) from the disposed waste specifically in the location and at the time of peak concentration. This assumption limits the safety functions provided by the natural environment (i.e., further delays and dilution of contaminants in an aquifer). It is also assumed that a more highly exposed individual with habits intended to increase doses will be the receptor (i.e., a subsistence farmer). People upgradient or further downgradient or people not using groundwater and growing their own food would receive lower exposures and doses due to disposed waste in E-Area. Given past history, if memory of the SRS is lost, there is evidence to suggest that people would potentially establish a residence and use untreated groundwater as their water source. However, given the widespread knowledge of the site, it is highly unlikely that people would unknowingly establish a residence in E-Area 100 years after closure. DOE M 435.1-1 Chg 2, therefore, provides an added layer of safety to the results of the analyses via this safety function where such exposures are assumed to occur at the time and location of the peak concentration very near the facility. Such defense-in-depth adds substantial margins of safety for short-lived radionuclides and radionuclides that migrate rather quickly to a 100-m well.

2.2 Engineered and Natural Safety Functions

The remaining parts of the safety concept involve the use of engineered features and the natural setting to provide multiple and redundant barriers to the release and migration of residual wastes from E-Area disposal units. The engineered barriers are divided into one of four categories: hydrological safety functions, intrusion safety functions, structural safety functions, and chemical safety functions. The hydrological safety functions limit the contact of water with the residual wastes, limit the rate at which contamination will migrate out of the units through the unsaturated zone to the compliance point in the aquifer, and provide dilution of contamination through dispersion and mixing with clean surrounding water. The chemical safety functions are intended to decrease the solubility or increase the sorption of key contaminants and to provide a stable and passive chemical environment for the engineered barriers.

The safety concept for E-Area relies on a graded approach for disposal where lower risk wastes are disposed in Slit Trenches (STs) or Engineered Trenches (ETs) with limited engineered controls, except for the cover. Higher risk waste is disposed in the Low-Activity Waste Vault (LAWV) or Intermediate-Level Vault (ILV), which provide additional layers of protection during operations and after closure.

Containerized waste in the Slit and Engineered Trenches is expected to result in subsidence as the containers degrade, which will lead to potential for increased infiltration through the cover. Plans for dynamic compaction prior to final closure will help limit the extent of subsidence. The vaults provide a longer-term stable support structure for the cover, delaying potential subsidence until the loss of physical integrity of the vault roof.

As discussed above, this PA is used to evaluate the safety concept and provide a reasonable expectation of meeting the performance objectives and measures. Confidence in the overall safety concept is enhanced if sufficient performance can be achieved even in the event that any of the safety functions are lost or are degraded in time (e.g., via subsidence). The safety functions in Appendix A describe how different barriers are expected to contribute to the ability to meet the performance objectives. Potential deleterious FEPs are also identified to flag key factors that could lead to reduced performance. Finally, the table includes how safety functions are considered in both the PA base case and additional analysis cases that are provided to address uncertainty associated with potentially deleterious FEPs.

3.0 Screening and Review of FEPs

In order to test the safety functions for the E-Area LLWF, it is necessary to consider potential FEPs with an emphasis on identifying FEPs that could potentially compromise the effectiveness of a given safety function. This section addresses the process implemented to screen and review FEPs to identify those that need to be considered for the E-Area PA. Special emphasis is placed on identifying FEPs that may have deleterious effects on any of the safety functions.

The results of the screening and review of FEPs for the safety functions identified for E-Area is documented in Appendix B. The review was conducted in a working meeting with the PA team and key site personnel using a graded approach based on similar work that was completed for the Waste Management Area C tank closure PA at the Hanford Site (Mehta et al. 2016) and the Calcine PA at the Idaho Site (DOE-ID 2019). The process began with identification of a representative list of FEPs as the basis for the screening exercise.

A FEPs list is intended to be sufficiently comprehensive to capture FEPs that might need to be accounted for in a PA. The list includes FEPs that are merely associated with a particular safety function and those that may be deleterious to a safety function. For instance, FEP 3.2.07, "Water-mediated transport of contaminants," (see Appendix B) is associated with all safety functions related to the groundwater pathway but is not necessarily deleterious to that pathway. By contrast, FEP 2.1.05, "EBS characteristics and degradation processes," includes degradation processes that would eventually lead to increased infiltration through a cover or creation of pathways for migration out of a concrete vault. It therefore may be a deleterious FEP for safety functions related to cover infiltration or engineered structure permeability.

The safety functions approach described in Chapter 1 helps to highlight important processes to include in conceptual models for individual components of the disposal system. The approach also provides a logical means to identify a set of sensitivity analyses that can be used to explore the implications of the loss of safety functions, while at the same time exploring the implications of aggregated FEPs that might affect the safety function in similar ways. The structure of the PA for E-Area includes identifying sensitivity cases and alternative models for the safety functions shown in Table A-1, developing distributions for key inputs for an uncertainty analysis, and examining what happens in the PA model when a safety function behaves differently than expected, is degraded compared to a base case, or is lost entirely. The process also addressed FEPs that might affect multiple safety functions simultaneously.

The choice of sensitivity analysis cases associated with deleterious FEPs also included barrier analyses. Barrier analyses are provided to investigate the robustness of the system in the face of complete loss of safety functions. The barrier analyses are not intended to represent realistic behavior of the system but instead to explore the importance of various parts of the system to the overall performance.

3.1 FEPs Review Process

A list of FEPs developed for the International Atomic Energy Agency (IAEA) Improvement of Safety Assessment Methodologies (ISAM) project (IAEA 2004) was used as the starting point for the screening process. The IAEA list is a reasonably comprehensive collection for the purposes of the E-Area PA. The list was developed with the participation of representatives from many countries actively involved in low-level waste (LLW) disposal around the globe. The DOE review process also provides redundant confirmation of the intent of the FEPs process as reviewers will also challenge whether key FEPs may have been missed.

A record was created for each FEP. Each record contains a title for and definition of the FEP, comments on the assessment context, key concepts, examples and related FEP's and finally, application to the disposal facility and potentially deleterious effects of a failed FEP. The table of FEP records from the IAEA report (2004) is reproduced in Appendix B. The emphasis of the review process described here was to document the information requested in the last (bottom) section for each FEP record. Namely, the applicability to the E-Area PA and whether each FEP posed any potential deleterious impacts that need to be considered in the PA.

A team of subject matter experts was assembled for the review. The team comprised expertise in PA, modeling, design, operations, and closure:

- Dan Burns
- Tom Butcher
- Tom Danielson
- Jim Dyer
- Larry Hamm
- Virginia Rigsby
- Roger Seitz
- Ira Stewart

The FEPs review process involved two key activities. Each team member independently reviewed the FEPs list and a working meeting was held to go through the complete list and develop consensus input for applicability and potentially deleterious effects. Following the initial review and screening, the results were documented in a draft table. The draft table was then reviewed again and finalized.

3.2 Results of FEPs Review and Screening

The effort focused on populating the last rows for each FEP record by identifying applicability to the E-Area PA and potentially deleterious effects. The description and example entries for each FEP record were not modified but preserved to use as context for understanding the relevance. The team determined whether each FEP is relevant for the E-Area PA and whether it is also potentially deleterious to the safety functions for E-Area. The result of this review of each FEP is provided in the table. When a FEP was relevant, each entry also includes brief explanatory information. At the end of the process, the results of the FEPs screening were integrated into the safety functions table in Appendix A to provide a cross-reference between the two efforts.

4.0 Conclusions

Safety functions and FEPs were considered in support of the E-Area PA. The table in Appendix A includes a description of the safety functions and provides cross-references to FEPs that may influence the safety functions as determined through the screening process. The table also summarizes how the safety functions and FEPs are addressed in the PA, including specific considerations to address uncertainty. The process of documenting safety functions helps to describe how defense-in-depth is addressed in the E-Area PA. The process also helps to identify and document FEPs that may impact performance of key barriers and how uncertainties regarding the effectiveness of key barriers are considered in the base case as well as sensitivity and uncertainty analyses. The efforts to review and screen FEPs that may influence the effectiveness of barriers in the PA provide added confidence that key factors for performance are not missed.

5.0 References

Aleman 2019. "Savannah River National Laboratory Dose Toolkit," SRNL-TR-2019-00337, Revision 0, December 2019.

Bagwell and Bennett 2017. "Elevation of Water Table and Various Stratigraphic Surfaces beneath E Area Low Level Waste Disposal Facility," SRNL-STI-2017-00301, Revision 1, November 2, 2017.

Carey 2006. "Low Activity Waste (LAW) Vault Structural Degradation Prediction," T-CLC-E-00018, Revision 1, June 8, 2006.

Danielson 2019. "PORFLOW Implementation of Vadose Zone Conceptual Model for Slit and Engineered Trenches in the E-Area Low Level Waste Facility Performance Assessment," SRNL-STI-2019-00193, Revision 0, December 30, 2019.

DOE 2007. DOE O 435.1 Chg 1, 2007, "Radioactive Waste Management," U.S. Department of Energy, January 9, 2007.

DOE 2011a. DOE M 435.1-1 Chg 2, "Radioactive Waste Management Manual," U.S. Department of Energy, June 8, 2011.

DOE 2011b. DOE-STD-1196-2011, 2011, DOE Standard, "Derived Concentration Technical Standard," U.S. Department of Energy, April 2011.

DOE 2013. DOE O 458.1 Chg 3, "Radiation Protection of the Public and the Environment," U.S. Department of Energy, January 15, 2013.

DOE 2015. DOE P 454.1 Chg 1, "Use of Institutional Controls," U.S. Department of Energy, December 7, 2015.

DOE 2017. DOE-STD-5002-2017, DOE Standard, "Disposal Authorization Statement and Tank Closure Documentation," U.S. Department of Energy, July 2017.

DOE-ID 2019. "Performance Assessment for the INTEC Calcined Solids Storage Facility at the INL Site" (Draft), DOE/ID-12008, Revision B, September 2019.

DOE-SR 2017. "Savannah River Site Environmental Management Program Management Plan," Department of Energy – Savannah River, November 2017.

Dyer 2019. "Infiltration Data Package for the E-Area Low-Level Waste Facility Performance Assessment," SRNL-STI-2019-00363, Revision 0, November 2019.

Flach 2018. "Updated Groundwater Flow Simulations of the Savannah River Site General Separations Area," SRNL-STI-2018-00643, Revision 0, January 15, 2019.

Hamm 2019. "Preliminary Assessment for Continued Use of Plume Interaction Factors and Other Options for Revised Performance Assessment Methodology," SRNL-STI-2019-00149, DRAFT, March 7, 2019.

Hang 2019. "GSA Aquifer Cutouts for E-Area PA Revision Transport Simulations," SRNL-STI-2019-00736, Revision 0, December 10, 2019.

IAEA 2004. *Safety Assessment Methodologies for Near Surface Disposal Facilities, Results of a Coordinated Research Project, Volume 1: Review and Enhancement of Safety Assessment Approaches and Tools*, IAEA-ISAM-1, International Atomic Energy Agency.

Jones and Phifer 2007. "E-Area Low-Activity Waste Vault Subsidence Potential and Closure Cap Performance (U)," WSRC-TR-2005-00405, Revision 0, August 2007.

Kaplan 2016. "Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site," SRNL-STI-2009-00473, Revision 1, July 22, 2016.

Mehta, S. et al. 2016. "Performance Assessment of Waste Management Area C, Hanford Site, Washington," RPP-ENV-58782, Rev. 0, Washington River Protection Solutions, October 2016.

Nichols 2020. "Hydraulic Properties Data Package for the E-Area Soils, Cementitious Materials, and Waste Zones – Update," SRNL-STI-2019-00355, Revision 0, January 2020.

Peregoy 2006. "Structural Evaluation of Intermediate Level Waste Disposal Vaults for Long-Term Behavior," T-CLC-E-00024, Revision 0, June 27, 2006.

Peregoy 2006, "Structural Evaluation of Components-in-Grout Trenches," T-CLC-E-00026, Revision 0, July 25, 2006.

SCDHEC 2016. "Well Standards," Published in State Register: Document 4571, Volume 40, Issue 6, South Carolina Department of Health and Environmental Control, June 24, 2016.

Smith et al. 2019. "Dose Calculation Methodology and Data for Solid Waste Performance Assessment and Composite Analysis at the Savannah River Site," SRNL-STI-2015-00056, Revision 1, August 2019.

SRNS 1993. "Federal Facility Agreement for the Savannah River Site," WSRC-OS-94-42, Effective Date: August 6, 1993 (latest update), Savannah River Nuclear Solutions.

SRNS 2011. "Land Use Control Assurance Plan for the Savannah River Site," WSRC-RP-98-4125, Revision 1.1, Savannah River Nuclear Solutions, February 2011.

SRNS 2015. "Savannah River Site Ten Year Site Plan, FY 2016-2025," SRNS-RP-2015-00001, Savannah River Nuclear Solutions, February 2011.

Stagich and Jannik 2020. "Exposure Pathways and Scenarios for the E-Area Low-Level Waste Facility Performance Assessment," SRNL-STI-2020-00007, Revision 0, January 2020.

SWM 2019. "Savannah River Site Solid Waste Management Facility Documented Safety Analysis," WSRC-SA-22, Revision 29, July 2019.

Wohlwend and Butcher 2018. "Proposed NRCDA Groundwater Pathway Conceptual Model," SRNL-STI-2018-00633, Revision 0, November 2018.

WSRC 2008. "E-Area Low-Level Waste Facility DOE 435.1 Performance Assessment," WSRC-STI-2007-00306, Revision 0, July 2008.

This page intentionally left blank.

Appendix A. Safety Functions

This page intentionally left blank.

Table A-1. List of safety functions; associated features, events, and processes (FEPs); potentially deleterious FEPs; and the analyses intended to explore the deleterious FEPs.

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
Administrative Controls					
AR1	Performance objectives and measures	The annual performance objectives for public exposure (25 mrem all pathways, 10 mrem air) in DOE M 435.1-1 Chg 2 are established at a fraction of the ICRP and IAEA dose limits for public exposures (100 mrem) and a substantial fraction of the average annual dose in the United States (630 mrem). The ICRP and IAEA dose limits can be exceeded, but an average dose over 5 yr should not exceed 100 mrem. 1,000-year time of compliance. Dose response assumptions are specified by DOE technical standards.	0.01 0.02 0.07 0.09	Performance objectives include safety margins compared to typical exposures. Calculations are conducted beyond 1,000 years to address potential later peaks.	Considered reasonably bounding.*
AR2	Exposure pathways	Assumptions about how humans are exposed to radioactivity must be made to calculate the dose. The types of potential exposures depend on the activities and conditions typical for the site. There were residents present on the Savannah River Site prior to establishment of the site boundaries, thus there is potential for exposures if institutional controls were to fail and memory of the site was lost. These exposures can include residential, hunter/fisherman, recreational, etc. DOE-SR, EPA and SCDHEC signed a Memorandum of Agreement to establish the *Land Use Control Assurance Plan* (LUCAP) (SRNS 2011). The LUCAP establishes and implements procedures to ensure the long-term effectiveness of Land Use Controls consistent with regulatory cleanup in the *Federal Facility Agreement* (FFA) for the SRS (SRNS 1993). At SRS, long-term stewardship begins at the completion of the Environmental Management mission. The current EM Program Management Plan (DOE-SR 2017) indicates the SRS cleanup program will continue to Fiscal Year (FY) 2065. The future use for the SRS is non-residential and will be maintained as such using institutional controls in accordance with the current *SRS Comprehensive Plan/Ten Year Site Plan FY 2016-2025* (SRNS 2015) and the *Land Use Control Assurance Plan for the Savannah River Site* LUCAP, individual RODs, facility specific Land Use Controls Implementation Plans (LUCIPs) and the DOE-SR Resource Conservation and Recovery Act (RCRA) Permit.	0.03 **0.04** 0.05 0.06 1.1.01 1.1.02 1.1.03 1.1.04 1.1.05 1.1.06 1.1.08 1.1.10 1.1.11 1.1.12 1.3.09 1.4.01 1.4.03 **1.4.06** 1.4.07 1.4.08 1.4.11 1.4.14 2.2.13 2.3.08 2.3.09 2.3.13 2.4.01 2.4.02 2.4.03 2.4.04 2.4.05 2.4.06 2.4.07 2.4.08 2.4.09 3.2.11 3.2.12 3.2.13 3.3.01 3.3.02 3.3.04 3.3.05 3.3.06 3.3.08	Upon loss of institutional control (see IC1), a more highly exposed individual located 100 m (328 ft) from the disposed waste at the time of peak concentration is assumed, ignoring the limited likelihood of such exposure.	Considered reasonably bounding.*
IC1	Institutional control	Institutional controls essentially remove the possibility of significant public exposures near the E-Area. DOE O 458.1 Chg 3 (DOE 2013) requires that DOE maintain control until the site can be released for unrestricted use. DOE P 454.1 Chg 1 (DOE 2015) and the CERCLA process under the FFA identify how that stewardship is to be carried out. The CERCLA process includes specific land use restrictions to complement DOE requirements. The description under AR2, Administrative Controls Safety Function, summarizes the current planning and implementing documents.	1.1.06 1.1.10 1.4.01 **1.4.03** **1.4.06** 1.4.07 1.4.08 **1.4.11** 1.4.14	100 years of active institutional control is assumed to end in 2165. Institutional controls are assumed to be ineffective after that time, although CERCLA agreements will be in place and DOE is required to maintain active controls in accordance with DOE O 458.1.	Considered reasonably bounding.*
IC2	Societal memory	Societal memory of E-Area can be preserved using records, deed restrictions, local memory of the site, education, and other passive controls that would warn someone of the potential hazards in the area. In order for a member of the public to unknowingly conduct activities in the vicinity of E-Area, all memory of the activities at the Savannah River Site would have to be lost, and any records would have to be forgotten or ignored. DOE O 458.1 Chg 3 (DOE 2013) requires recordkeeping that would lessen the likelihood of this occurrence. DOE P 454.1 Chg 1 (DOE 2015) and the *Land Use Control Assurance Plan for the Savannah*	1.1.06 1.1.10 1.4.01 **1.4.03** **1.4.06** 1.4.07 **1.4.08** **1.4.11** 1.4.14	Complete loss of memory and ineffectiveness of records and passive controls after 100 years of institutional control is assumed, ignoring widespread knowledge of the site and requirements for land use controls and recordkeeping.	Considered reasonably bounding.*

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
		River Site LUCAP (SRNS 2011), individual RODs, facility-specific Land Use Controls Implementation Plans (LUCIP) will assure the reliability of land use assumptions**.** DOE Legacy Management also engages in a number of activities to prolong memory of the site (e.g., visitor centers, active engagement at schools and with the community).			
Natural Site Features					
SC1	Site characteristics	Conditions at the site determine infiltration and groundwater migration rates, geochemical conditions, and factors influencing atmospheric releases. E-Area is located in a humid, temperate climate, resulting in moderate infiltration rates under natural conditions. The water table is relatively shallow and surface water is available in the vicinity making access to water relatively easy.	**1.1.01** **1.3.02** **1.3.06** **1.3.07** **1.3.10** **1.4.01** **2.2.01** **2.2.02** **2.2.03** **2.2.07** **2.3.01** **2.3.02** **2.3.07** **2.3.08** **2.3.09** **2.3.10** **2.3.11** **2.3.12** **2.3.13** **2.3.14**	Table A-1 in SRNL-STI-2019-00363 (Dyer 2019) provides monthly average precipitation rates yielding an average of roughly 49 inches of precipitation in a year. After accounting for evaporation, transpiration and runoff, it is assumed that natural infiltration is about 16 inches per year.	Sensitivity and uncertainty analyses considering ranges or variation in annual average precipitation rates TBD.
VZ1	Water flow in unsaturated zone	The unsaturated zone ranges from roughly 45 to 80 feet thick in E-Area with moderate infiltration as a driving force. Some dispersion is expected to occur as water moves through the unsaturated zone. In the closed disposal system, it would be expected that higher fluxes of water would be directed around the covered areas, which would tend to provide some dilution for releases occurring slowly beneath the cover. South Carolina Well Standards, Regulation 61-71 (SCDHEC 2016) provides requirements for properly sealing abandoned wells and boreholes.	**0.04** **1.1.01** **1.1.02** **1.3.02** **1.3.06** **1.3.07** **1.3.10** **1.4.01** **2.2.01** **2.2.02** **2.2.03** **2.2.07** **2.3.01** **2.3.02** **2.3.08** **2.3.09** **2.3.10** **2.3.11** **2.3.12** **2.3.13** **2.3.14** 3.1.01 3.2.09	Nominal assumptions and values for unsaturated zone hydraulic properties are described in SRNL-STI-2019-00355 (Nichols 2020). Nominal or "best estimate" hydraulic property values are generally assumed in deterministic modeling for establishing disposal limits.	Planned sensitivity and uncertainty analyses will be based on hydraulic property value uncertainty distributions provided in SRNL-STI-2019-0355.

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
VZ2	Sorption in unsaturated zone	Unsaturated zone soils comprise a mix of clay and sand and will sorb some of the contaminants of potential concern, reducing concentrations in pore water and delaying their arrival at the water table. There is variability in the amounts of clay and sand above the water table in different parts of E-Area, which is addressed in the conceptual model. Sorption is generally expected to be higher in clayey soils than sands.	**1.1.01** **3.2.01** 3.2.05 **1.4.07** **3.2.02** 3.2.06 **2.1.09** **3.2.03** **3.2.07** **2.2.03** **3.2.04** **2.2.07** **2.2.08** **2.2.09**	"Best", "minimum" and "maximum" estimates of sorption coefficient or *Kd* values for unsaturated zone geochemical properties are described in SRNL-STI-2009-00473, Rev. 1, (Kaplan 2016). "Best estimate" values are considered central values derived from experimental data, the literature, or, where no sorption data are available, based on chemical analogue. Best estimate geochemical values are assumed in deterministic modeling for establishing disposal limits. Sorption tends to be higher in clayey soils rather than sandy soils. Except where noted otherwise, soil backfill in the trenches is treated as clayey soil. The average clay thickness beneath each disposal unit was provided in SRNL-STI-2017-00301, Rev. 1 (Bagwell and Bennett 2017). Trench units stretch across the full extent of the E-Area footprint. Trench units were collected into 18 unique hydrostratigraphic groupings and the minimum clay thickness selected as representative of each grouping in SRNL-STI-2019-00193, Rev. 0 (Danielson 2019).	Planned sensitivity and uncertainty analyses will be based on geochemical value uncertainty distributions provided in SRNL-STI-2009-00473.
VZ3	Dispersion in unsaturated zone	Spreading of contaminants in the unsaturated zone disperses them and decreases concentrations.	**2.2.01** **2.2.03** **2.2.12** **2.2.02** **2.2.07**	The E-Area PA will conservatively assume that the process of mechanical dispersion can be neglected at the scale considered in the vadose zone (VZ) flow model because dispersion associated with downward flow is expected to be relatively low within native soils.	The nominal case assumption is considered reasonably bounding.*
SZ1	Water flow in saturated zone	Mixing of slowly released contaminants from the vadose zone into advective flow in the saturated zone leads to some dilution of the concentrations. Covers over the disposal facility will further reduce flow rates in the vadose zone, which should lead to further decreases in concentrations expected in the saturated zone. There is substantial experience modeling flow in the saturated zone in the GSA.	**0.04** **2.3.01** **2.3.12** **1.1.01** **2.3.02** **2.3.13** **1.1.02** **2.3.08** **2.3.14** **1.3.02** **2.3.09** 3.1.01 **1.3.06** **2.3.10** 3.2.07 **1.3.07** **2.3.11** **1.3.10** 1.4.01 **1.4.10** **2.2.03** **2.2.07**	The GSA flow model was recently updated to account for current understanding in SRNL-STI-2018-00643, Rev. 0 (Flach 2019). This report documents further refinement of the GSA_2016 model in 2018 to incorporate, among other things, construction of E-Area Slit Trench operational covers. Refined grid spacing specifically for the E-Area LLW disposal facility was recently adopted in SRNL-STI-2019-00736 (Hang 2019). Modeling is intended to represent expected conditions. Depth to water and thickness of clay were selected at minimum values to bias migration rates on the high end. The range	Sensitivity and uncertainty analyses considering alternative aquifer models to be determined (TBD).

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
				of depths to the water table beneath trenches required use of multiple models to adequately represent hydrostratigraphic features while maintaining a reasonable level of conservatism. Trench units were collected into 18 unique hydrostratigraphic groupings and the minimum depth to water table selected as representative of each grouping in SRNL-STI-2019-00193, Rev. 0 (Danielson 2019).	
SZ2	Sorption on saturated zone soils	Saturated zone soils sorb some of the contaminants of potential concern, delaying their arrival at the point of compliance. The assumed fractions of clay and sand can influence the sorption of some key radionuclides. A number of key contaminants are not believed to sorb significantly.	**1.1.01** **2.2.03** **2.2.08** **2.2.09** **3.2.01** **3.2.02** **3.2.03** **3.2.04** 3.2.05 3.2.06 **3.2.07**	"Best", "minimum" and "maximum" estimates of *Kd* values for unsaturated zone geochemical properties are described in SRNL-STI-2009-00473, Rev. 1, (Kaplan 2016). "Best estimate" values are considered central values derived from experimental data, the literature, or, where no sorption data are available, based on chemical analogue. Best estimate geochemical values are assumed in deterministic modeling for establishing disposal limits. Sorption tends to be higher in clayey soils rather than sandy soils. Except where noted otherwise, soil backfill in the trenches is treated as clayey soil. The average clay thickness beneath each disposal unit was provided in SRNL-STI-2017-00301, Rev. 1 (Bagwell and Bennett 2017). Trench units stretch across the full extent of the E-Area footprint. Trench units were collected into 18 unique hydrostratigraphic groupings and the minimum clay thickness selected as representative of each grouping in SRNL-STI-2019-00193, Rev. 0 (Danielson 2019).	Planned sensitivity and uncertainty analyses will be based on geochemical value uncertainty distributions provided in SRNL-STI-2009-00473.
SZ3	Dispersion in saturated zone	Mixing and spreading of the plume in water in the aquifer acts to reduce downstream concentrations. The effects are somewhat limited for a point only 100 m downstream from the waste but do contribute to reducing the impacts.	**2.2.03** **2.2.07**	Four refined cutouts for the E-Area LLW disposal facility were implemented in the GSA flow model to allow better representation of dispersion for the E-Area LLW facility in SRNL-STI-2019-00736 (Hang 2019). For base case, inventory limit calculations best estimate dispersion parameter settings are being used as recommended in SRNL-STI-2019-00149 DRAFT (Hamm 2019). Smaller discretization of the aquifer transport model cutouts (i.e., horizontal and vertical grid	Sensitivity and uncertainty analyses considering alternative saturated zone dispersion parameter setting TBD.

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
				sizes of 20 ft and 3 ft, respectively) is being employed to reduce the effects of numerical dispersion as described in SRNL-STI-2019-00736.	
SZ4	Dilution in well	Dilution is caused by drawing a mixture of water with different levels of contamination into the screened section of a well, where it is pumped to the surface, where it is useable and accessible by a member of the public. The vertical and horizontal size of grids used in the model can serve to represent averaging over a well's zone of influence to some extent.	2.2.13 3.2.12 3.3.02 3.2.07 3.3.01 3.3.04	The calculated peak concentration at the 100-m groundwater point of assessment (POA) is based on the mesh size element used in the model. Thus, dose impacts from groundwater are calculated without directly accounting for potential dilution from pumping a domestic well at the 100-m POA. As described in SRNL-STI-2019-00736 (Hang 2019), the grid size used in the latest GSA aquifer cutout models is 20 ft horizontal and 3 ft vertical. This mesh size is small relative to the zone of plume capture from a typical domestic well down gradient of a trench sized source term and groundwater plume.	The model construct described for obtaining the maximum concentration at the 100-m POA for the nominal case is considered to be reasonably bounding.*
Engineered Barriers					
Hydrological safety functions					
EB1	Engineered cover	Engineered covers are used to promote runoff, evapotranspiration and lateral drainage, in order to control the amount of infiltration that can percolate to the waste. The final E-Area multi-layer soil-geomembrane cover is designed to limit infiltration to the disposed waste. Waste layer subsidence is expected in E-Area trenches due to the presence of containerized compactible waste. To address this issue, dynamic compaction will be used over Slit & Engineered Trenches to largely eliminate void volume in crushable containers prior to final closure reducing the extent of subsidence expected. The E-Area Vaults, LAWV and ILV, and wastes within them, as well as the robust waste forms on the Naval Reactor Component Disposal Areas (NRCDAs), are also assumed to eventually fail structurally, which will also lead to additional subsidence of the cover in the far future well beyond the end of the 1000-year performance period.	**1.1.02** **1.3.08** **2.1.09** **1.1.03** **1.3.10** **2.1.10** **1.1.04** **1.3.06** **2.3.01** **1.1.05** **1.3.07** **2.3.02** **1.1.07** **1.3.08** 2.3.07 **1.1.08** **1.3.10** **2.3.08** **1.1.09** **1.4.01** **2.3.09** **1.1.12** **1.4.07** **2.3.10** **1.2.08** **1.4.08** **2.3.11** **1.2.10** **2.1.02** **2.3.12** **1.3.02** **2.1.03** **2.3.13** **1.3.06** **2.1.04** **2.3.14** **1.3.07** **2.1.05** **2.1.06** **2.1.07** **2.1.08**	SRNL-STI-2019-00363 (Dyer 2019) includes a description of the cover performance assumptions for each of the disposal concepts in E-Area (i.e., Slit & Engineered Trenches, Component-in-Grout (CIG) Trench segments, ILV & LAWV, and NRCDA's). Each concept is assigned specific assumptions regarding the timing and extent of subsidence based on the nature of the waste disposed. Three dimensional VZ modeling is being employed for Slit & Engineered Trenches to account for impacts of subsidence cases and closure cap edge effects on trench performance.	A variety of uncertainty and sensitivity cases are being considered to address the projected impact of ranges of closure cap conditions over time (e.g., spatial distribution of subsided regions of the cover) on the projected infiltration rate through the cover.
EB2	E-Area Vaults (ILV and LAWV)	The reinforced-concrete structures associated with the ILV and LAWV provide enhanced stability to limit potential subsidence of the cover. Voids within the structures will be limited to reduce potential subsidence. The LAWV is assumed to eventually fail structurally, which is anticipated to lead to subsidence in the cover. The vaults in combination with the cover will also serve as a hydraulic barrier to water flow while intact. As the concrete degrades, cracks are expected to form which will lead to increasing flow rates, limited by infiltration through	**1.1.02** **1.1.12** **2.1.07** **1.1.03** 1.2.03 **2.1.08** **1.1.04** **2.1.02** **2.1.09** **1.1.05** **2.1.03** **2.1.10** **1.1.07** **2.1.04** 2.1.11 **1.1.08** **2.1.05** 2.1.13 **1.1.09** **2.1.06** **2.2.08** **2.2.09**	The vaults in combination with the cover are assumed to provide hydraulic protection while they remain intact. E-Area vault failure assumptions are based on LAWV and ILV structural degradation calculations in T-CLC-E-00018, Rev. 1 (Carey 2006) and T-CLC-E-00024, Rev. 0 (Peregoy 2006a), respectively, performed by SRNS	The structural degradation analysis is judged to be conservative based on the bounding seismic loads used, applying both oxic and anoxic rebar corrosion mechanisms, and simplifying loads for ease of calculations, such as dynamic earth pressures, etc. Thus, the nominal case is considered to be reasonably bounding.*

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)			Nominal Case Assumption	Associated Analyses
		the cover system, and eventually the concrete will no longer serve as a barrier to water flow.				Design Engineering. Structural failure is assumed to occur after a mean time of approximately 2800 years (LAWV) and 6700 (ILV) years, leading to subsidence of the cover and greatly increased infiltration into the vaults. The vault structural analyses provided statistical variability estimates for all results including predicted times of collapse of vault roof and side walls. Seismic loads and differential settlement are assumed to lead to separation at joints in the base of the vaults enabling releases to the vadose zone beneath the vaults.	
EB3	Waste Forms, Containers, & Backfill	A wide variety of waste forms and containers are disposed in E-Area. Low permeability waste forms, such as cementitious materials, can limit water contact with radionuclides and reduce release rates. Containers will delay contact of infiltrating water with the waste while intact and limit water contact as the containers degrade. Robust containers could potentially delay releases for long time frames while they remain intact.	**1.1.02** **1.1.03** **1.1.04** **1.1.05** **1.1.07** **1.1.08** **1.1.09**	**1.1.12** 1.1.08 **2.1.01** **2.1.02** **2.1.03** **2.1.04** **2.1.06**	**2.1.07** **2.1.08** **2.1.09** **2.1.10** 2.1.11 2.1.13 **2.2.08** **2.2.09**	The two broad categories of waste forms and containers in terms of modeling are generic and special waste forms. Generic waste forms comprise the largest fraction of LLW, where no credit is taken for the container or waste form in holding up contaminants (e.g., job control waste in B-25 boxes). In effect, contaminants are assumed to be immediately released and available to the surrounding waste zone medium (e.g., backfill soil in trenches). Two general sub-categories of special waste forms are those that rely on sorption properties alone (e.g., ion exchange resins) in controlling release, and those that rely on the hydraulic integrity of the container, or other properties of the waste form, or a combination (e.g., welded NR casks holding activated metal components) to control release. The latter subcategory is generally precluded from receiving waste layer stabilization measures (e.g., dynamic compaction) prior to installation of the final closure cap. Trench backfill consists of soils typically excavated in creating the trench segment. Because the upper vadose zone in E-Area typically exceeds the 20-foot trench depth, assignment of loose, clayey soil hydraulic and geochemical properties to trench backfill is considered reasonable. Hydraulic properties of cementitious materials used as backfills [i.e, controlled low-strength material (CLSM) and grouts] have been measured and are therefore well characterized.	Sensitivity and uncertainty analyses of waste forms and containers are not considered necessary. Treatment of generic wastes in E-Area nominal case modeling (i.e., radionuclides immediately available for release) is considered to be reasonably bounding. Special waste forms relying on sorption properties have had those properties measured in the laboratory and are therefore generally well characterized. Those special waste forms relying on waste container hydraulic integrity or other waste form properties have been evaluated in Special Analyses using overall bounding assumptions and have been generally tested with limited sensitivity analyses to ensure special waste form disposal limits are defensible. Any sensitivity and uncertainty analyses of backfill properties will be based on hydraulic property value uncertainty distributions provided in SRNL-STI-2019-0355 (Nichols 2020).

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
Intrusion safety functions					
EB4	Engineered cover	Potential inadvertent human intrusion scenarios are limited by the cover thickness and depth of waste and could also be limited by design features included in a cover to deter intrusion. Generally, if the waste is expected to remain more than 3 m (10 ft) below the surface of any cover after erosion, a basement excavation scenario into the waste is excluded. Inadvertent intrusion via basement excavation is also considered highly unlikely as long as obvious barriers remain (e.g., HDPE layer in cover, biotic intrusion barriers, etc. that are distinguishable from soil that would normally be expected). A cover may also include features that make drilling less likely (e.g., relatively large stones), and the general nature of a cover (relatively steep slopes) make it more likely that a well would be constructed beside rather than on top of a cover.	**1.1.02** **1.1.03** **1.1.04** **1.1.05** **1.1.07** **1.1.08** **1.1.09** **1.1.12** **1.2.07** 1.3.10 **1.4.03** **1.4.06** **1.4.08** **1.4.11** **2.1.05** **2.3.01** **2.3.12** 2.4.07	Intrusion scenarios for E-Area are assumed to result in penetration through the final closure cap and into or near the waste zone. Thus, doses to an inadvertent intruder are directly related to the concentration of contaminants in the waste disposal facility. Potential intruder scenarios and exposure pathways have been screened in SRNL-STI-2020-00007 (Stagich and Jannik 2020) to determine those needing to be carried forward into the PA for calculating disposal limits. Intruder scenarios, assumptions, and associated model inputs to be used in the E-Area PA revision are defined in SRNL-STI-2015-00056, Rev. 1 (Smith et al. 2019). Intruder dose calculation methodology and associated inputs have been encoded in the SRNL Dose Toolkit described in SRNL-TR-2019-00337 (Aleman 2019) for calculating intruder-based dose impacts and disposal limits. Assumptions regarding impact of erosion on the closure cap, effectiveness of the erosion barrier, potential for biotic intrusion, and depth to the waste layer are all addressed in these documents establishing the nominal case.	A consistent set of standard intruder scenarios has been established and employed in DOE O 435.1 PA's across the DOE Complex. These highly conceptualized intruder models are generally recognized as hypothetical constructs based on knowledge of current land use practices and therefore not the subject of sensitivity and uncertainty evaluations. Inputs to these calculations are typically well known (e.g., radionuclide decay data), mandated (e.g., dose coefficients) or assumed based on typical or reference human behavior (e.g., consumption rates) or regional practices (e.g., well drilling, basement construction).
EB5	E-Area Vaults (LAWV and ILV)	The reinforced concrete vaults provide a significant barrier to intrusion, especially in an environment where drilling and excavation activities will be directed to working in clay and sandy soils. While the reinforced concrete remains intact, it will be an effective physical barrier against inadvertent excavation and drilling. Furthermore, concrete structures would be obviously distinguishable from soil for a very long time and an intruder would be expected to recognize that something was wrong. As long as the concrete and steel maintained some integrity (thousands of years), an inadvertent intruder would not proceed to excavate a basement and drill cuttings would be distinctly different from soil. The disposed waste will also be deeper than 3 m (10 ft).	**1.1.02** **1.1.03** **1.1.04** **1.1.05** **1.1.07** **1.1.08** **1.1.09** **1.1.12** **1.2.03** **1.4.03** **1.4.06** **1.4.08** **1.4.11** 2.1.05 **2.1.06** **2.2.13**	As described in SRNL-STI-2015-00056, Rev. 1 (Smith, et al. 2019), both the LAWV and ILV reinforced concrete roofs are considered to be effective barriers to acute well drilling and basement construction intruder scenarios throughout the 1000-year period of performance and are therefore screened out from consideration for E-Area vault units in the PA revision. Structural degradation analyses performed for the LAWV in T-CLC-E-00018, Rev. 1 (Carey 2005) and for the ILV in T-CLC-E-00024 Rev. 0 (Peregoy 2006a), demonstrated that vaults will maintain their structural integrity well past the 1000-year period of performance. Once sufficient erosion has occurred, as limited by the closure cap erosion barrier, an intruder is assumed to reach or come near the waste zone with basement construction. Thus, the chronic residential scenario assumes an intruder	Vault structural failure for both the ILV and LAWV is predicted to occur well past the end of the post-closure 1000-year performance period with a high degree of confidence. Thus, the nominal case is considered reasonably bounding.*

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
				lives in a home with a basement located directly above the disposal facility. The resident is shielded from external exposure to radionuclides in the waste by the concrete floor slab and the soil remaining between the basement and the vault, trench or pad.	
EB6	Enhanced Waste Forms and Containers	Numerous special waste forms rely on the hydraulic integrity of the container, or other properties of the waste form, or a combination to control contaminant release to the waste zone. Examples, include welded, carbon steel casks containing Naval Reactor components, Heavy Water Component Test Reactor, Reactor Process Heat Exchangers, etc.	**1.1.02** **1.1.09** **1.4.14** **1.1.03** **1.1.12** **2.1.03** **1.1.04** **1.4.03** 2.1.04 **1.1.05** **1.4.06** **2.2.13** **1.1.07** **1.4.08** **1.1.08** **1.4.11**	Historically, intruder pathway dose impacts have been relatively insignificant compared to the groundwater pathway. Thus, if special waste form treatment is unnecessary to produce acceptable intruder dose impacts then no further analysis is needed, and intruder-based disposal limits are established without taking waste form credit. If waste form credit is needed to produce acceptable limits, then the intruder analysis can consider the long-term integrity of the outer container and the waste form itself to arrive at special waste form limits for the inadvertent intruder based on the specific intrusion scenario. A potential example of this case is the welded, carbon steel cask containing naval reactor components on the NRCDA's. These robust, welded casks are assumed to be structurally stable for thousands of years after placement on the pads based on estimated corrosion rates discussed in SRNL-STI-2018-00633 (Wohlwend and Butcher 2018). However, at 750 years, the casks are assumed to hydraulically fail, allowing radionuclides from inside the cask to be released to the surrounding waste zone. Release of contaminants from the cask is controlled by the surface corrosion rate of the activated metal components within the cask. These aspects would be considered in establishing special waste form intruder limits.	For the generic waste category, the PA disposal unit model assumes no barriers to intrusion following loss of institutional control. Exceptions for certain special waste forms as described under the nominal case are based on conservative assumptions of container integrity and barrier performance and, therefore, are considered reasonably bounding.*

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
Structural safety functions					
EB7	Containers (Slit and Engineered Trenches)	Structural considerations are a critical assumption for long-term evolution of the cover and estimates of the infiltration rates through the cover. Containers used for the Slit and Engineered Trenches generally provide structural stability for safe operations and interim covers. However, the largest category of waste is considered "crushable" consisting of low-density, compactible waste that will eventually lead to extensive subsidence when containers, such as B-25 boxes and SeaLand containers, structurally fail. In recognition of the eventual structural failure of containers, waste stabilization measures are planned to consolidate the waste layer and mitigate non-uniform subsidence of the overlying closure cap. Dynamic compaction is proposed near the end of the 100-year institutional control period (prior to final closure) to allow time for metal (painted, carbon-steel) disposal containers to substantially corrode in order to optimize the effectiveness of dynamic compaction. Corrosion studies have indicated that this timeframe will be sufficient for a significant amount of degradation of containers leading to a more uniform failure of the closure cap. This condition is known as the "intact" case. A smaller category of waste disposed in Slit & Engineered Trenches, known as "non-crushable" waste, is not expected to be greatly impacted by dynamic compaction measures. Non-crushable waste typically consists of a robust waste form (e.g., vessels with large internal voids) or robust disposal container (e.g., thick-gauge steel boxes fabricated for tank farm equipment) with a higher degree of structural stability than containers typically used for crushable waste (e.g., B-25 boxes). The PA conservatively assumes that non-crushable wastes survive dynamic compaction largely structurally intact, but then fail simultaneously and catastrophically shortly after installation of the final closure cap. This assumption results in localized failure of those portions of the closure cap directly overlying the waste resulting in increased infiltration through the waste zone. This condition is known as the "subsided" case. Historically, the most restrictive radionuclide disposal limits for Slit & Engineered Trenches are based on the subsided case. Such containers are the primary focus because they would fail after the final cover is in place. A final general category consists of robust containers and waste forms that will maintain structural integrity for very long times (e.g., heat exchangers with substantial internal structural elements) and bulk wastes (e.g., concrete rubble) which are not expected to be a subsidence concern.	**1.1.02** **1.2.08** **2.1.09** **1.1.03** **1.2.10** **2.1.10** **1.1.04** **2.1.02** 2.1.11 **1.1.05** **2.1.03** 2.1.13 **1.1.07** **2.1.04** **1.1.08** **2.1.05** **1.1.09** **2.1.06** **1.1.12** **2.1.07** **2.1.08**	The conceptual model includes assumptions about the fraction of non-crushable packages in a given trench disposal unit and uses this to establish the extent of subsidence over the cap from localized failures of non-crushable containers. The current operational restriction on the trench area that can be occupied by non-crushable waste varies between 2 and 10% depending on the trench unit location. Four specific subsidence scenarios (i.e., 0.54%, 2%, 3.6%, and 4.9%) were determined from reviewing historical Slit and Engineered Trench inventory data for non-crushable packages. To incorporate the effect of localized cap subsidence, a weighted blending of radionuclide fluxes to the water table was employed in PORFLOW vadose zone simulations representative of these specific subsidence scenarios.	HELP model results from sensitivity studies of the intact infiltration case were fit to a log-logistic function to generate infiltration profiles over a 10,000-year period for most-optimistic, more-optimistic, best-estimate, more-pessimistic, and most-pessimistic cases, for both the intact and four subsidence scenarios. These discrete cases take into account uncertainty in infiltration due to uncertainties in slope, slope length, surface vegetation, evapotranspiration and geomembrane degradation rate.
EB8	E-Area Vaults (LAWV and ILV)	The primary role for stability is the influence on the cover performance when the concrete vault roof eventually fails. The concrete vaults will delay subsidence while intact, which would be expected to be very long times for reinforced concrete. Structural calculations discussed in EB5, Engineered Barriers Safety Function, were conducted and estimated collapse of the LAW vault roof at a mean time of 2800 years and ILV roof at a mean time of 6700 years after closure. There will be some void space at the roof of the LAWVs and containers will be subject to compaction under the weight of the roof and overlying soils. Thus, although delayed, the impact of subsidence of the LAWV on infiltration will be significant. Structural considerations also will impact the assumptions for degraded hydraulic functions for the concrete roof, walls and floor.	**1.1.02** **1.1.12** **2.1.07** **1.1.03** **1.2.03** **2.1.08** **1.1.04** **2.1.02** **2.1.09** **1.1.05** **2.1.03** **2.1.10** **1.1.07** **2.1.04** 2.1.11 **1.1.08** **2.1.05** **1.1.09** **2.1.06**	For the E-Area vaults, LAWV and ILV, infiltration rate profiles for a 10,000-year period were developed for both an on-vault (above the concrete vault roof) and an off-vault (10-foot soil zone adjacent to vault walls) scenario. The actual period of performance for the PA is 1,000 years following final closure; however, infiltration estimates were extended to 10,000 years to capture roof collapse. The purpose of the off-vault simulations was to confirm that subsurface runoff from the concrete vault roof will adequately drain	Vault structural failure for both the ILV and LAWV is predicted to occur well past the end of the post-closure 1000-year performance period with a high degree of confidence. Thus, the nominal case is considered reasonably bounding.*

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
				through the lowermost backfill layers adjacent to the vault walls. Upon structural failure of the ILV and LAWV roof, the conservative assumption is that the roof collapses into the vault over all waste cells simultaneously (i.e., nine ILV waste cells and 12 LAWV waste cells) and the overlying closure cap subsides. Closure cap subsidence results in the cap losing its runoff and drainage layer functionality together with a decrease in evapotranspiration in the subsided area. Increased infiltration will occur through the portion of the closure cap overlying the collapsed vault. Subsidence potential was estimated to be approximately 21 feet for the LAWV in WSRC-TR-2005-00405 (Jones and Phifer 2007) and 19 feet for the ILV in WSRC-TR-2007-00306 (WSRC 2008). This assumes that the waste in the two vaults has the same density as generic containerized waste in Slit & Engineered Trenches. The hydraulic properties assumed for the collapsed roof, walls and floor reflect the results of the structural analysis.	
EB9	High-Density or Stabilized Waste Forms, High-Integrity Containers	Waste forms and containers may also be considerations for structural stability (beyond the general assumptions for the Slit and Engineered Trenches). Wastes that are considered non-crushable are assumed to remain relatively stable and not significantly contribute to subsidence and impacts on infiltration rates through the cover. Component-in-grout disposal would be expected to provide some enhanced stability over normal disposal containers.	**1.1.02** **1.1.03** **1.1.04** **1.1.05** **1.1.07** **1.1.08** **1.1.09** **1.1.12** **1.2.03** **2.1.01** **2.1.02** **2.1.03** **2.1.04** **2.1.06** **2.1.07** **2.1.08** **2.1.09** **2.1.10** 2.1.11 2.1.13	In general, high-density waste forms and high-integrity containers will have no long-term impact on final closure cap performance during the 1,000-year period of performance. A structural evaluation of each category of CIG disposals was performed in T-CLC-E-00026 (Peregoy 2006b). Fully grouted containers (i.e., containers grouted internally and encapsulated externally) were estimated to provide structural stability for the overlying closure cap throughout the entire 1,000-year period of performance. CIG Trench segments containing low-density waste will require a reinforced concrete mat similar to the existing mat over CIG01 segment 8 to provide sufficient long-term structural support to the final cover. CIG Trench segments protected by the prescribed reinforced concrete mat designs are estimated to provide a minimum of 300	The assumptions of the nominal case are considered reasonably bounding.*

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
				years of structural support to the closure cap.	
Chemical safety functions					
EB10	Waste Forms, Containers, and Backfill	Waste forms and containers can serve to condition the water prior to contact with the radionuclides and also bind radionuclides to limit the fraction available for transport. In a number of cases, the waste forms result from processes that are designed to retain specific radionuclides (e.g., carbon vessels, ion exchange). There are also cases, such as activated metals, where the radionuclides are bound in the matrix of a metal (e.g., NRCDA). In these cases, the radionuclides would be expected to be strongly retained in the waste form. In other cases, a waste form may be designed to isolate specific radionuclides to limit releases in a disposal environment (e.g., CIG, other grouted waste). The retention capability for such designed waste forms needs to be confirmed and justified.	**1.1.02** **2.1.04** **3.2.01** **1.1.03** **2.1.06** **3.2.02** **1.1.04** **2.1.07** **3.2.03** **1.1.08** **2.1.08** **3.2.04** **2.1.01** **2.1.09** 3.2.05 **2.1.02** **2.1.10** 3.2.06 **2.1.03** 2.1.11 **3.2.07**	The container itself or backfill surrounding containers is generally assumed to control the chemistry in the waste zone. For example, iron-oxide content resulting from the surrounding clayey soil and rusted metal containers are expected to control waste zone chemistry in the Slit & Engineered Trenches. In the LAWV, cementitious leachate from infiltrating water migrating through the cracks in the vault roof and walls is expected to alter the tendency of radionuclides to bind to the iron-oxide phases present, i.e., the *Kd* values will change. In the ILV and CIG trench segments, waste is encapsulated by grout or CLSM, as such, oxidizing grout *Kd* values are used. Some special waste forms include adjusted *Kds* or special release models (e.g., solubility limits) based on the known properties and the process from which the waste is generated. Releases from special waste forms with activated metals are addressed using a corrosion-based release rate. The effectiveness and duration of such chemical barriers are specifically defended and justified.	Planned sensitivity and uncertainty analyses will be based on geochemical value uncertainty distributions provided in SRNL-STI-2009-00473 (Kaplan 2016).
EB11	E-Area Vaults (LAWV and ILV)	The concrete of the vaults is designed to initially provide for reducing redox conditions and will age over long times to eventually approach natural pH and redox conditions in the groundwater. The vaults are assumed to maintain structural stability for more than 1000 years, which controls the rate of water flow through the vaults and serves to allow only slow changes in the assumed chemistry for the vault concrete.	**1.1.02** 2.1.05 **3.2.01** **1.1.03** **2.1.06** **3.2.02** **1.1.04** **2.1.07** **3.2.03** **1.1.08** **2.1.08** **3.2.04** **2.1.02** **2.1.09** 3.2.05 **2.1.03** **2.1.10** 3.2.06 **2.1.04** 2.1.11 **3.2.07**	As described in SRNL-STI-2009-00473, Rev. 1 (Kaplan, 2016), the concrete in the vaults is assumed to evolve in three phases from high to a relatively neutral pH. The *Kds* for key radionuclides are modified based on the assumed conditions.	Planned sensitivity and uncertainty analyses will be based on geochemical value uncertainty distributions provided in SRNL-STI-2009-00473.
Air Pathway					
AP1	Engineered Cover	The engineered cover will provide a robust barrier against gaseous releases. A high-density polyethylene (HDPE) geomembrane and the geosynthetic clay liner (GCL) are expected to essentially block any gas-phase migration due to the low air permeability of both and the expected high-moisture content in the clay layer. The remaining layers of the cover will provide additional distance over which gas-phase diffusion has to occur. Upward gas-phase diffusion will also compete	**1.1.02** **1.2.07** 2.1.05 **1.1.03** **1.2.08** 2.1.12 **1.1.04** **1.2.10** **2.3.07** **1.1.05** 1.3.10 **2.3.08** **1.1.07** **1.4.03** **2.3.09** **1.1.08** **1.4.06** **2.3.10**	Nominal diffusion properties were assumed for the cover layers, ignoring any advective downward water flow. Layers above the erosion barrier were ignored. Boundary conditions were set to maximize upwards diffusion. No HDPE liner or GCL were	Considered reasonably bounding.*

ID	Safety Function	Description	Associated FEPs (Deleterious FEPs bolded)	Nominal Case Assumption	Associated Analyses
		against advective water flow downward and laterally through the upper layers of the cover.	**1.1.09** **1.4.08** **2.3.12** **1.1.12** **1.4.11** 3.1.01 **1.2.03** **1.4.14** 3.1.04 3.2.09 3.2.10	included in the model (these two barriers would likely preclude any significant upward diffusion).	
AP2	E-Area Vaults (LAWV and ILV)	The vaults provide a robust barrier against gas-phase migration to the surface. Diffusion rates through the grout fill and the vault roof are expected to be very low.	**1.1.02** **1.2.03** 2.1.12 **1.1.03** **1.2.07** 2.3.07 **1.1.04** 1.3.10 **2.3.10** **1.1.05** **1.4.03** **2.3.12** **1.1.07** **1.4.06** 3.1.04 **1.1.08** **1.4.08** 3.2.09 **1.1.09** **1.4.11** 3.2.10 **1.1.12** **1.4.14**	High moisture content for relatively intact concrete located underground was not included. Instead, a lower moisture content representative of rubble exposed to the atmosphere was used. The CLSM layer was included for the ILV, but saturation was biased low based on a pessimistic value for suction.	Considered reasonably bounding.*
AP3	Waste Forms, Containers and Backfill	Most radionuclides are not expected to be present in a gaseous form at the conditions in the vault. Thus, the general potential for gas-phase releases is expected to be very low.	**1.1.02** **1.2.03** 2.1.12 **1.1.03** **1.2.07** 2.3.07 **1.1.04** 1.3.10 **2.3.10** **1.1.05** **1.4.03** **2.3.12** **1.1.07** **1.4.06** 3.1.01 **1.1.08** **1.4.08** 3.1.04 **1.1.09** **1.4.11** 3.2.09 **1.1.12** **1.4.14** 3.2.10	Containers and waste forms were generally ignored. However, in the case of the NRCDA's, both the container (welded carbon steel cask) and the waste form (activated metal components) were credited in holding up and controlling the rate of release of volatile radionuclides.	Considered reasonably bounding.*

* "Considered reasonably bounding" is used to describe cases where pessimistic assumptions in the PA are considered to reasonably address or bound any uncertainties. Thus, no additional sensitivity or uncertainty analyses are necessary.

Appendix B. Features, Events and Processes

This page intentionally left blank.

Table B-1. List of features, events, and processes (FEPs) from the Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (IAEA 2004) applied to the Calcined Solids Storage Facility performance assessment.

ASSESSMENT CONTEXT	0
Definition: Factors that the analyst will consider in determining the scope of the analysis. These may include factors related to regulatory requirements, definition of desired calculation end points, requirements in a particular phase of assessment, description of the domain of concern, and a description of the target groups in the assessment. Decisions at this point will affect the phenomenological scope of a particular phase of assessment, i.e., what "physical FEPs" will be included.	
Comment: *"Assessment Context" is a category in the International FEP List and is subdivided into individual FEPs.*	

Assessment endpoints	0.01
Definition: The long-term human health and environmental effects or risks that may arise from the disposed wastes and repository. These FEPs include health or environmental effects of concern in an assessment (what effect and to whom/what), and health or environmental effects ruled to be of no concern.	
Comment: *From the disposed radioactive waste to the health impact to humans, various indicators and associated criteria can be defined to serve as assessment endpoints. Which one to choose will depend on the purpose of the assessment. The indicator most frequently considered is the radiation dose or risk to man, often represented by the annual dose rate or risk to a member of a "critical group" of potentially most exposed individuals (see FEP 0.06).*	
Key concepts, examples, and related FEPs • *Annual individual dose* • *Annual individual risk* • *Collective doses* • *Lifetime individual dose* • *Collective effective dose* • *Lifetime individual risk* • *Radionuclide concentration in the environment* • *Flux through engineered barriers* • *Flux from geosphere to biosphere* • *Increase in radiation levels in the environment* • *Release or concentration of non-radiological toxic contaminants* • *Dose to biota other than man* • *Collective risk*	
Application to E-Area: *Addressed in DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance.* ***Potentially deleterious FEP:*** *Not applicable.*	

Time scales of concern	0.02
Definition: The time periods over which the disposed wastes and repository may present some significant human health or environmental hazard.	
Comment: *These may correspond to the time scale over which the safety of the disposed wastes and repository is estimated or discussed. In some countries, national regulations set a limit up to which quantitative assessment is required, with more qualitative arguments to demonstrate safety being sufficient at later times.*	

Key concepts, examples, and related FEPs

- *Description of the spatial domain of concern*

Application to E-Area: *Addressed in DOE M 435.1-1 Chg 2 and associated guidance.*
Potentially deleterious FEP: *Not applicable.*

Spatial domain of concern	0.03
Definition: The domain over which the disposed wastes and repository may present some significant human health or environmental hazard.	
Comment: *This may correspond to the spatial domain over which the safety of the disposed wastes and repository is estimated, or the domain which is necessary to model in order to develop an understanding of the movement of contaminants and exposures. This may be limited by the purpose of the assessment, for example, if the performance of a component of the total system has to be assessed.*	
Key concepts, examples, and related FEPs • *Description of the spatial domain of concern*	
Application to E-Area: *Addressed in DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance. Described in E-Area PA (see Sections TBD).* ***Potentially deleterious FEP:*** *Not applicable.*	

Repository assumptions	0.04
Definition: The assumptions that are made in the assessment about the construction, operation, closure, and administration of the repository.	
Comment: *For example, most post-closure assessments make the assumption that a repository has been successfully closed, although, in practice, such decisions may be delayed or be the subject of uncertainty.*	
Key concepts, examples, and related FEPs • *Description of the construction, operation, closure, and operation of the repository* • *Repository has been successfully closed* • *Waste emplacement configuration has change* • *Change in volume of disposed waste* • *Change in repository design*	
Application to E-Area: *Relevant to the E-Area PA. Addressed in the E-Area PA (see Sections TBD). Uncertainties in disposal facility assumptions are addressed in sensitivity and uncertainty analyses for various safety functions.* ***Potentially deleterious FEP:*** *Changes in the planned areal footprint and/or orientation of future trenches (e.g., rotation by 90 degrees) will potentially result in different contaminant transport, plume interaction, and peak concentrations at the points of assessment. There is a staged closure approach that will be applied, some uncertainty about how it will be implemented. Construction and implementation of each disposal concept involves uncertainties in material properties, release rates and placement of wastes that must be accounted for.*	

Future human action assumptions	0.05
Definition: The assumptions made in the assessment concerning general boundary conditions for assessing future human actions.	
Comment: *For example, it can be expected that human technology and society will develop over the time scales of relevance for repository safety assessment. However, this development is unpredictable. Therefore, it is usual to make some assumptions in order to constrain the range of future human activities that are considered.*	
Key concepts, examples, and related FEPs • *Only present-day technologies will be considered* • *Description of general human society* • *Only technologies practiced in the past will be considered* • *Description of human society development* • *The past is an accurate reflection of the future*	
Application to E-Area: *Addressed in DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance. Sections TBD of the PA describe the assumed human actions.* ***Potentially deleterious FEP:*** *Not applicable.*	

Future human behavior (target group) assumptions	0.06
Definition: The assumptions made concerning potentially exposed individuals or population groups that are considered in the assessment.	
Comment: *Doses or risks are usually estimated for critical groups (individuals or groups) thought to be representative of the individuals or population groups that may be at highest risk or receive the highest doses as a result of the disposed wastes and repository. This is the accepted approach for assessing radiological risk or dose to members of the public resulting from a source of radioactive release to the environment. To assess the doses or risks at times in the far future, when the characteristics of potentially exposed populations are unknown, a hypothetical critical group, or groups, is/are usually defined.*	
Key concepts, examples, and related FEPs • *Description of an actual critical group* • *Description of a hypothetical critical group*	
Application to E-Area: *Addressed in DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance. Resident farmer exposed at time and location of peak concentrations is considered reasonably bounding.* ***Potentially deleterious FEP:*** *Not applicable.*	

Dose response assumptions	0.07
Definition: Those assumptions made in an assessment in order to convert received dose to a measure of risk to an individual or population.	
Comment: *Usually this will refer to individual human dose response, e.g., by a dose-risk conversion factor where the factor is the probability of a specified health effect per unit of radiation exposure. If other organisms are considered, then a risk to individual organisms or a species might be considered. The variation of a given response or human health effect (e.g., cancer incidence, cancer mortality) with the amount of radiation dose an individual or a group of individuals received is referred to as the dose-response relation. It is not possible to determine the shape of the dose response curve at low doses with any precision, because the incidence of health effects is very low. A linear dose-response relation with no dose threshold is generally assumed cautious.*	

Key concepts, examples, and related FEPs

- *None*

Application to E-Area: *Specified in DOE O 458.1 Chg 3, DOE M 435.1-1 Chg 2, and associated guidance.*
Potentially deleterious FEP: *Not applicable.*

Assessment purpose	0.08
Definition: The purpose for which the assessment is being undertaken.	
Comment: *The aim of the assessment is likely to depend on the stage in the repository development project at which the assessment is carried out and may also affect the scope of assessment.*	
Key concepts, examples, and related FEPs • *Site selection* • *Demonstrate regulatory compliance* • *Concept design* • *Demonstrate the feasibility of a disposal concept* • *Rehabilitation of contaminated site* • *Public confidence* • *System optimization*	
Application to E-Area: *Addressed in the E-Area PA (see Section TBD). This PA is an update for an operating facility.* ***Potentially deleterious FEP:*** *Not applicable.*	

Regulatory requirements and exclusions	0.09
Definition: The specific terms or conditions in the national regulations or guidance related to all stages of the repository that will influence the post-closure safety assessment.	
Comment: *Regulatory requirements and exclusions may be expressed in terms of release, dose or risk limits, or targets to individuals or populations effective over a specified time scale; they may also make demands about procedures following closure of the repository. In some regulations, the long-term scenarios to be assessed are specified, or some scenarios or events are specifically ruled out of consideration.*	
Key concepts, examples, and related FEPs • *Independence of safety from control* • *Optimization* • *Effects in the future* • *Environmental protection standards* • *Quality assurance* • *Quality control* • *Multi-factor safety case* • *Radiological protection standards*	
Application to E-Area: *Addressed in DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance. Described in Sections TBD of the PA* ***Potentially deleterious FEP:*** *Not applicable.*	

Model and data issues	0.10
Definition: Model and data issues in the context of a safety assessment refer to general (i.e., methodological) issues affecting the assessment modeling process and use of data during the process.	
Comment: *A post-closure safety assessment is an attempt to quantify the exposure or risk posed by a radioactive waste disposal site to future generations of humanity and their environment. Intrinsically, to do this, one can say that the observations needed for the safety assessment of a site should be carried out for the life span of the proposed disposal facility. However, this is neither physically possible nor desirable. The only viable approach to perform a complete radiological safety assessment is to try to obtain as much observational data as possible, on a limited time scale, and then simulate the future behavior of the disposal system through what is known as a model.*	
Key concepts, examples, and related FEPs • *Treatment of uncertainty* • *Method of handling site data* • *Assessment philosophy* • *Modeling studies* • *Model and data reduction/simplification* • *Data availability* • *Application of conservatism*	
Application to E-Area: *Relevant to E-Area PA. General approach is addressed in DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance. Data and Modeling approach described in the E-Area PA (see Section TBD). Parameter nominal or average values, uncertainties or data ranges and data quality are described in specific data packages as well (E-Area PA Data packages include; Geochemical Data Package, SRNL-STI-2009-00473, Rev. 1 (Kaplan 2016), Radionuclide-Dose Data Package, SRNL-STI-2015-00056, Rev. 1 [(Smith et al. 2019), Infiltration Data Package, SRNL-STI-2019-00363, Rev. 0 (Dyer 2019) and Hydraulic Properties Data Package, SRNL-STI-2019-00355, Rev. 0 (Nichols 2020)].* ***Potentially deleterious FEP:*** *If data are outside/inconsistent with the assumptions considered in the PA, the resulting doses could change.*	

EXTERNAL FACTORS	1
Definition: FEPs with causes or origin outside the disposal system domain, i.e., natural or human factors of a more global nature and their immediate effects. Included in this category are decisions related to repository design, operation, and closure since these are outside the temporal boundary of the disposal system domain for post-closure assessment.	
Comment: *"External Factors" is a category in the International FEP List and is divided into subcategories.*	

REPOSITORY ISSUES	1.1
Definition: Decisions on designs and waste allocation (repository type) and also events related to site investigation, operations, and closure (site context).	
Comment: *"Repository Issues" is a subcategory of External Factors in the International FEP List and is divided into individual FEPs.*	

Site investigation	1.1.01
Definition: FEPs related to the investigations that are carried out at a potential repository site in order to characterize the site both prior to repository excavation and during construction and operation.	
Comment: *Site investigation activities provide detailed site-specific performance assessment data and information necessary for the safety case to demonstrate the suitability of the site and to establish baseline conditions*	

Key concepts, examples, and related FEPs

- *Geography and demography*
- *Meteorology and climatology (regional and local)*
- *Geology and seismology*
- *Hydrology characteristics*
- *Geotechnical characteristics*
- *Aquifer tests*
- *Investigative boreholes*
- *Biosphere characteristics*
- *Natural resources*
- *Geochemical characteristics*
- *Ecological features*
- *Preoperational monitoring program*
- *Hydrogeology characteristics*
- *Geohydrological characteristics*
- *Geomorphology characteristics*

Application to E-Area: *Relevant to the E-Area PA (see Section TBD for a discussion of site investigations).*

Potentially deleterious FEP: *Backfill materials obtained during trench excavation may vary chemically and hydraulically (e.g., horizontal and vertical conductivities of Upper VZ (UVZ) vs Lower VZ (LVZ) differ by an order of magnitude) depending on the location in the E-Area. Variability in data must be addressed in the PA using sensitivity and uncertainty analyses. The PA and CA maintenance program is continuously evaluating monitoring data and new characterization data that is reported in Annual Summaries for the disposal facility.*

Design, repository	1.1.02
Definition: FEPs related to the design of the repository including both the safety concept, i.e., the general features of design and how they are expected to lead to a satisfactory performance, and the more detailed engineering specification for excavation, construction, and operation.	
Comment: *The repository design and construction are established in a general way in the disposal concept for the repository, which is based on expected host lithology characteristics, waste and backfill characteristics, construction technology, and economics. Repository design includes the principal design features that are designed to provide long-term isolation of disposed waste, minimize the need for continued active maintenance after site closure, and improve the site's natural characteristics in order to protect public health and the environment. There may, nevertheless, be a range of engineering design and construction options still open. As the repository project proceeds, and more detailed site-specific information becomes available, the range of options may be constrained, and decisions will be made. At any stage, repository safety assessments may only analyze a subset of the total range of option. (See FEP 1.103.)*	
Key concepts, examples, and related FEPs • *The general repository design features (e.g., host lithology, waste form, backfill, waste packages, construction technology, etc.)* • *The principal design criteria or considerations for normal and abnormal condition* • *Operational monitoring program*	
Application to E-Area: *Relevant to the E-Area PA. The E-Area PA provides descriptions of how the different design features are addressed (see Section TBD).* ***Potentially deleterious FEP:*** *(Redundant with FEP 0.04) Changes in the planned areal footprint and/or orientation of future trenches (e.g., rotation by 90 degrees), waste forms, operations, waste placement will potentially result in different contaminant transport, plume interaction, and peak concentrations at the points of assessment. Any changes to waste forms, design, operation, waste placement, etc. are evaluated through the PA Maintenance process prior to implementation to provide reasonable expectation of continued compliance.*	

Construction, repository	1.1.03
Definition: FEPs related to the construction (e.g., excavation) of shafts, tunnels, disposal galleries, silos, trenches, vaults, etc., of a repository, as well as the stabilization of these openings and installation/assembly of structural elements according to the design criteria.	
Comment: *Repository construction refers to the implementation of the design considerations and specifically to the construction of features of the repository necessary to provide long-term isolation of disposed waste, minimize the need for continued active maintenance after site closure, and improve the site's natural characteristics in order to protect public health and the environment. In addition, it includes the construction methods. (See FEP 1.102.)*	
Key concepts, examples, and related FEPs • *Drilling of borehole* • *Excavation of trenches, holes, vaults* • *Construction equipment* • *Construction of walls, floors, mounds, layers of mounds* • *Site plans, engineering drawing, and construction specifications* • *Control and diversion of water* • *Site preparations*	

<u>Application to E-Area</u>: *Relevant to the E-Area PA. This relates to E-Area disposal unit construction, operation and closure assumptions (i.e., excavation, trench and vault construction, soil backfill & grout emplacement and operational, interim and final cover installation) (see Sections TBD).* ***<u>Potentially deleterious FEP</u>:*** *Potential degradation of safety functions associated with the engineered components of the system may result from quality control failure. Poor placement quality and introduction of an abnormally high number of defects in the geomembrane/GCL composite barrier during installation could lead to increased leakage rate into waste zone. Significant deviations from design specs on trench geometries, dimensions, orientations, etc. Any deviations from planned construction must be addressed through the PA maintenance process.*

Emplacement of wastes and backfilling	1.1.04
Definition: FEPs related to the placing of wastes (usually in containers) at their final position within the repository and placing of buffer and/or backfill materials in the disposal zone.	
Comment: *Some waste types and inventories may require special waste emplacement arrangements to simplify the disposal practice, to ensure safety, or to ensure structure stability in the repository area. The backfill material is used to refill excavated portions of the repository or any void spaces left unfilled after waste has been emplaced (see also FEP 1.1.07).*	
<u>Key concepts, examples, and related FEPs</u> • *Emplacement method* • *Waste emplacement configuration* • *Filling of void spaces between the containers and in the rest of the repository* • *Covering of waste in-between containers*	
<u>Application to E-Area:</u> *Relevant to the E-Area PA for placement of containers and grout and/or backfill emplacement. Relevant also to the E-Area PA for number and assumed placement of non-crushable containers and the impact on subsidence assumptions. This is important for E-Area due to the wide variety of waste forms, packaging and placement approaches. Any changes from assumed operations as described in PA Sections TBD must be addressed via the PA maintenance process.* ***<u>Potentially deleterious FEP</u>***: *Safety functions associated with the grout, containers and cover may be degraded by incorrect emplacement of the materials. Emplacement of grout must take due account of heat of hydration and potential shrinkage. Non-crushable packages have the potential to result in enhanced subsidence of closure cap leading to increased infiltration. Improper backfilling could also lead to increased closure cap subsidence. (Redundant from 1.1.01) Backfill materials obtained during trench excavation may vary chemically and hydraulically (e.g., horizontal and vertical conductivities of UVZ vs LVZ differ by an order of magnitude) depending on the location in the E-Area). Conceptual models address potential variability in emplacement assumptions. Non-crushable containers are specifically defined., if different than assumed there could be an impact.*	

Closure, repository	1.1.05
Definition: FEPs related to the cessation of waste disposal operations at a site, the backfilling and sealing of borehole type facilities, and the capping and covering of trenches, vaults, etc.	
Comment: *The term closure refers to the status of, or an action directed at, a disposal facility at the end of its operational life. A disposal facility is placed under permanent closure, usually after completion of waste emplacement, by covering a near-surface disposal facility, by backfilling and/or sealing of a borehole type facility, and termination and completion of activities in any associated structure. The intention of repository capping and sealing is to prevent infiltrating water as well as human access to the wastes. Individual sections of a repository may be closed in sequence, but closure usually refers to final closure of the whole repository and will probably include removal of surface installations. The schedule and procedure for capping, sealing, and closure may need to be considered in the assessment.*	
Key concepts, examples, and related FEPs • *Trench/vault capping* • *Site stabilisation* • *Cover construction* • *Backfilling of boreholes* • *Removal of surface structures* • *Closure procedures* • *Decontamination and decommissioning plan* • *Post-operational monitoring program* • *Closure compartments*	
Application to E-Area: *Relevant to the E-Area PA for grout and backfill and cover emplacement. Incremental closure using dynamic compaction is an important assumption (see Sections TBD of the PA).* ***Potentially deleterious FEP:*** *Safety functions associated with the grout and cover may be degraded by incorrect closure. Emplacement of fill grout must take due account of heat of hydration and shrinkage. Dynamic compaction is assumed to be implemented consistent with assumptions in the PA, if there is a difference it could impact performance.*	

Records and markers, repository	1.1.06
Definition: FEPs related to the retention of records of the content and nature of a repository after closure and also the placing of permanent markers at or near the site.	
Comment: *It is expected that records will be kept allowing future generations to recall the existence and nature of the repository following closure. In some countries, the use of site markers has been proposed where the intention is that the location and nature of the repository might be recalled even in the event of a lapse of present-day administrative controls.*	
Key concepts, examples, and related FEPs • *Records of the content and nature of the repository* • *Disposal unit and boundary markers* • *Archive of the records* • *Site markers*	
Application to E-Area: *Addressed as part of institutional control assumptions in DOE M 435.1-1 Chg 2 (DOE 2011a). Safety functions associated with institutional control are treated pessimistically by assuming loss of memory of the facility and temporary loss of institutional controls at 100 years. Assumed to be bounding, further reduction of these safety functions is not credible.* ***Potentially deleterious FEP:*** *Not applicable.*	

Waste allocation	1.1.07
Definition: FEPs related to the choices on allocation of wastes to the repository, including waste type(s) and amount(s).	
Comment: *The waste type and waste allocation are established in a general way in the repository disposal concept. There may, however, be a number of options concerning these factors. Final decisions may not be made until the repository is operating and will be subject to regulation. In safety assessments, assumptions may need to be made about future waste arisings and future waste allocation strategies (see FEP 1.1.04).*	
Key concepts, examples, and related FEPs • *Waste allocation description* • *Future waste arisings* • *Future waste allocation strategies* • *Projected inventories* • *Waste acceptance criteria for the repository*	
Application to E-Area: *Relevant to the E-Area PA. General tendency is to bias radionuclide inventories pessimistically high to account for difficulties in measuring key radionuclides (see Section TBD of the PA). PA maintenance process evaluates changes from expected waste projections.* ***Potentially deleterious FEP:*** *Applicable. Potential for underestimated projected inventories in future trenches due to changes in waste delivery or generation.*	

Quality control	1.1.08
Definition: FEPs related to quality assurance and control procedures and tests during the design, construction, and operation of the repository, as well as the manufacture of the waste forms, containers, and engineered features.	
Comment: *It can be expected that a range of quality control measures will be applied during construction and operation of the repository, as well as to the manufacture of the waste forms, containers, etc. In an assessment, these may be invoked to avoid analysis of situations that, it is expected, can be prevented by quality control. There may be specific regulations governing quality control procedures, objectives, and criteria.*	
Key concepts, examples, and related FEPs • *Defects in construction of disposal system* • *Defects in the construction of container* • *Improper or faulty waste emplacement and backfilling* • *Defects during the conditioning of the waste* • *Defects in cap constructions*	
Application to E-Area: *Relevant to the E-Area PA for waste characterization, packaging, waste placement, vault and trench construction, grout/fill and cover emplacement (see Sections TBD of the PA). Site quality programs are in place that are applied to all activities.* ***Potentially deleterious FEP:*** *Safety functions associated with waste release (inventory and waste form), construction, operation and closure may be degraded if there is a failure of quality control. Poor placement quality and introduction of an abnormally high number of defects in the geomembrane/GCL composite barrier during installation will lead to increased leakage into waste zone.*	

Schedule and planning	1.1.09
Definition: FEPs related to the sequence of events and activities occurring during repository excavation, construction, waste emplacement, and sealing.	
Comment: *Relevant events may include phased construction of units and emplacement of wastes, backfilling, sealing, capping and closure of sections of the repository after wastes are emplaced, and monitoring activities to provide data on the transient behavior of the system or to provide input to the final assessment. The sequence of events and time between events may have implications for long-term performance, e.g., decline of activity and heat production from the wastes, material degradation, and chemical and hydraulic changes during a prolonged "open" phase.*	
Key concepts, examples, and related FEPs • *Phased construction of units* • *Planning of monitoring activities to provide data on the transient behavior of the system* • *Phased emplacement of wastes, backfilling, sealing, capping, and closure of sections of the repository*	
Application to E-Area: *Relevant for E-Area. The PA includes assumptions for operations and closure that have some flexibility. Assumed timing and sequence of events is described in Section TBD of the PA.* ***Potentially deleterious FEP:*** *Applicable. Changes to the sequence of events assumed for the PA could impact the projected results. Changes in operating and closure assumptions for each trench and vault can influence timing of peaks, etc. Timing of the placement of interim stormwater runoff covers over Slit Trenches had some impact on the projected doses during the compliance period. Any changes in plans from the envelope of assumptions in the PA will be addressed using the PA Maintenance process before a change is implemented.*	

Administrative control, repository site	1.1.10
Definition: FEPs related to measures to control events at or around the repository site, both during the operational period and after closure.	
Comment: *The responsibility for administrative control of the site before closure of the repository during the construction and operational phases and subsequently following closure of the repository may not be the same. Furthermore, the type of administrative control may vary depending on the stage in the repository lifetime.*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Addressed in multiple DOE orders and policies (see Section TBD of the E-Area PA). Safety functions associated with institutional control are treated pessimistically by assuming loss of memory of the facility and temporary loss of institutional controls at 100 years. Reduction of these safety functions is not credible.* ***Potentially deleterious FEP:*** *Only applicable for inadvertent intrusion, which is assumed to occur.*	

Monitoring of repository	1.1.11
Definition: FEPs related to any monitoring that is carried out during operations or following closure of sections of, or the total, repository. This includes monitoring for operational safety and also monitoring of parameters related to the long-term safety and performance.	
Comment: *The extent and requirement for such monitoring activities may be determined by repository design and host lithology, regulations, and public pressure.*	
<u>Key concepts, examples, and related FEPs</u> • *Preoperational monitoring program* • *Post-operational monitoring program* • *Operational monitoring program*	
<u>Application to E-Area</u>: *Will be addressed in the appropriate closure documentation and maintenance plans for the facility consistent with DOE M 435.1-1 (DOE 2011a) requirements. Monitoring of defects and subsidence of interim covers during operational and institutional control periods.* ***<u>Potentially deleterious FEP</u>:*** *Not applicable. Monitoring will be designed to not impact long term performance.*	

Accidents and unplanned events	1.1.12
Definition: FEPs related to accidents and unplanned events during construction, waste emplacement, and closure, which might have an impact on long-term performance or safety.	
Comment: *Accidents are events that are outside the range of normal operations, although the possibility that certain types of accidents may occur should be anticipated in repository operational planning. Unplanned events include accidents but could also include deliberate deviations from operational plans.*	
<u>Key concepts, examples, and related FEPs</u> • *Deviations from operations in response to an accident* • *Reduction in waste delivery* • *Earlier than anticipated cap failure* • *Unexpected waste arising during operations* • *Unexpected geological event* • *Deliberate deviations from operational plans* • *Increase in waste delivery* • *Earlier than anticipated container failure*	
<u>Application to E-Area</u>: *Relevant to the E-Area PA. The Solid Waste Management Facility documented Safety Analysis (DSA) (SWM 2019) is in place that covers operation of the facility. From a long-term performance perspective, subsidence of trench covers is assumed to occur immediately following the end of the institutional control period and longer-term degradation of the vaults and covers is also addressed (see section TBD of the PA).* ***<u>Potentially deleterious FEP</u>:*** *Operational accidents are addressed in the DSA. Potential early degradation of cover safety function from surface events; potential geological event may lead to early degradation of hydraulic safety functions in the engineered system. Non-crushable packages and concrete roof collapse over vaults result in subsidence of closure cap leading to increased infiltration.*	

Retrievability	1.1.13
Definition: FEPs related to any special design, emplacement, or operational or administrative measures that might be applied or considered in order to enable or ease retrieval of wastes.	
Comment: *Designs may specifically allow for retrieval or rule it out. In some cases, an interim period might be planned, between waste emplacement and final repository closure, during which time retrieval is possible.*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Not relevant. Retrievability is not a requirement.* ***Potentially deleterious FEP:*** *Not applicable.*	

GEOLOGICAL PROCESSES AND EFFECTS	1.2
Definition: Processes arising from the wider geological setting and long-term processes.	
Comment*. "Geological Processes and Effects" is a subcategory of External Factors in the International FEP List and is divided into individual FEPs.*	

Orogeny and related tectonic processes at plate boundaries	1.2.01
Definition: Rock deformation and translation (commonly referred to as tectonics) of this nature arise when rock masses belonging to different plates either collide with each other or slide past each other. Literally speaking, orogeny is the process of formation of mountains, often occurring over periods of a few million years but up to several tens of millions of years.	
Comment: *By present geological usage, orogeny is the process by which structures within mountain areas were formed through processes that include thrusting, folding, and faulting in the lithosphere. The "latter h" is the name given to the rigid, outermost layer of the earth, made up predominantly of solid rock, which is affected by processes such as metamorphism, plutonism, and, at great depth (>10 km [>6.2 mi]), plastic folding.* *The term folding is generally used to imply the shortening of strata that results from the formation of fold structures on a broad scale and sometimes has the connotation of general deformation of which the actual folding is only a part. A fault is a fracture in the Earth's crust accompanied by displacement of one side of the fracture relative to the other, from a few centimeters to several kilometers. Orogenic belts are typically characterized by compressive reverse faults as this leads to crustal shortening and duplication of geological formations. Transform faults typically occur where crustal plates slide past each other without colliding (e.g., the San Andreas Fault in California), and the relative displacement can be on the order of thousands of kilometers. Fractures and joints may be caused by compressional or tensional forces in the earth crust but do not present displacement between the rocks on each side. These forces may result in the reactivation of existing faults or, less likely, in the generation of new ones.* *It is important to acknowledge that orogenic processes experience periods of quiescence alternating with periods of paroxysm and that such periods are not necessarily synchronous along the whole length of an orogenic belt.* ***Implications to near-surface disposal systems:*** *These types of movements should be considered with great care, because orogenic processes can lead, in areas of active collision (e.g., Chile, Turkey, Iran, Morocco), to the propagation of fault and thrust planes up to the surface. In such events (see seismicity), extreme ground fracturing and faulting could lead to breakage of containment barriers.*	

Key concepts, examples, and related FEPs

- *Collision of the Earth's crustal plates*
- *Transcurrent, strike-slip faults*
- *Thrusts: low-angle reverse faults*
- *Subduction zones*
- *Faulting and folding of lithosphere: thin-skinned tectonics vs. thick-skinned tectonics*
- *Metamorphism, anatexis (partial melting/migmatization), and plastic folding in the inner and deeper layer*
- *Granitic to granodioritic batholiths; calc-alkaline igneous activity*
- *Orogeny*
- *Neotectonics*

Application to E-Area: *Not relevant on the time scale of the E-Area PA, and the facility is located far from plate boundaries.*

Potentially deleterious FEP: *Not applicable.*

Anorogenic and within-plate tectonic processes (deformation, elastic, plastic, or brittle)	1.2.02
Definition: FEPs related to the physical deformation of geological structures in the interior of continental or oceanic plates in response to stress fields generated either at plate margins or in regions of anomalous stress. This includes mainly faulting and fracturing of rocks and, less frequently, their compression and folding rocks.	
Comment. *The term folding is generally used for the compression of strata in the formation of fold structures on a broad scale and sometimes has the connotation of general deformation of which the actual folding is only a part. A fault is a fracture in the Earth's crust accompanied by displacement of one side of the fracture relative to the other, from a few centimeters to a few kilometers on scale. Fractures may be caused by compressional or tensional forces in the Earth's crust. Such forces may result in the activation of existing faults and, less likely, the generation of new faults.* ***Implications to near-surface disposal systems:*** *Within the time scales of concern, deformation is unlikely to have an effect on near-surface disposal systems.*	
<u>Key concepts, examples, and related FEPs</u> • *Faulting: normal, extensional faults* • *Extrusion* • *Neotectonics* • *Alkaline volcanism, volcanoes* • *Dyke swarms* • *Fractures* • *Fracturing* • *Compression of rocks* • *Rifting, rift valleys* • *Horst and grabens* • *Jointing, master joints* • *Hot springs* • *Basin and Range* • *Continental; breakup* • *Uplift axes* • *Stress field* • *Cross-fabrics*	
<u>Application to E-Area</u>: *Not relevant on the time scale of the E-Area PA.* ***<u>Potentially deleterious FEP</u>:*** *Not applicable.*	

Seismicity	1.2.03
Definition: FEPs related to seismic events and the potential for seismic events. Rapid relative movements within the Earth's crust, usually along existing faults or geological interfaces cause a seismic event. The accompanying release of energy may result in ground movement and/or rupture, e.g., earthquakes.	
Comment: *Seismic events may result in changes in the physical properties of rocks due to stress changes and induced hydrological changes. Seismic events are most common in tectonically active or volcanically active regions at crustal plate margins; less commonly, they occur in the interior of continental/oceanic plates. The seismic waves that are generated by a tectonic or volcanic disturbance of the ocean floor may result in a seismic (giant) sea wave known as a tsunami. These may be amplified by submarine soft sediment slumps along steep continental margins. In extreme cases, soil liquefaction has been reported in areas where soils and sedimentary strata of appropriate moisture content and composition are subjected to strong seismic shaking.*	
<u>Key concepts, examples, and related FEPs</u> • *Change in the physical properties of rocks due to stress changes* • *Hydrological changes* • *Faulting* • *Tsunami* • *Earthquakes* • *Seismic swarms* • *Soil liquefaction* • *Aftershocks*	

Application to E-Area: *Relevant to the E-Area PA in considering the longevity of safety functions for the engineered barriers. However, the SRS is located in a relatively seismically inactive area.*

Potentially deleterious FEP: *The primary potential effect on the disposal system is degradation of hydraulic safety functions of the E-Area structures. Other safety functions would be unaffected. Unanticipated earlier fractures in and collapse of concrete vaults and unexpected changes in closure cap drainage patterns/effectiveness could result in increased infiltration.*

Volcanic and magmatic activity	1.2.04

Definition: FEPs related to volcanic and magmatic activities. Magma is molten, mobile rock material generated below the Earth's crust, which gives rise to igneous rocks when solidified. Magmatic activity occurs when there is intrusion of magma into the crust. A volcano is a vent or fissure in the Earth's surface through which molten or part-molten materials (lava) may flow and through which ash and hot gases may be expelled.

Comment: *The high temperatures and pressures associated with volcanic and magmatic activity may result in permanent changes in the surrounding rocks; this process is referred to as metamorphism but is not confined to volcanic and magmatic activity (see FEP 1.2.05). Intrusive magmatic activity refers to the process of emplacement of magma in pre-existing rock. Extrusive magmatic activity refers to the process whereby magma is ejected onto the surface of the Earth.*

Key concepts, examples, and related FEPs

- *Temperature and pressure rise*
- *Change in surrounding rocks*
- *Slope tilting*
- *Intrusive magmatic activity*
- *Extrusive magmatic activity*
- *Lava flows*
- *CO_2 emissions*
- *Pyroclastic explosion / flow / cloud*
- *Fumaroles*
- *Hydrothermal alteration*

Application to E-Area: *Not relevant to the E-Area geological setting. Lava intrusion or magma intrusion associated with volcanism is improbable considering the volcanic history of the E-Area.*

Potentially deleterious FEP: *Not applicable.*

Metamorphism	1.2.05

Definition: FEPs induced by the mineralogical and structural adjustment of solid rock to physical and chemical conditions, which have been imposed by the action of heat (T>200°C) and pressure at great depths (usually several kilometers) beneath the Earth's surface or near magmatic activity.

Comment: *Metamorphic processes are unlikely to be important at typical repository depths, but past metamorphic history of a host lithology may be very important to understanding its present-day characteristics.*

Implications to near-surface disposal systems: *Within the time scales of concern, metamorphism is unlikely to have an effect on near-surface disposal systems.*

Key concepts, examples, and related FEPs

- *Metamorphic history of a host lithology*

Application to E-Area: *Not relevant on the time scale of the E-Area PA.*

Potentially deleterious FEP: *Not applicable.*

Hydrothermal activity	1.2.06
Definition: FEPs associated with high-temperature groundwater, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high-temperature groundwater flows.	
Comment: *Groundwater temperature is determined by the large-scale geological and petrophysical properties of the rock formations (e.g., radiogenic heat formation, thermal conductivity), as well as the hydrogeological characteristics (e.g., hydraulic conductivity) of the rock and by the tectonic environment (neotectonic deformation, extension).* ***Implications to near-surface disposal systems:*** *Within the time scales of concern, hydrothermal activity is unlikely to have an effect on typical near-surface disposal systems.*	
Key concepts, examples, and related FEPs • *Hydrothermal synthesis* • *Density-driven groundwater flow* • *Hydrothermal alterations of minerals in the rocks* • *Hydrothermal metamorphism* • *Scalding springs*	
Application to E-Area: *Not relevant to the E-Area geological setting.* ***Potentially deleterious FEP:*** *Not applicable.*	

Erosion and sedimentation	1.2.07
Definition: FEPs related to the large-scale (geological) removal and accumulation of rocks and sediments, with associated changes in topography and geological/hydrogeological conditions of the repository host lithology.	
Comment: *Erosion is the process or group of processes whereby the earthy and rocky materials of the Earth's crust are loosened, dissolved, or worn away, and simultaneously removed from one place to another, by natural agencies that include weathering, solution, corrosion, and transportation. Compare FEP 2.3.12, which is concerned with more local processes over shorter periods of time. Sedimentation is the act or process of forming or accumulating sediment in layers, including such processes as the separation of rock particles from the material from which the sediment is derived, the transportation of these particles to the site of deposition or settling of the particles, the chemical and other (diagenetic) changes occurring in the sediment, and the ultimate consolidation of the sediment into solid rock.* ***Implications to near-surface disposal systems:*** *Within the time scales of concern, large-scale erosion and sedimentation are unlikely to have an effect on near-surface disposal systems.*	
Key concepts, examples, and related FEPs • *Change in topography, uplift* • *Coastal erosion* • *Deposition of sediment* • *Changes in geological conditions* • *Stream erosion* • *Changes in hydrogeological conditions*	
Application to E-Area: *Not relevant to time scales considered in the E-Area PA (near-surface disposal).* ***Potentially deleterious FEP:*** *Not applicable.*	

Diagenesis and pedogenesis	1.2.08
Definition: The processes by which deposited sediments at or near the Earth's surface are formed into rocks by compaction, cementation, and crystallisation, i.e., under conditions of temperature and pressure normal to the upper few kilometers of the Earth's crust.	
Comment: *Diagenesis includes all the chemical, physical, and biological changes, modifications, or transformations undergone by a sediment after its initial deposition and during and after its lithification, exclusive or surficial alteration (weathering) and metamorphism. It embraces those nondestructive or reconstructive processes (e.g., consolidation, compaction, cementation, reworking, authigenesis, replacement, solution, precipitation, crystallisation, oxidation, reduction, leaching, hydration, polymerisation, adsorption, bacterial action, and formation of concretions) that occur under conditions of pressure and temperature that are normal to the surficial or outer part of the Earth's crust.* *Pedogenesis represents the mode of origin of soils, with reference to the factors responsible for the formation of "solum," or true soil, from unconsolidated parent material. Pedogenesis may have an effect on the behavior of near-surface disposal systems as it involves geohydrologic, atmospheric, and biological processes (burrowing animals, plant roots activity/invasion) in operation at or near surface on time scales of a few hundred to thousands of years* ***Implications to near-surface disposal systems:*** *Within the time scales of concern, diagenesis is unlikely to have an effect on near-surface disposal systems.*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Relevant to the E-Area PA in specific cases.* ***Potentially deleterious FEP:*** *Intrusion of pine trees on the original vegetative grass cover, leading to increased infiltration because of root penetration through the composite geomembrane/GCL barrier layer. Feral pigs may also damage the vegetative cover leading to increased erosion and less evapotranspiration.*	

Salt diapirism and dissolution	1.2.09
Definition: The long-term evolution of salt formations. Diapirism is the lateral or vertical intrusion or upwelling of either buoyant or non-buoyant rock into overlying strata (the overburden) from a source layer. Dissolution of the salt may occur where the evolving salt formation is in contact with groundwater with salt content below saturation.	
Comment: *Diapirism is most commonly associated with salt formations where a salt diapir comprises a mass of salt that has flowed in a ductile manner from a source layer and pierces or intrudes into the overlying rocks. The term can also be applied to magmatic or migmatic intrusion.* ***Implications to near-surface disposal systems:*** *Within the time scales of concern, salt diapirism and dissolution are unlikely to have an effect on near-surface disposal systems.*	
Key concepts, examples, and related FEPs • *Diapirism* • *Brine pockets*	
Application to E-Area: *Not relevant to the E-Area geological setting.* ***Potentially deleterious FEP:*** *Not applicable.*	

Hydrological/hydrogeological response to geological changes	1.2.10
Definition: FEPs related to changes in the hydrological or hydrogeological regime arising from the large-scale geological changes listed in FEPs 1.2.01 to 1.2.09.	
Comment: *These could include changes of hydrological boundary conditions due to effects of erosion on topography, changes of hydraulic properties of saturated and unsaturated zones due to changes in rock stress or fault movements, or a change in the geochemical behavior of the saturated and unsaturated zones. In and below low-permeability geological formations, hydrogeological conditions may evolve very slowly and often reflect past geological conditions, i.e., be in a state of disequilibrium.*	
Key concepts, examples, and related FEPs • *Geochemical change* • *Changes in hydraulic properties* • *Changes of hydrological boundary conditions*	
Application to E-Area: *Relevant to the E-Area PA for FEP 1.2.08 above.* ***Potentially deleterious FEP:*** *Long-term degradation of closure cap and soil properties due to surface erosion, silting in, and barrier failure.*	

CLIMATIC PROCESSES AND EFFECTS	1.3
Definition: Processes related to global climate change and consequent regional effects.	
Comment: "Climatic Processes and Effects" is a subcategory of External Factors in the International FEP List and is divided into individual FEPs.	

Climate change, global	1.3.01
Definition: FEPs related to the possible future and evidence for past, long-term change of global climate. This is distinct from resulting changes that may occur at specific locations according to their regional setting and also climate fluctuations (c.f. FEP 1.3.02).	
Comment: *The last 2 million years of the Quaternary have been characterized by glacial/interglacial cycling. According to the Milankovitch theory, the Quaternary glacial/interglacial cycles are caused by long-term changes in seasonal and latitudinal distribution of incoming solar radiation that are due to the periodic variations of the Earth's orbit about the sun (Milankovitch cycles). The direct effects are magnified by factors such as changes in ice, vegetation, and cloud cover, and atmospheric composition.*	
Key concepts, examples, and related FEPs • *Description of global climate changes* • *Changes in atmospheric composition* • *Eustatic change (c.f. FEP 1.3.03)* • *Changes in ice, vegetation, and cloud cover* • *Greenhouse effect* • *Isostatic movement (c.f. FEP 1.3.03)* • *Glaciation (large scale)*	

Application to E-Area: *Not relevant to the E-Area PA. Climate change may affect infiltration and saturated zone flow assumptions. However, global climate changes are expressed locally in these processes (see FEP 1.3.02). See Section TBD of the E-Area PA for a discussion of the basis for long-term precipitation estimation.*

Potentially deleterious FEP: *Not applicable.*

Climate change, regional and local	1.3.02
Definition: FEPs related to the possible future changes, and evidence for past changes, of climate at the repository site. This is likely to occur in response to global climate change, but the changes will be specific to the situation and may include shorter-term fluctuations (c.f. FEP 1.3.01).	
Comment: *Climate is characterized by a range of factors, including temperature, humidity, precipitation, and pressure, as well as other components of the climate system such as oceans, ice and snow, biota, and the land surface. The Earth's climate varies by location, and for convenience broad climate types have been distinguished in assessments, e.g., tropical, savannah, Mediterranean, temperate, boreal, and tundra. Climatic changes lasting only a few decades are referred to as climatic fluctuations. These are unpredictable at the current state of knowledge, although historical evidence indicates the degree of past fluctuations.*	
Key concepts, examples, and related FEPs • *Climate fluctuations* • *Description of regional and local climate change* • *Increase/decrease in temperature* • *Increase/decrease in precipitation*	
Application to E-Area: *Relevant to the E-Area PA. Climate change may affect infiltration rates and saturated zone flow. See Section TBD of the E-Area PA for a discussion of the basis for long-term precipitation estimates.* ***Potentially deleterious FEP:*** *Changes in infiltration associated with climate change are uncertain and will be considered in the GoldSim system model. Climate change may potentially affect the performance of the cover. Significant and sustained changes to mean water table elevation may impact the transport times in the unsaturated zone.*	
Sea level change	1.3.03
Definition: FEPs related to changes in sea level that may occur as a result of global (eustatic) change and regional geological change, e.g., isostatic movements.	
Comment: *The component of sea level change involving the interchange of water between land ice and the sea is referred to as eustatic change. As ice sheets melt, so the ocean volume increases and sea levels rise. Sea level at a given location will also be affected by vertical movement of the land mass, e.g., depression and rebound due to glacial loading and unloading, referred to as isostatic change (c.f. FEP 1.3.01).*	
Key concepts, examples, and related FEPs • *Flooding* • *Saline intrusion into repository or geosphere* • *Change in the hydrogeological regime*	
Application to E-Area: *Not relevant to the E-Area PA. Sea level changes will not significantly impact the GSA or have a significant influence on aquifer flow within 100 m of the waste.* ***Potentially deleterious FEP:*** *Not applicable.*	

Periglacial effects	1.3.04
Definition: FEPs related to the physical processes and associated landforms in cold but ice-sheet-free environments. This may be at the immediate margins of former and existing glaciers and ice sheets or an environment in which frost actions are dominant.	
Comment: *An important characteristic of periglacial environments is the seasonal change from winter freezing to summer thaw with large water movements and potential for erosion. The frozen subsoils are referred to as permafrost. Meltwater of the seasonal thaw is unable to percolate downward due to permafrost and saturates the surface materials. This can result in a mass movement called solifluction (literally soil flow). Permafrost layers may isolate the deep hydrological regime from surface hydrology, or flow may be focused at "taliks" (localized unfrozen zones, e.g., under lakes, large rivers, or at regions of groundwater discharge).*	
Key concepts, examples, and related FEPs • *Large water movement* • *Erosion* • *Strong seasonal influences* • *Soil flow (movement) – solifluction* • *Permafrost* • *Saturation of surface materials*	
Application to E-Area: *Not relevant for the SRS or on the time scale of the E-Area PA.* ***Potentially deleterious FEP:*** *Not applicable.*	

Glacial and ice sheet effects, local	1.3.05
Definition: FEPs related to the effects of glaciers and ice sheets within the region of a repository, e.g., changes in the geomorphology, erosion, meltwater, and hydraulic effects. This is distinct from the effect of large ice masses on global and regional climate (c.f. FEPs 1.3.01, 1.3.02).	
Comment: *Erosional processes (abrasion, over-deepening) associated with glacial action, especially advancing glaciers and ice sheets, and with glacial meltwaters beneath the ice mass and at the margins, can lead to morphological changes in the environment, e.g., U-shaped valleys, hanging valleys, fjords, and drumlins. Depositional features associated with glaciers and ice sheets include moraines and eskers. The pressure of the ice mass on the landscape may result in significant and even depression of the regional crustal plate.*	
Key concepts, examples, and related FEPs • *Erosional processes (abrasion, over-deepening)* • *Hydrogeological change* • *Transportation and depositional processes and features (moraines, eskers)* • *Morphological changes (hanging valleys, fjords, drumlins)* • *Depression of the regional crustal plate*	
Application to E-Area: *Not relevant on the time scale of the E-Area PA and based on past extent of ice sheets.* ***Potentially deleterious FEP:*** *Not applicable.*	

Warm climate effects (tropical and desert)	1.3.06
Definition: FEPs related to warm tropical and desert climates, including seasonal effects, and meteorological and geomorphological effects special to these climates.	
Comment: *Regions with a tropical climate may experience extreme weather patterns (monsoons, hurricanes) that could result in flooding, storm surges, high winds, etc., with implications for erosion and hydrology. The high temperatures and humidity associated with tropical climates result and soils are generally thin. In arid climates, total rainfall, erosion, and recharge may be dominated by infrequent storm events.*	
<u>Key concepts, examples, and related FEPs</u> • *Extreme weather patterns* • *Monsoons* • *Hurricanes* • *Flooding* • *Storm surges* • *Alkali flats* • *Infrequent storm events* • *High rainfall* • *High winds* • *Effective recharge* • *Change in hydrological regime* • *Rapid biological degradation* • *Erosion*	
<u>Application to E-Area</u>: *Relevant and addressed in the E-Area PA in evaluation of the infiltration rate (see Section TBD).* ***<u>Potentially deleterious FEP</u>:*** *Effects are included in estimates and uncertainties in the infiltration rate for the cover safety functions.*	

Hydrological/hydrogeological response to climate changes	1.3.07
Definition: FEPs related to changes in the hydrological and hydrogeological regime, e.g., recharge, sediment load, and seasonality, in response to climate change in a region.	
Comment: *The hydrology and hydrogeology of a region is closely coupled to climate. Climate controls the amount of precipitation, evaporation, and seasonal ice cover and thus the soil water balance, extent of soil saturation, surface run-off, and groundwater recharge. Vegetation and human actions may modify these responses.*	
<u>Key concepts, examples, and related FEPs</u> • *Change in groundwater recharge* • *Change in sediment load* • *Change in soil water balance* • *Change in regional precipitation/infiltration/ evaporation* • *Change in seasonal ice cover* • *Change in surface run-off* • *Increase in groundwater velocity* • *Creation of local ponds*	
<u>Application to E-Area</u>: *Relevant to the E-Area PA in evaluating the infiltration rate (see Section TBD).* ***<u>Potentially deleterious FEP</u>:*** *This FEP has the potential to affect the cover infiltration and site conditions safety functions. Effects of climate change on infiltration are included in the range of rates considered. Potential anthropogenic effects are within the range considered (see Section TBD of the E-Area PA).*	

Ecological response to climate changes	1.3.08
Definition: FEPs related to changes in ecology, e.g., vegetation, plant, and animal populations, in response to climate change in a region.	
Comment: *The ecology of an environment is linked to climate. Ecological adaptation has allowed flora and fauna to survive and exploit even the most hostile of environments. For example, cacti have evolved to survive extreme heat and desiccation of the desert environment, and certain plant species complete their entire life cycle over very short time periods following rare rain events in the desert. Some tree and plant species have evolved to survive natural events such as forest fires and may require them to complete their life cycle.*	
Key concepts, examples, and related FEPs • *Desert formation* • *Change in vegetation* • *Change in animal life* • *Ecological adaptation*	
Application to E-Area: *Relevant to the E-Area PA in evaluating the infiltration rate.* ***Potentially deleterious FEP:*** *This FEP has the potential to affect the cover infiltration safety function by altering the plant community over the waste, which could in turn impact evapotranspiration and cap physical/chemical degradation rates (e.g., rate of pine tree intrusion).*	

Human response to climate changes	1.3.09
Definition: FEPs related to changes in human behavior, e.g., habits, diet, community size, in response to climate change in a region.	
Comment: *Human response is closely linked to climate. Climate affects the abundance and availability of natural resources such as water, as well as the types of crops that can be grown. The more extreme a climate, the greater the extent of human control over these resources is necessary to maintain agricultural productivity, e.g., through the use of dams, irrigation systems, and controlled agricultural environments (greenhouses).*	
Key concepts, examples, and related FEPs • *Change in human habits* • *Effect of climate change on food chain* • *Change in agricultural activities/products* • *Increase/decrease in usage of irrigation systems* • *Change in population density* • *Change in diet* • *Effect of climate change on water availability* • *Construction of dams*	
Application to E-Area: *Addressed in the exposure assessment requirements in DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance.* ***Potentially deleterious FEP:*** *Not applicable.*	

Other geomorphologic changes	1.3.10
Definition: FEPs related to geomorphologic (also known as physiography) changes on a regional and local scale, i.e., the general configuration of the Earth's surface.	
Comment: *Geomorphology refers to the classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features. The term is especially applied to the generic interpretation of landforms but has also been restricted to features produced only by erosion and deposition.*	

Key concepts, examples, and related FEPs • *Denudation*
Application to E-Area: *Potentially relevant for considerations related to the cover.* ***Potentially deleterious FEP:*** *Addition of cap has the potential to impact local surface drainage, GW flow patterns and depth to water table.*

FUTURE HUMAN ACTIONS (ACTIVE)	1.4
Definition: Human actions and regional practices, in the post-closure period, that can potentially affect the performance of the engineered and/or geological barriers, e.g., intrusive actions, but not the passive behavior and habits of the local population (c.f. 2.4).	
Comment: *"Human Actions (Active)" is a subcategory of the External Factors in the International FEP List and is divided into individual FEPs.*	

Human influences on climate	1.4.01
Definition: FEPs related to human activities that could affect the change of climate either globally or in a region.	
Comment: *These activities could be intentional or unintentional, with an indirect influence more than a direct influence on the climate.*	
Key concepts, examples, and related FEPs • *Deforestation* • *Emissions of greenhouse gases such as CO_2 and CH_4*	
Application to E-Area: *Relevant to the E-Area PA in evaluating the infiltration rate. Projected anthropogenic effects on future climates may either increase or decrease infiltration rate.* ***Potentially deleterious FEP:*** *This FEP has the potential to affect the cover infiltration and site conditions safety functions. Effects of climate change on infiltration are included in the range of rates considered. Potential anthropogenic effects are within the range considered (see Section TBD of the E-Area PA).*	

Motivation and knowledge issues (inadvertent/deliberate human actions)	1.4.02
Definition: FEPs related to the degree of knowledge of the existence, location, and/or nature of the repository. Also, reasons for deliberate interference with, or intrusion into, a repository after closure with complete or incomplete knowledge.	
Comment: *Some future human actions, e.g., see FEPs 1.4.03 and 1.4.04, could directly impact the repository performance. Many assessments distinguish between:* - *Inadvertent actions, which are actions taken without knowledge or awareness of the repository, and* - *Deliberate actions, which are actions that are taken with knowledge of the repository's existence and location, e.g., deliberate attempts to retrieve the waste, malicious intrusion, and sabotage.* *Intermediate cases of intrusion with incomplete knowledge could also occur.*	

Key concepts, examples, and related FEPs		
• *Human intrusion (instigate mechanical processes)* • *Incomplete knowledge intrusion*	• *Deliberate actions, e.g., war, sabotage, waste recovery, malicious intrusion*	• *Inadvertent actions, e.g., exploratory drilling, resource mining, archaeological intrusion*
Application to E-Area: *Not relevant to the E-Area PA, because this FEP relates to probability of occurrence of inadvertent intrusion. Probabilities are not specifically accounted for in the PA. Advertent intrusion is generally excluded from consideration in the PA international community.* ***Potentially deleterious FEP:*** *Not applicable.*		

Drilling activities (human intrusion)			1.4.03
Definition: FEPs related to any type of drilling activity near the repository.			
Comment: *These activities may be taken with or without knowledge of the repository and, in fact, compose a subgroup of FEP 1.4.02.*			
Key concepts, examples, and related FEPs			
• *Exploratory and/or exploitation drilling for natural resources and raw materials* • *Drilling for research or site characterization studies*	• *Water well drilling* • *Drilling for waste injection*	• *Drilling for hydrothermal resources* • *Extraction of valuable components of the disposed waste*	
Application to E-Area: *Relevant to the E-Area PA intrusion scenario.* ***Potentially deleterious FEP:*** *Intrusion can result in waste being brought to the surface, leading to exposures. Addressed in the evaluation of inadvertent intrusion (see Section TBD of the E-Area PA).*			

Mining and other underground activities (human intrusion)			1.4.04
Definition: FEPs related to any type of mining or excavation activity carried out near the repository.			
Comment: *These activities may be taken with or without knowledge of the repository and, in fact, compose a subgroup of FEP 1.4.02.*			
Key concepts, examples, and related FEPs			
• *Resource mining* • *Excavation for industry* • *Geothermal energy production* • *Mine drillings*	• *Shaft construction, underground construction, and tunneling* • *Recovery of repository materials (reuse of waste)* • *The presence of mine galleries – after closure*	• *Malicious intrusion, sabotage, or war* • *Injection of liquid wastes and other fluids* • *Scientific underground investigation* • *Underground nuclear testing*	
Application to E-Area: *Not relevant to the E-Area PA. Drilling activities are accounted for in the inadvertent intruder scenario (see Section TBD of the E-Area PA). Other mining activities are excluded based on lack of resources at E-Area. Potential for intrusive activities is also limited by depth of waste disposal and presence of intrusion barriers.* ***Potentially deleterious FEP:*** *Not applicable.*			

Un-intrusive site investigation	1.4.05
Definition: FEPs related to airborne, geophysical, or other surface-based investigation of a repository site after repository closure.	
Comment: *Such investigation, e.g., prospecting for geological resources, might occur after information of the location of a repository had been lost. The evidence of the repository itself, e.g., discovery of an old shaft, might itself prompt investigation, including research of historical archives.*	
Key concepts, examples, and related FEPs • *Prospecting for geological resources* • *Investigation of an old shaft* • *Research of historical archives*	
Application to E-Area: *Not relevant to the E-Area PA, because this FEP relates to probabilities of intrusion. Probabilities are not specifically addressed in the PA. Intrusion is assumed to occur.* ***Potentially deleterious FEP:*** *Not applicable.*	

Surface excavations	1.4.06
Definition: FEPs related to any type of human activities during surface excavations that can potentially affect the performance of the engineered and/or natural (geological) barriers or affect the exposure pathways.	
Comment: *This FEP relates to the surface environment. Strictly speaking, excavation refers to an act or process of removing soil and/or rock materials from one location and transporting them to another. This may include, for example, digging, blasting, breaking, loading, and hauling, which may result in direct human intrusion in the case of a near-surface repository.*	
Key concepts, examples, and related FEPs • *Quarrying, trenching, plowing* • *Digging, blasting, breaking, loading, hauling* • *Recycling of materials* • *Dredging of sediments in estuaries* • *Excavation for construction (earthworks)* • *Excavation for storage or disposal* • *Shallow excavations for site investigations* • *Excavation for military purposes*	
Application to E-Area: *Relevant to the E-Area PA for intrusion scenarios, if waste can be closer than 3 m to the surface of the cover. Evaluation excluded for most waste based on depth of waste disposal and presence of intrusion barriers. Reinforced concrete is considered a substantial barrier to an excavation scenario while recognizable and relatively intact. See discussion in Section TBD of the PA.* ***Potentially deleterious FEP:*** *Discovery or excavation scenario for intrusion-related safety functions. If waste is less than 3 m from the surface after considering erosion, potential for this scenario must be considered.*	

Pollution	1.4.07
Definition: FEPs related to any type of human activities associated with pollution that can potentially affect the performance of the engineered and/or natural (geological) barriers or affect the exposure pathways.	
Comment: *As used here, pollution refers to the alteration of the chemical composition of the surface environment in the vicinity of the repository in such a way that the performance of the disposal system is influenced.*	

Key concepts, examples, and related FEPs

- *Acid rain*
- *Chemical liquid waste disposal*
- *Soil pollution*
- *Soil fertilization*
- *Groundwater pollution*

Application to E-Area: *Relevant to the E-Area PA for potential changes to the ecology and the cover performance (see Section TBD of the PA).*
Potentially deleterious FEP: *Potential effects in cover infiltration safety function. Damage to the vegetative cover would potentially lower evapotranspiration rates and increase infiltration rates through the waste zone. Potential changes to soil geochemistry.*

Site development	1.4.08

Definition: FEPs related to any type of human activities during site development that can potentially affect the performance of the engineered and/or natural (geological) barriers or affect the exposure pathways.

Comment: *As used here, site development refers to alterations to the surface environment after memory of the repository has been lost. These alterations may result in direct human intrusion in the near-surface facility or may result in an alteration of the host lithology or topography.*

Key concepts, examples, and related FEPs

- *Site occupation*
- *Leveling of hills (e.g., airport layout)*
- *Construction of roads, houses, buildings, dams, etc.*
- *Human modification of the site drainage*
- *Residential, industrial, transport, and road construction*
- *Land reclamation/extension*

Application to E-Area: *Relevant to the E-Area PA for potential changes to the degradation rates of a cover and for inadvertent intrusion (see Sections TBD of the PA.*
Potentially deleterious FEP*: Potential effects in the cover function for infiltration and intrusion.*

Archaeology	1.4.09

Definition: FEPs related to any type of human activities associated with archaeology that can potentially affect the performance of the engineered and/or natural (geological) barriers or affect the exposure pathways.

Comment: *As used here, the FEP refers to archaeological investigations in the surface environment.*

Key concepts, examples, and related FEPs

- *Archaeological, inadvertent human intrusion*
- *Archaeological artifacts found during construction*

Application to E-Area: *Not relevant to the E-Area PA, because this FEP relates to probabilities of intrusion, which are not accounted for in the PA The PA assumes intrusion will occur.*
Potentially deleterious FEP: *Not applicable.*

Water management (wells, reservoirs, dams)	1.4.10
Definition: FEPs related to groundwater and surface-water management, including water extraction, reservoirs, dams, and river management.	
Comment: *Water is a valuable resource, and water extraction and management schemes provide increased control over its distribution and availability through construction of dams, barrages, canals, pumping stations, and pipelines. Groundwater and surface water may be extracted for human domestic uses (e.g., drinking water, washing), agricultural uses (e.g., irrigation, animal consumption), and industrial uses. Extraction and management of water may affect the movement of radionuclides to and in the surface environment.*	
Key concepts, examples, and related FEPs • *Waterworks* • *Artificial mixing of lakes* • *Reservoirs* • *Industrial usage* • *Human effects on water potential* • *Chemical liquid waste disposal* • *Intentional artificial groundwater recharge/discharge by humans* • *Dam, barrage, canals, pumping stations, and pipeline building* • *Desalination of water in estuaries and marines* • *Drainage systems* • *Extraction of contaminated water from aquifer via a well* • *Impoundment of water for fishing/fish farming, bathing* • *Groundwater/surface water extraction for irrigation, animal consumption, drinking water, washing* • *Salt production*	
Application to E-Area: *Relevant to the E-Area PA. Groundwater and surface water use is considered in the exposure scenarios. Changes in aquifer flow are anticipated to have limited impact on concentrations at the 100 m well but are considered (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Sensitivity and uncertainty analyses consider changes in aquifer flow and impact on predicted concentrations at the 100 m well.*	

Social and institutional developments	1.4.11
Definition: FEPs related to changes in social patterns and degree of local government, planning, and regulation.	
Comment: *The decisions made in the future concerning social and institutional development may have a significant influence on the disposal system, e.g., if a change in land use is promulgated or regulatory requirements change.*	
Key concepts, examples, and related FEPs • *Loss of archives/records, loss/degradation of societal memory* • *Changes in planning controls and environmental legislation* • *Demographic change and urban development* • *Change in land use* • *Change in regulatory requirements* • *Change in institutional control*	
Application to E-Area: *Relevant to the E-Area PA. Loss of memory of the site and institutional controls is assumed at 100 years after closure (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Assumed loss of memory and control lead to possible drilling intrusion, basement intrusion, and resident farmer scenarios.*	

Technological developments	1.4.12
Definition: FEPs related to future developments in human technology and changes in the capacity and motivation to implement technologies. This may include retrograde developments, e.g., loss of capacity to implement a technology.	
Comment: *Of interest are those technologies that might change the capacity of man to intrude deliberately or otherwise into a repository, to cause changes that would affect the movement of contaminants, or to affect the exposure or its health implications. Technological developments are likely but may not be predictable, especially at longer times into the future. In most assessments, assumptions are made to limit the scope of consideration.*	
<u>Key concepts, examples, and related FEPs</u> • *Retrograde developments* • *Loss of capacity to implement technology*	
<u>Application to E-Area</u>: *Not relevant to the E-Area PA. Current technology is considered consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and associated guidance.* ***<u>Potentially deleterious FEP</u>:*** *Not applicable.*	
Remedial actions	1.4.13
Definition: FEPs related to actions that might be taken following repository closure to remediate problems with a waste repository that was not performing to the standards required, had been disrupted by some natural event or process, or had been inadvertently or deliberately damaged by human actions.	
Comment:	
<u>Key concepts, examples, and related FEPs</u> • *None*	
<u>Application to E-Area</u>: *Not relevant to the E-Area PA. DOE M 435.1-1 Chg 2 and associated guidance require a PA maintenance process that would address any future remediation needs.* ***<u>Potentially deleterious FEP</u>:*** *Not applicable.*	

Explosions and crashes	1.4.14
Definition: FEPs related to deliberate or accidental explosions and crashes such as might have some impact on a closed repository, e.g., underground nuclear testing, aircraft crash on the site, or acts of war.	
Comment:	
<u>Key concepts, examples, and related FEPs</u> • *Intrusions by war, sabotage, terrorism* • *Underground nuclear testing* • *Likelihood of crashes onto surface facilities, e.g., plane crashes*	
<u>Application to E-Area</u>: *Potentially relevant to the performance of the cover but very low probability of occurrence.* ***<u>Potentially deleterious FEP</u>:*** *Not applicable.*	

DISPOSAL SYSTEM DOMAIN: ENVIRONMENTAL FACTORS	2
Definition: Features and processes occurring within that spatial and temporal (post-closure) domain whose principal effect is to determine the evolution of the physical, chemical, biological, and human conditions of the domain that are relevant to estimating the release and migration of radionuclides and consequent exposure to man.	
Comment: *"Disposal System Domain: Environmental Factors" is a category in the International FEP List and is divided into subcategories.*	

WASTES AND ENGINEERED FEATURES	2.1
Definition: Features and processes within the waste and engineered components of the disposal system. (output – source term characteristics).	
Comment: *"Wastes and Engineered Features" is a subcategory of Disposal Domain: Environmental Factors in the International FEP List and is divided into individual FEPs.* *Note that FEPs 2.1.01 to 2.1.06 describe the features in the disposal system, in other words, a description of the system as it is constructed, whereas FEPs 2.1.07 to 2.1.11 describe the processes or the changes in the disposal system.*	

Inventory, radionuclide, and other material	2.1.01
Definition: FEPs related to the total content of the repository of a given type of material, substance, element, individual radionuclides, total radioactivity, or inventory of toxic substances.	
Comment: *The FEP often refers to content of radionuclides, but the content of other materials, e.g., steels, other metals, concrete, or organic materials, could be of interest.*	
Key concepts, examples, and related FEPs • *Radionuclide content* • *Concrete or organic material content* • *Steel and other metal content* ***Application to E-Area:*** *Relevant to the E-Area PA. The Waste Acceptance Criteria specify limits on allowable wastes and contaminants and prohibit specific deleterious substances. There is uncertainty in the actual radionuclide inventories that are disposed. Potential influences of chemicals in the waste are considered (e.g., Kds, pH, etc.) and are generally assumed to be insignificant (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Uncertainties in the inventory of residual waste and its chemical and physical form after retrieval can influence release and migration rates. Key inputs tend to be biased to account for potential deleterious effects and uncertainties in key parameters are considered.*	

Waste form materials, characteristics, and degradation processes	2.1.02
Definition: FEPs related to the physical, chemical, and biological characteristics of the waste form at the time of disposal and as they may evolve in the repository, including FEPs that are relevant specifically as waste degradation processes.	
Comment: *The waste form will usually be conditioned prior to disposal, e.g., by solidification and inclusion of grout materials. The waste form is a component of the waste package. The waste characteristics will evolve due to various processes that will be affected by the physical and chemical conditions of the repository environment. Processes that are relevant specifically as waste degradation processes, as compared to general evolution of the near field, are included in this FEP.*	
Key concepts, examples, and related FEPs • *Physical degradation* • *Chemical degradation* • *Solid matrix of resin, bitumen, cement* • *Ash* • *Cloves, clothing, plastics, paper wood* • *Spent sources* • *Activated metal* • *Sludges, evaporation residue, compacted solids, filters*	
Application to E-Area: *Relevant to E-Area PA. In general, no added credit is taken for limitation of releases from a given waste form. Generic limits assuming no release limitations are primarily applied. A number of special waste forms have been identified and specific credit for enhanced performance is included in the PA and limits applied to those wastes (e.g., activated metals, ion exchange resins or specific wastes) – See Section TBD of the PA)* ***Potentially deleterious FEP:*** *Potential impacts of uncertainty regarding waste forms is generally addressed by assuming release is instantaneous. Justification is required for special case waste forms.*	

Container materials, characteristics, and degradation/failure processes	2.1.03
Definition: FEPs related to the physical, chemical, and biological characteristics of the container at the time of disposal and as they may evolve in the repository, including FEPs that are relevant specifically as container degradation/failure processes.	
Comment: *The container refers to the vessel into which the waste form is placed for handling, transportation, storage, and/or disposal. It is also the outer barrier protecting the waste from external intrusions. The container is a component of the waste package.*	
Key concepts, examples, and related FEPs • *Container degradation/failure processes* • *Metal drums* • *Concrete containers* • *Stainless-steel containers* • *Lead containers*	
Application to E-Area: *Relevant to E-Area PA. Degradation (corrosion) of B-25 boxes, SeaLand containers, and non-crushable packages influences closure cap performance. In general, no credit is taken for hydraulic performance of most containers. Some special containers are credited as a hydraulic barrier (e.g., TPBAR cask, heat exchangers) – see Section TBD of the PA.* ***Potentially deleterious FEP:*** *Changes from assumptions in the PA could be a concern for calculated infiltration rates and projected doses. An increase in the assumed number of non-crushable packages remaining after dynamic compaction will lead to increased cap subsidence and infiltration. Containers assumed to provide some isolation capability must be justified.*	

Buffer/backfill materials, characteristics, and degradation processes	2.1.04
Definition: FEPs related to the physical, chemical, and biological characteristics of the buffer and/or backfill at the time of disposal and as they may evolve in the repository, including FEPs that are relevant specifically as buffer/backfill degradation processes (effect on hydrology/flow).	
Comment: *Buffer and backfill are sometimes used synonymously. In some high-level waste/spent fuel concepts, the term buffer is used to mean material immediately surrounding a waste container and having some chemical and/or mechanical buffering role, whereas backfill is used to mean material used to fill other underground openings. However, in intermediate-level waste/low-level waste concepts, the term backfill is used to describe the material placed between waste containers, which may have a chemical role. Buffer/backfill materials may include clays, cement, and mixtures of cement with aggregates, e.g., of crushed rock.* *The buffer/backfill characteristics will evolve due to various processes that will be affected by the physical and chemical conditions of the repository environment. Processes that are relevant specifically as buffer/backfill degradation processes, as compared to general evolution of the near field, are included in this FEP.*	
Key concepts, examples, and related FEPs • *Buffer/backfill degradation processes* • *Clay, cement, sand, soil* • *Mixture of clay and crushed rock* • *Bentonite clay*	
Application to E-Area: *Relevant to the E-Area PA for backfill materials and use of grout fill (see Sections TBD of the PA). Properties for backfill are based on the source for the backfill soil. Generally, backfill is assumed to be obtained from the soils excavated to create a trench. Grout properties are assigned based on specific design of the grout mix.* ***Potentially deleterious FEP:*** *Changes from assumptions in the PA could be a concern for projected doses. There will be uncertainty in the properties and performance of backfills or grout. If different soils or grout are used, different properties may need to be assumed.*	

Engineered barrier system (EBS) characteristics and degradation processes	2.1.05
Definition: FEPs related to the design, physical, chemical, hydraulic, etc., characteristics of the cavern/tunnel/shaft seals at the time of sealing and closure and also as they may evolve in the repository, including FEPs that are relevant specifically as cavern/tunnel/shaft seal and cap degradation processes (effect on hydrology/flow—change over time).	
Comment: *Cavern/tunnel/shaft seal and cap failure may result from gradual degradation processes or may be the result of a sudden event. The importance is that alternative routes for groundwater flow and radionuclide transport may be created along the various layers and tunnels and/or shafts and associated excavation disturbed or damaged zone (see FEP 2.2.01).*	
Key concepts, examples, and related FEPs • *Engineered caps (cover)* • *Intrusion resistance caps* • *Cap materials: clay, concrete* • *Cover degradation*	

Application to E-Area: *Relevant to the E-Area PA engineered barriers (e.g., CIG, cover system). As built properties are controlled using site quality assurance procedures. Long term degradation is addressed for key engineered features, see Sections TBD of the PA.*

Potentially deleterious FEP: *Changes from assumptions in the PA could be a concern for projected doses. Uncertainties in the current state and long-term performance of the cover system are addressed in the PA using uncertainty distributions or ranges for intact and degraded material properties, bounding assumptions and stochastic models for failure of containers in Slit & Engineered Trenches, and Monte Carlo simulations of structural degradation of E-Area vaults (ILV and LAWV).*

Other engineered features materials, characteristics, and degradation processes	2.1.06

Definition: FEPs related to the physical, chemical, and biological characteristics of the engineered features (other than containers, buffer/backfill, caps, and seals) at the time of disposal and also as they may evolve in the repository, including FEPs that are relevant specifically as degradation processes acting on the engineered features.

Comment: *Examples of other engineered features are rock bolts, shotcrete, tunnel liners, silo walls, and any services and equipment not removed before closure. The engineered features, materials, and characteristics will evolve due to various processes that will be affected by the physical and chemical conditions of the repository environment. Processes that are relevant specifically as degradation processes acting on the features, as compared to general evolution of the near field, are included in this FEP.*

Key concepts, examples, and related FEPs

- *Trenches, holes, vaults*
- *Walls, floors, mounds, layers of mounds*
- *Rock bolts, tunnel liners, silo walls*
- *Reduction in flow through structures due to impermeable membrane and subsequent degradation of impermeable membrane*
- *Cut-off walls*
- *Degradation processes*

Application to E-Area: *Relevant to safety functions for concrete vault walls and roofs. As built properties are controlled using site quality assurance procedures. Long term degradation is addressed for key engineered features, see Sections TBD of the PA.*

Potentially deleterious FEP: *Changes from assumptions in the PA could be a concern for projected doses. Potential degradation in the current state and future evolution of the safety functions of the engineered barriers (intrusion, water flow, and chemical) is considered in the PA and sensitivity and uncertainty analyses. Degradation of the membrane layer on ILV and LAWV roofs and formation of cracks in vault roofs leading to increased infiltration during period before roof collapse.*

Mechanical processes and conditions (in wastes and EBS)	2.1.07

Definition: FEPs related to the mechanical processes that affect the wastes, containers, seals, and other engineered features, and the overall mechanical evolution of near field with time. This includes the effects of hydraulic and mechanical loads imposed on wastes, containers, and repository components by the surrounding geology.

Comment:

Key concepts, examples, and related FEPs

- *Waste and container compression*
- *Container collapse*
- *Buffer swelling pressure*
- *Material volume changes*
- *Subsidence as a result of compression of waste and cover layers*
- *Fracture formation in vault, backfill, joints, cover materials, host geology (local fractures)*
- *Container movement*
- *Differential behavior of joints*
- *Tunnel roof or lining collapse*

Application to E-Area: *Relevant to the PA in the influence on conditions of E-Area engineered barriers structure. Hydraulic performance of concrete vault walls and roof as cracks form and closure cap changes resulting from subsidence. Structural loads in the design of engineered barriers are considered (see Section TBD of the PA).*

Potentially deleterious FEP: *Potential degradation in the current state and future evolution of the E-Area hydraulic safety function. Formation of cracks in vault roofs could lead to increased infiltration during period before roof collapse. Subsidence of closure cap after roof collapse will lead to increased infiltration through waste zone.*

Hydraulic/hydrogeological processes and conditions (in wastes and EBS)	2.1.08
Definition: FEPs related to the hydraulic/hydrogeological processes that affect the wastes, containers, seals and other engineered features, and the overall hydraulic/hydrogeological evolution of the near field with time. This includes the effects of hydraulic/hydrogeological influences on wastes, containers, and repository components by the surrounding geology.	
Comment:	

Key concepts, examples, and related FEPs

- *Failure of drainage system*
- *Failure of cut-off walls*
- *Failure of cap/cover*
- *Failure of the joints*
- *Bathtubbing*
- *Fracturing of concrete components*
- *Effect of cap+cover+backfill*
- *Influence of climate change*
- *Influence of saline intrusion*
- *Gas-mediated water flow*
- *Interaction of backfill with pore water*
- *pH change*
- *Redox change*
- *Sulphate attack*
- *Effect of chelating agents*
- *Modification of pore water by cover caused by chemical*
- *Interaction of vault material with pore water*
- *pH change*
- *Redox potential change*
- *Mineralization*
- *Modification of pore water by cover*
- *Interaction of container material with pore water*
- *Matrix corrosion*
- *Gas generation*
- *Polymer degradation (high-integrity containers)*
- *Mineralization change*
- *Osmotic effect*
- *Interaction of vault materials with host groundwater*
- *Carbonation*
- *Osmotic effects*
- *Infiltration and movement of fluids in the repository environment*
- *Resaturation/desaturation of the repository or its components*
- *Water flow and contaminant transport paths within the repository*
- *Induced fluid effects caused by temperature change*
  - *Pressure change*
  - *Natural convection*
  - *Viscosity*
- *Reduction in flow through structures due to grouting*
- *Chloride attack*
- *Sulphate attack*
- *Colloid formation*

Application to E-Area: *Relevant to the E-Area PA in the influence of the FEP to release and transport of waste from the different E-Area structures and disposal concepts (see Sections TBD of the PA).*

Potentially deleterious FEP: *Potential degradation in the current state and future evolution of the water flow safety functions of the engineered barriers is considered in the base case and sensitivity and uncertainty analyses.*

Chemical/geochemical processes and conditions (in wastes and EBS)	2.1.09
Definition: FEPs related to the chemical/geochemical processes that affect the wastes, containers, seals, and other engineered features, and the overall chemical/geochemical evolution of near field with time. This includes the effects of chemical/geochemical influences on wastes, containers, and repository components by the surrounding geology.	
Comment:	

Key concepts, examples, and related FEPs

- *Chemical interaction of backfill with pore water*
- *pH changes*
- *Redox changes*
- *Sulphate attack*
- *Osmotic effects*
- *Chemical interaction of vault materials with pore water*
- *pH changes*
- *Redox potential changes*
- *Chemical interaction of vault materials with host groundwater*
- *Carbonation*
- *Chloride attack*
- *Sulphate attack*
- *Chemical interaction of waste with pore water*
- *Metallic corrosion processes (general and pitting)*
- *Polymer degradation (resins)*
- *Chemical interaction of containers (including overpacks) with pore water*
- *Metallic corrosion*
- *Polymer degradation (high-integrity containers)*
- *Chemical interaction of waste with containers*
- *Precipitation/dissolution reactions*
- *Evolution of redox (Eh) and acidity/alkalinity (pH), etc.*
- *Silting/pore closure*
- *Geochemical changes*
- *Induced galvanic metallic corrosion*
- *Polymer degradation (high-integrity containers)*
- *Chemical interaction of backfill with containers (including overpacks)*
- *Induced galvanic metallic corrosion*
- *Polymer degradation (high-integrity containers)*
- *Chemical interaction of nonradioactive waste components with radioactive waste components*
- *pH changes*
- *Redox potential changes*
- *Change in chemical reaction rate caused by temperature change*
- *Electrochemical processes*
- *Chemical conditioning and buffering processes*

Application to E-Area: *Relevant to the PA for the influence of assumed geochemical properties of engineered features on release and transport waste. For example, Kds in LAW vaults are influenced by corrosion products from containers and variability in Kds needs to be addressed and cementitious materials can influence the migration of radionuclides (see Sections TBD of the PA).*

Potentially deleterious FEP: *If assumed geochemistry is overly optimistic, releases could be underestimated. Intentional pessimistic bias and sensitivity and uncertainty analyses are used to address potential variability.*

Biological/biochemical processes and conditions (in wastes and EBS)	2.1.10
Definition: FEPs related to the biological/biochemical processes that affect the wastes, containers, seals and other engineered features, and the overall biological/biochemical evolution of the near field with time. This includes the effects of biological/biochemical influences on wastes, containers, and repository components by the surrounding geology.	
Comment:	
<u>Key concepts, examples, and related FEPs</u> • *Microbial growth and poisoning* • *Microbially/biologically mediated processes* • *Effect of organic material* • *Microbial/biological effects of evolution of redox (Eh) and acidity/alkalinity (pH), etc.* • *Effect of organic materials* • *Change in microbial caused by change in temperature*	
<u>Application to E-Area</u>: *Relevant to the PA for the influence of assumptions regarding biological processes on release and transport. Potential influence of cellulosic materials has been considered and determined to not have a significant impact (see Section TBD of the PA).* ***<u>Potentially deleterious FEP</u>:*** *Biological influences could impact mobility of radionuclides. Potential impacts are addressed.*	

Thermal processes and conditions (in wastes and EBS)	2.1.11
Definition: FEPs related to the thermal processes that affect the wastes, containers, seals and other engineered features, and the overall thermal evolution of the near field with time. This includes the effects of heat on wastes, containers, and repository components from the surrounding geology.	
Comment:	
<u>Key concepts, examples, and related FEPs</u> • *Temperature evolution* • *Differential elastic response* • *Nonelastic response* • *Fracture aperture changes caused by the temperature change* • *Change in microbial activity* • *Radiogenic, chemical, and biological heat production from the wastes* • *Chemical heat production from engineered features, e.g., concrete hydration* • *Change in chemical reaction rates, e.g., corrosion* • *Temperature dependence of physical/chemical/biological/hydraulic processes, e.g., corrosion and re-saturation* • *Fluid pressure, density viscosity changes* • *Induced chemical changes caused by the temperature change*	
<u>Application to E-Area</u>: *Relevant to the E-Area PA for heat of hydration of the grout and is considered for TPBARs (see Section TBD of the PA). Procedures will ensure that potential thermal considerations are addressed (heat of hydration is considered to obtain cured properties and that proper controls are in place for managing heat from the TPBARs).* ***<u>Potentially deleterious FEP</u>:*** *Limited relevance considered to be managed by existing procedures. Deleterious impacts are bounded by procedures that are in place, not assumed to be significant for the PA. If there was some change in assumptions regarding heat loading, it would be considered as part of PA Maintenance.*	

Gas sources and effects (in wastes and EBS)	2.1.12
Definition: FEPs within and around the wastes, containers, and engineered features resulting in the generation of gases and their subsequent effects on the repository system.	
Comment: *Gas production may result from degradation and corrosion of various waste, container and engineered feature materials, as well as radiation effects. The effects of gas production may change local chemical and hydraulic conditions and the mechanisms for radionuclide transport, i.e., gas-induced and gas-mediated transport.*	
Key concepts, examples, and related FEPs • *Explosion* • *Pressurisation* • *Radiation effects* • *Gas generation* • *Corrosion* • *Decomposition of organic matter (microbial)* • *Degradation of vault, overpacks, or backfill (instigate mechanical processes)* • *Chemical interaction of containers (including overpacks) with pore water* • *Chemical interaction of waste with containers* • *Chemical interaction of backfill with containers (including overpacks)*	
Application to E-Area: *Not relevant to the E-Area PA. The kinds of solid low-level waste received in E-Area simply have insufficient quantities of radionuclides to cause radiolytic generation of gases, and tight controls (WAC, waste certification, review of waste receipts) strictly limit the receipt of organics and pressurized vessels that could lead to gas pressurization in containers).* ***Potentially deleterious FEP:*** *Not applicable—none identified.*	

Radiation effects (in wastes and EBS)	2.1.13
Definition: FEPs related to the effects that result from the radiation emitted from the wastes that affect the wastes, containers, seals and other engineered features, and the overall radiogenic evolution of the near field with time.	
Comment: *Examples of relevant effects are ionization, radiolytic decomposition of water (radiolysis), radiation damage to waste matrix or container materials, and helium gas production due to alpha decay.*	
Key concepts, examples, and related FEPs • *Radiolysis* • *Decay product gas generation* • *Irradiation effects on metals, concrete* • *Polymer degradation (resins and high integrity containers)* • *Concrete degradation* • *Metallic degradation*	
Application to E-Area: *Relevant to the E-Area PA but negligible. Engineered features are designed to address radiation levels allowed in WAC and operating procedures.* ***Potentially deleterious FEP:*** *Not applicable—none identified.*	

Nuclear criticality	2.1.14
Definition: FEPs related to the possibility and effects of spontaneous nuclear fission chain reactions within the repository.	
Comment: *A chain reaction is the self-sustaining process of nuclear fission in which each neutron released from a fission triggers, on average, at least one other nuclear fission. Nuclear criticality requires a sufficient concentration and localized mass (critical mass) of fissile isotopes (e.g., U-235, Pu-239) and also presence of neutron-moderating materials in a suitable geometry; a chain reaction is liable to be damped by the presence of neutron-absorbing isotopes (e.g., Pu-240).*	
Key concepts, examples, and related FEPs • *Radiological criticality*	
Application to E-Area: *Not relevant to the performance assessment. Waste inventory screened for potential for criticality and assessed via the site criticality programs.* ***Potentially deleterious FEP:*** *Not applicable.*	

GEOLOGICAL ENVIRONMENT	2.2
Definition: The features and processes of the geological environment surrounding the repository including, for example, the hydrogeological, geomechanical, and geochemical features and processes, both in a pre-emplacement state and as modified by the presence of the repository and other long-term changes.	
Comment: *" Geological Environment" is a subcategory in the International FEP List and is divided into individual FEPs.* *Note that FEPs 2.2.01 to 2.2.06 describe the features in the disposal system, in other words, a description of the features of the system as it is constructed, whereas FEPs 2.2.07 to 2.2.11 describe the processes or the changes in the disposal system.*	

Disturbed zone, host lithology	2.2.01
Definition: FEPs related to the host lithology zone around the repository or any other underground openings that may be mechanically disturbed during construction, and the properties and characteristics as they may evolve both before and after repository closure.	
Comment: *The disturbed zone may have different properties to the undisturbed host lithology, e.g., opening of fractures or change of hydraulic properties due to stress relief.*	
Key concepts, examples, and related FEPs • *Fracture formed by the construction* • *Change of hydraulic properties due to stress relief*	
Application to E-Area: *Relevant to the E-Area PA as the excavation zone for the E-Area. Current models of the aquifer are based on data for the existing conditions at E-Area. Recharge assumptions consider the potential for disturbed conditions and the presence of covers (see Section TBD of the PA).* ***Potentially deleterious FEP****: Changes from assumed influence of disturbed soil and covers could result in different recharge and water flow. Uncertainty in recharge is addressed.*	

Host lithology	2.2.02
Definition: FEPs related to the properties and characteristics of the lithology in/on which the repository is sited (excluding the zone disturbed by the construction) as they may evolve both before and after repository closure. In most cases, this FEP will be associated with the unsaturated zone.	
Comment: *Relevant properties include thermal and hydraulic conductivity, compressive and shear strength, porosity, etc. In most cases, this FEP will be associated with the unsaturated zone (see FEP 2.2.03).*	
Key concepts, examples, and related FEPs • *Thermal and hydraulic conductivity* • *Porosity* • *Description of the host lithology* • *Compressive and shear strength*	
Application to E-Area: *Relevant to the E-Area PA. Host lithology is considered the alluvium in which the E-Area resides (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Uncertainties in the lithology and its properties can impact water flow and chemical safety functions around engineered barriers, which are addressed in the sensitivity and uncertainty analyses.*	

Lithological units, other	2.2.03
Definition: FEPs related to the properties and characteristics of the lithology other than the host lithology as they may evolve both before and after repository closure.	
Comment: *These lithological units are those that make up the region in which the repository is located. These units are identified in the geological investigations of the region. Each geological unit is characterized according to its geometry and its general physical properties and characteristics. Details concerning inhomogeneity and uncertainty associated with each unit are included in the characterization. In most cases, this FEP will be associated with the saturated zone (see FEP 2.2.02).*	
Key concepts, examples, and related FEPs • *Non-uniform stratigraphy* • *Heterogeneity* • *Description of the lithology units*	
Application to E-Area: *Relevant to the E-Area PA. "Other lithological units" are those below the E-Area (i.e., not the "host" lithology) (see Section TBD of the PA).* ***Potentially deleterious FEP****: Uncertainties in the lithology and its properties can impact water flow and chemical safety functions in the unsaturated zone and are addressed in the sensitivity and uncertainty analyses.*	

Discontinuities, large scale (in geosphere)	2.2.04
Definition: FEPs related to the properties and characteristics of discontinuities in and between the saturated and unsaturated zones, including faults, shear zones, intrusive dykes, and interfaces between different rock types.	
Comment:	

Key concepts, examples, and related FEPs		
• *Fault*	• *Shear zones*	• *Interfaces between different rock types*
• *Intrusive dykes*		
Application to E-Area: *Not relevant to the E-Area PA. Areas of interest for the E-Area PA, do not involve rock.* ***Potentially deleterious FEP:*** *Not applicable.*		

Contaminant transport path characteristics (in geosphere)	2.2.05
Definition: FEPs related to the properties and characteristics of smaller discontinuities and features within saturated and unsaturated zones that are expected to be the main paths for contaminant transport through the geosphere, as they may evolve both before and after repository closure.	
Comment: *Groundwater flow and contaminant transport through rocks may occur in a variety of systems depending on the rock characteristics. Porous flow is predominantly through pores in the medium or through the interstitial spaces between small grains of materials. Fracture flow is predominantly along fractures in the rock which represent the only connected open spaces. Changes in the contaminant transport path characteristics due to the repository construction or its chemical influence, etc., are included.*	
Key concepts, examples, and related FEPs • *Fracture flow* • *Fracture-matrix interaction* • *Porous flow*	
Application to E-Area: *Not relevant to the E-Area PA. Areas of interest for the E-Area PA, do not involve rock.* ***Potentially deleterious FEP:*** *Not applicable.*	

Mechanical processes and conditions (in geosphere)	2.2.06
Definition: FEPs related to the mechanical processes that affect the saturated and unsaturated zones, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g., rock stress due to the excavation, construction, and long-term presence of the repository.	
Comment:	
Key concepts, examples, and related FEPs • *Subsidence* • *Upliftment*	
Application to E-Area: *Not relevant to the E-Area PA.* ***Potentially deleterious FEP:*** *Not applicable.*	

Hydraulic/hydrogeological processes and conditions (in geosphere)	2.2.07
Definition: FEPs related to the hydraulic and hydrogeological processes that affect the saturated and unsaturated zones, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g., hydraulic head due to the excavation, construction, and long-term presence of the repository.	
Comment: *The hydrogeological regime is the characterization of the composition and movement of water through the relevant geological formations in the repository region and the factors that control this. This requires knowledge of the recharge and discharge zones, the groundwater flow systems, saturation, and other factors that may drive the hydrogeology, such as density effects due to salinity gradients or temperature gradients. Changes of the hydrogeological regime due to the construction and/or presence of the repository are included.*	
Key concepts, examples, and related FEPs • *Saline intrusion* • *Darcy flow* • *Non-Darcy flow* • *Fracture flow* • *Groundwater discharge to surface water, soil, estuary, seas, wells* • *Channeling and preferential flow pathways* • *Aquifer (groundwater) discharge/recharge (e.g., well)* • *Saturated/unsaturated conditions* • *Flow between two aquifers* • *Infiltration* • *Flow direction*	
Application to E-Area: *Relevant to E-Area PA. Excavations and addition of covers can have an influence on flow and contaminant migration in the unsaturated zone and aquifer (see Sections TBD of the PA).* ***Potentially deleterious FEP:*** *Uncertainty regarding influence on infiltration, aquifer flow and contaminant migration rates is considered in the base case and sensitivity and uncertainty analyses.*	

Chemical/geochemical processes and conditions (in geosphere)	2.2.08
Definition: FEPs related to the chemical and geochemical processes that affect the saturated and unsaturated zones, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g., Eh, pH, due to the excavation, construction, and long-term presence of the repository.	
Comment: *The hydrochemical regime refers to the groundwater chemistry in the geological formations in the repository region and the factors that control this. This requires knowledge of the groundwater chemistry including speciation, solubility, complexants, redox (reduction/oxidation) conditions, rock mineral composition and weathering processes, salinity, and chemical gradients. Changes of the hydrochemical regime due to the construction and/or presence of the repository are included.*	
Key concepts, examples, and related FEPs • *pH change* • *Redox potential changes* • *pH effects of cement on the environment, soil, etc.* • *Mineralization changes* • *Effect of nonradioactive solute plume*	
Application to E-Area: *Relevant to the E-Area PA. Changes in backfill soil versus natural conditions and potential influence of cementitious materials are considered (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Uncertainty regarding influence on degradation/corrosion of barriers and contaminant migration rates is considered in the base case and sensitivity and uncertainty analyses.*	

Biological/biochemical processes and conditions (in geosphere)	2.2.09
Definition: FEPs related to the biological and biochemical processes that affect the saturated and unsaturated zones, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g., microbe populations, due to the construction and long-term presence of the repository.	
Comment:	
Key concepts, examples, and related FEPs • *Generating of chelating agents* • *Influences on pH* • *Influences on redox potential* • *Change in microbe population* • *Microbiology-enhanced mobility*	
Application to E-Area: *Relevant to the E-Area PA and considered in Kds assumed for natural materials (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Uncertainty regarding influence on degradation/corrosion of barriers and uncertainty regarding contaminant migration rates.*	

Thermal processes and conditions (in geosphere)	2.2.10
Definition: FEPs related to the thermal processes that affect the saturated and unsaturated zones, and the overall evolution of conditions with time. This includes the effects of changes in condition, e.g., temperature, due to the construction and long-term presence of the repository.	
Comment: *Geothermal regime refers to sources of geological heat, the distribution of heat by conduction and transport (convection) in fluids, and the resulting thermal field or gradient. Changes of the geothermal regime due to the construction and/or presence of the repository are included.*	
Key concepts, examples, and related FEPs • *Bio-heat* • *Chemical reactions* • *Change in temperature*	
Application to E-Area: *Not relevant to the E-Area PA.* ***Potentially deleterious FEP:*** *Not applicable.*	

Gas sources and effects (in geosphere)	2.2.11
Definition: FEPs related to natural gas sources and production of gas within the geosphere and also the effect of natural and repository-produced gas on the geosphere, including the transport of bulk gases and the overall evolution of conditions with time.	
Comment: *Gas movement in the geosphere will be determined by many factors including the rate of production, gas permeability and solubility, and the hydrostatic pressure regime.*	
Examples • *Natural gas intrusion*	
Application to E-Area: *Not relevant to the E-Area PA.* ***Potentially deleterious FEP:*** *Not applicable.*	

Undetected features (in geosphere)	2.2.12
Definition: FEPs related to natural or man-made features within the geology that may not be detected during the site investigation.	
Comment: *Examples of possible undetected features are fracture zones, brine pockets, or old mine workings. Some physical features of the repository environment may remain undetected during site surveys and even during pilot tunnel excavations. The nature of the geological environment will indicate the likelihood that certain types of undetected features may be present, and the site investigation may be able to place bounds on the maximum size or minimum proximity to such features.*	
Key concepts, examples, and related FEPs • *Boreholes (drillings)* • *Mine shafts or mine galleries* • *Faults, shear zones, breccia pipes, lava tubes, intrusive dykes* • *Gas or brine pockets*	
Application to E-Area: *Not relevant. Aquifer is relatively shallow and site is well characterized.* ***Potentially deleterious FEP:*** *Not applicable—none identified.*	

Geological resources	2.2.13
Definition: FEPs related to natural resources within the geosphere, particularly those that might encourage investigation or excavation at or near the repository site.	
Comment: *Geological resources could include oil and gas, solid minerals, water, and geothermal resources. For a near-surface repository, quarrying of near-surface deposits, e.g., sand, gravel, or clay, may be of interest.*	
Key concepts, examples, and related FEPs • *Oil and gas* • *Sand, gravel, clay* • *Solid minerals* • *Water*	
Application to E-Area: *Relevant to the E-Area PA.* ***Potentially deleterious FEP:*** *Drilling for water resources assumed for inadvertent intrusion in the E-Area PA (see Section TBD of the PA).*	

SURFACE ENVIRONMENT	2.3
Definition: The features and processes within the surface environment, including near-surface aquifers and unconsolidated sediments but excluding human activities and behavior (see FEP 1.4 and 2.4).	
Comment: *"Surface Environment" is a subcategory in the International FEP List and is divided into individual FEPs.* *Note that FEPs 2.3.01 to 2.3.06 describe the features in the disposal system, in other words, a description of the features of the system as it is constructed, whereas FEPs 2.3.07 to 2.3.11 describe the processes or the changes in the disposal system.*	

Topography and morphology	2.3.01
Definition: FEPs related to the relief and shape of the surface environment and its evolution.	
Comment: *This FEP refers to local land form and land form changes with implications for the surface environment, e.g., plains, hills, valleys, and effects of river and glacial erosion thereon. In the long term, such changes may occur as a response to geological changes (see 1.3).*	
Key concepts, examples, and related FEPs • *Land forms* • *Hills* • *Valleys* • *Plains*	
Application to E-Area: *Relevant to the E-Area PA. Some of the E-Area structures and the closure cover change the local topography (see Section TBD of the PA)..* ***Potentially deleterious FEP****: Changes in surface drainage and recharge are considered in the base case and uncertainty analyses.*	

Soil and sediment	2.3.02
Definition: FEPs related to the characteristics of the soils and sediments and their evolution.	
Comment: *Different soil and sediment types, e.g., characterized by particle-size distribution and organic content, will have different properties with respect erosion/deposition and contaminant sorption, etc.*	
Key concepts, examples, and related FEPs • *Soil and sediment development* • *Soil conversion*	
Application to E-Area: *Relevant to the E-Area PA. Soil properties will impact closure cap performance with respect to surface run-off, silting in of lateral drainage layer, off-vault infiltration rates, and percolation through GCL.* ***Potentially deleterious FEP:*** *Changes in performance of the covers and resulting infiltration rates are considered in the base case and sensitivity and uncertainty analyses.*	

Aquifers and water-bearing features, near surface	2.3.03
Definition: FEPs related to the characteristics of aquifers and water-bearing features within a few meters of the land surface and their evolution.	
Comment: *Aquifers are water-bearing features, geological units, or near-surface deposits that yield significant amounts of water to wells or springs. The presence of aquifers and other water-bearing features will be determined by the geological, hydrological, and climatic factors.*	
Key concepts, examples, and related FEPs • *Weathered aquifer* • *Fractured aquifer* • *Description of aquifers in repository region* • *Sandy aquifer*	
Application to E-Area: *Not relevant to the E-Area PA due to depth of aquifer and use of 100 m receptor location.* ***Potentially deleterious FEP:*** *Not applicable.*	

Lakes, rivers, streams, and springs	2.3.04
Definition: FEPs related to the characteristics of terrestrial surface water bodies and their evolution.	
Comment: *Streams, rivers, and lakes often act as boundaries on the hydrogeological system. They usually represent a significant source of dilution for materials, including radionuclides entering these systems, but in hot, dry environments, where evaporation dominates, concentration is possible.*	
Key concepts, examples, and related FEPs *Description of lakes, rivers, streams, and springs in the repository region*	
Application to E-Area: *Not relevant to the E-Area PA owing to the DOE M 435.1-1 Chg 2 (DOE 2011a) assessment point and distance to surface water features influencing the aquifer.* ***Potentially deleterious FEP:*** *Not applicable.*	

Coastal features	2.3.05
Definition: FEPs related to the characteristics of coasts and the near shore, and their evolution. Coastal features include headlands, bays, beaches, spits, cliffs, and estuaries.	
Comment: *The processes operating on these features, e.g., active erosion, deposition, and longshore transport, determine the development of the system and may represent a significant mechanism for dilution or accumulation of materials (including radionuclides) entering the system.*	
Key concepts, examples, and related FEPs • *Description of the coastal features in the repository region* • *Headlands, bays, beaches, spits, cliffs, and estuaries* • *Coastal erosion* • *Saline intrusion* • *Salinity changes* • *Sedimentation* • *Resuspension* • *Volatilisation* • *Coastal surge* • *Storm* • *Tsunami* • *Groundwater discharge to estuary, shore* • *Bioturbation* • *Tidal currents* • *Sea spray* • *Behavior of coastal waters and marine sediment* • *Estuarine changes* • *Temperature change* • *Recharge* • *Bed-load processes* • *Flooding* • *Plant/animal uptake/metabolism* • *Sand dune encroachment* • *Coastal currents* • *Description of coastal features in vicinity of repository* • *Beach development*	
Application to E-Area: *Not relevant to the E-Area PA.* ***Potentially deleterious FEP:*** *Not applicable.*	

Marine features	2.3.06
Definition: FEPs related to the characteristics of seas and oceans, including the seabed, and their evolution. Marine features include oceans, ocean trenches, shallow seas, and inland seas.	
Comment: *Processes operating on these features, such as erosion, deposition, thermal stratification, and salinity gradients, determine the development of the system and may represent a significant mechanism for dilution or accumulation of materials (including radionuclides) entering the system.*	
Key concepts, examples, and related FEPs • *Ocean trenches* • *Shallow seas* • *Inland seas* • *Sedimentation* • *Resuspension* • *Volatilisation* • *Tidal currents* • *Marine currents* • *Marine sediment transport and deposition* • *Groundwater discharge towards sea* • *Sea spray* • *Sediment transport* • *Sea currents* • *Temperature change* • *Vertical mixing and isolation* • *Salinity changes* • *Plant/animal uptake/metabolism* • *Bed-load processes* • *Description of marine features in vicinity of repository* • *Recharge*	
Application to E-Area: *Not relevant to the E-Area PA.* ***Potentially deleterious FEP:*** *Not applicable.*	

Atmosphere	2.3.07
Definition: FEPs related to the characteristics of the atmosphere, including capacity for transport, and their evolution.	
Comment:	
Key concepts, examples, and related FEPs • *Physical transport of gases* • *Chemical and photochemical reactions* • *Aerosols and dust in the atmosphere*	
Application to E-Area: *Relevant to the performance objectives in DOE M 435.1-1 Chg 2 (DOE 2011a). Effects of atmospheric FEPs are also relevant in a stylized way through the infiltration rate. Pessimistic bias is introduced for atmospheric assumptions and calculations to bound uncertainty.* ***Potentially deleterious FEP:*** *Not applicable—none identified.*	

Vegetation	2.3.08
Definition: FEPs related to the characteristics of terrestrial and aquatic vegetation, both as individual plants and in mass, and their evolution.	
Comment:	
Key concepts, examples, and related FEPs • *Chemical changes caused by plants* • *Description of the vegetation in vicinity of repository*	

Application to E-Area: *Relevant to the E-Area PA estimation of infiltration rate. Changes in infiltration over time due to evolution of cover performance (see Section TBD of the PA).*   ***Potentially deleterious FEP:*** *Potential changes to vegetative cover type and the rate of pine tree intrusion may affect infiltration. Safety function is addressed in cover evolution assumptions and in sensitivity and uncertainty analyses.*

Animal populations	2.3.09
Definition: FEPs related to the characteristics of the terrestrial and aquatic animals, both as individual animals and as populations, and their evolution.	
Comment:	
Key concepts, examples, and related FEPs • *Animal diets* • *External contamination of animals* • *Description of the animal population in vicinity of repository*	
Application to E-Area: *Relevant to the E-Area PA. The effects of native animal populations (e.g., feral pigs) are embedded in the assumptions for biotic intrusion, consequences of which were screened based on insignificant impacts (see Section TBD of the PA).* ***Potentially deleterious FEP****: Can potentially impact cover infiltration safety function, bounded by degradation and variability in recharge assumed.*	

Meteorology	2.3.10
Definition: FEPs related to the characteristics of weather and climate, and their evolution.	
Comment: *Meteorology is characterized by precipitation, temperature, pressure, and wind speed and direction. The variability in meteorology should be included so that extreme events such as drought, flooding, storms, and snowmelt are identified.*	
Key concepts, examples, and related FEPs • *Rainfall* • *Snowfall* • *Flooding related to high precipitation* • *Storms related to strong winds* • *Climate fluctuation* • *Dew-freezing cycles* • *Wet-dry cycles* • *Seasonality* • *Hurricanes* • *High rainfall/flooding* • *Temperature* • *Tsunamis*	
Application to E-Area: *Relevant to the E-Area PA estimation of infiltration rate and atmospheric transport.* ***Potentially deleterious FEP:*** *Potential changes to climate may affect infiltration safety function and atmospheric transport. Pessimistic bias and sensitivity and uncertainty analyses are used.*	

Hydrological regime and water balance (near-surface)	2.3.11
Definition: FEPs related to near-surface hydrology at a catchment scale and also soil water balance, and their evolution.	
Comment: *The hydrological regime is a description of the movement of water through the surface and near-surface environment. It includes the movement of materials associated with the water such as sediments and particulates. Extremes such as drought, flooding, storms, and snowmelt may be relevant.*	
Key concepts, examples, and related FEPs • *Surface run-off to marines/estuaries* • *River flow to marines/estuaries* • *Evaporation* • *Evapotranspiration* • *Infiltration* • *Groundwater discharge to surface water, soils, estuaries/marines* • *Water discharge/recharge processes that affect radionuclide content* • *Stream silting* • *Change in lake or reservoir levels* • *Alkali flats* • *Stream and river flow changes* • *River meander* • *Stream flow*	
Application to E-Area: *Relevant to the E-Area PA estimation of infiltration in Section TBD of the PA.* ***Potentially deleterious FEP:*** *Potential changes in surface conditions may affect infiltration safety function. Pessimistic bias and sensitivity and uncertainty analyses are used to address.*	

Erosion and deposition	2.3.12
Definition: FEPs related to all the erosional and depositional processes that operate in the surface environment, and their evolution.	
Comment: *Relevant processes may include fluvial and glacial erosion and deposition, denudation, eolian erosion, and deposition. These processes will be controlled by factors such as the climate, vegetation, topography, and geomorphology.*	
Key concepts, examples, and related FEPs • *Deposition* • *Wind erosion related to storms* • *Erosion related to flooding* • *Erosion related to glaciation* • *Coastal erosion due to rise and fall of sea level (greenhouse effect)* • *Landsliding (instigate mechanical processes)* • *Erosion (instigate mechanical processes)* • *Erosion by wave action, landslides, or rockfalls* • *Agriculture erosion* • *Erosion of cover* • *Weathering*	
Application to E-Area: *Relevant to the E-Area PA estimation of infiltration and potential for intrusion via excavations. Needs to be considered for the longevity of safety functions for the engineered cover and management of surface water during operations. Procedures are in place to address surface water management. PA accounts for these measures as described in Section TBD.* ***Potentially deleterious FEP:*** *Potential changes in surface conditions may affect infiltration rates through the cover and could potentially impact assumptions related to excavation intrusion scenarios.*	

Ecological/biological/microbial systems	2.3.13
Definition: FEPs related to living organisms and relations among populations of animals and plants and their evolution.	
Comment: *Characteristics of the ecological system include the vegetation regime and natural cycles such as forest fires or flash floods that influence the development of the ecology. The plant and animal populations occupying the surface environment are an intrinsic component of its ecology. The wide range of processes that define the ecological system regulates their behavior and population dynamics. Human activities have significantly altered the natural ecology of most environments.*	
Key concepts, examples, and related FEPs • *Ecological and biological features* • *Chemical changes caused by microorganisms* • *Chemical changes caused by plants*	
Application to E-Area: *Relevant to the E-Area PA estimation of infiltration in Section TBD of the PA.* ***Potentially deleterious FEP:*** *Potential changes in ecology may affect infiltration safety function (e.g., vegetative cover type and the rate of pine tree intrusion). Considered using pessimistic bias and sensitivity and uncertainty analyses*	

Animal/Plant intrusion	2.3.14
Definition: Animal and plant intrusion leading to vault or trench disruption.	
Comment:	
Key concepts, examples, and related FEPs • *Seeds* • *Burrowing animals* • *Root intrusion (instigate mechanical processes)* • *Bio-intrusion by plants and animals* • *Animal intrusion (instigate mechanical processes)*	
Application to E-Area: *Relevant to the E-Area PA for evolution of cover performance and resulting changes in infiltration rate over time (see Section TBD in the PA).* ***Potentially deleterious FEP:*** *Intrusion of pine trees on the original vegetative grass cover, leading to increased infiltration because of root penetration through the composite geomembrane/GCL barrier layer. Feral pigs may also damage the vegetative cover leading to increased erosion and less evapotranspiration.*	

HUMAN BEHAVIOR	2.4
Definition: The habits and characteristics of the individuals or populations, e.g., critical groups, to whom exposures are calculated, not including intrusive or other activities that will have an impact on the performance of the engineered or geological barriers (see 1.4).	
Comment: "Human Behavior (passive)" is a subcategory in the International FEP List and is divided into individual FEPs.	

Human characteristics (physiology, metabolism)	2.4.01
Definition: FEPs related to characteristics, e.g., physiology and metabolism, of individual humans.	
Comment: *Physiology refers to body and organ form and function. Metabolism refers to the chemical and biochemical reactions, which occur within an organism, or part of an organism, in connection with the production and use of energy.*	
Key concepts, examples, and related FEPs • *Physiological and metabolism description of humans that will be the subject of the assessment.*	
Application to E-Area: *Dose factors addressed in DOE orders and standards [i.e. DOE-STD-1196-2011 (DOE 2011b)].* ***Potentially deleterious FEP:*** *Not applicable.*	

Adults, children, infants, and other variations	2.4.02
Definition: FEPs related to considerations of variability, in individual humans, of physiology, metabolism, and habits.	
Comment: *Children and infants, although similar to adults, often have characteristic differences, e.g., metabolism, respiratory rates, and habits (e.g., pica, ingestion of soil), that may lead to different exposure characteristics.*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Dose factors addressed in DOE orders and standards (i.e., DOE-STD-1196-2011).* ***Potentially deleterious FEP:*** *Not applicable.*	

Diet and fluid intake	2.4.03
Definition: FEPs related to intake of food and water by individual humans and the compositions and origin of intake.	
Comment: *The human diet refers to the range of food products consumed by humans.*	
Key concepts, examples, and related FEPs • *Diet* • *Description of the human diet and assumptions regarding quantities/volume*	
Application to E-Area: *Stylized assumptions of a more highly exposed individual used for the E-Area PA exposure analysis in Section TBD is consistent with DOE M 435.1-1 Chg 2 and related guidance.* ***Potentially deleterious FEP:*** *Not applicable.*	

Habits (non-diet-related behavior)	2.4.04
Definition: FEPs related to non-diet-related behavior of individual humans, including time spent in various environments, pursuit of activities, and uses of materials.	
Comment: *The human habits refer to the time spent in different environments in pursuit of different activities and other uses of materials. Agricultural practices and human factors such as culture, religion, economics, and technology will influence the diet and habits. Smoking, plowing, fishing, and swimming are examples of behavior that might give rise to particular modes of exposure to environmental contaminants.*	
Key concepts, examples, and related FEPs • *Human habits* • *Resource usage* • *Storage of products* • *Ventilation* • *Location of shielding factors* • *Impoundment of water* • *Fishing/fish farming* • *Bathing* • *Description of human habits and behavior* • *Air filtration*	
Application to E-Area: *Stylized exposures of a more highly exposed individual used for the E-Area PA exposure analysis in Section TBD is consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance.* ***Potentially deleterious FEP:*** *Not applicable.*	

Community characteristics	2.4.05
Definition: FEPs related to characteristics, behavior, and lifestyle of groups of humans that might be considered as target groups in an assessment.	
Comment: *Relevant characteristics might be the size of a group and degree of self-sufficiency in food stuffs/diet. For example, hunter/gathering describes a subsistence lifestyle employed by nomadic or semi-nomadic groups who roam relatively large areas of land hunting wild game and/or fish, and gathering native fruits, berries, roots, and nuts, to obtain their dietary requirements.*	
Key concepts, examples, and related FEPs • *Demographic changes* • *General human society description*	
Application to E-Area: *Stylized exposures of a more highly exposed individual used in the E-Area PA exposure analysis in Section TBD is consistent with DOE M 435.1-1 Chg 2 and related guidance.* ***Potentially deleterious FEP:*** *Not applicable.*	

Food and water processing and preparation	2.4.06
Definition: FEPs related to treatment of foodstuffs and water between raw origin and consumption.	
Comment: *Once a crop is harvested or an animal slaughtered, it may be subject to a variety of storage, processing, and preparational activities prior to human or livestock consumption. These may change the radionuclide distribution and/or content of the product, e.g., radioactive decay during storage, chemical processing, washing losses, and cooking losses during food preparation.* *Water sources may be treated prior to human or livestock consumption, e.g., chemical treatment and/or filtration.*	

Key concepts, examples, and related FEPs
• *Water filtration* • *Food processing*
Application to E-Area: *Stylized exposures of a more highly exposed individual used in the E-Area PA exposure analysis in Section TBD is consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance.* ***Potentially deleterious FEP:*** *Not applicable.*

Dwellings	2.4.07
Definition: FEPs related to houses or other structures or shelter in which humans spend time.	
Comment: *Dwellings are the structures that humans live in. The materials used in their construction and their location may be significant factors for determining potential radionuclide exposure pathways.*	
Key concepts, examples, and related FEPs • *Construction of buildings, houses* • *Ventilation* • *Location and shielding factors* • *Site occupation*	
Application to E-Area**:* *Stylized exposures of a more highly exposed individual used in the E-Area PA exposure analysis in Section TBD is consistent with DOE M 435.1-1 Chg 2 and related guidance.* ***Potentially deleterious FEP: *Not applicable.*	

Wild and natural land and water use	2.4.08
Definition: FEPs related to use of natural or semi-natural tracts of land and water such as forest, bush, and lakes.	
Comment: *Special foodstuffs and resources may be gathered from natural land and water, which may lead to significant modes of exposure.*	
Key concepts, examples, and related FEPs *Natural and semi-natural environments*	
Application to E-Area**:* *Stylized exposures of a more highly exposed individual used in the E-Area PA exposure analysis in Section TBD is consistent with DOE M 435.1-1 Chg 2 and related guidance.* ***Potentially deleterious FEP: *Not applicable.*	

Rural and agricultural land and water use (including fisheries)	2.4.09
Definition: FEPs related to use of permanently or sporadically agriculturally managed land and managed fisheries.	
Comment: *An important set of processes is that related to agricultural practices, their effects on land form, hydrology and natural ecology, and also their impact in determining uptake through food chains and other exposure paths.*	

Key concepts, examples, and related FEPs • *Use of land for agriculture* • *Plowing* • *Land use change* • *Fertilization* • *Fishing/ fish farming in estuaries/marines*	
Application to E-Area: *Stylized exposures of a more highly exposed individual used in the E-Area PA exposure analysis in Section TBD is consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance.* ***Potentially deleterious FEP:*** *Not applicable.*	

Urban and industrial land and water use	2.4.10
Definition: FEPs related to urban and industrial developments, including transport, and their effects on hydrology and potential contaminant pathways.	
Comment: *Human populations are concentrated in urban areas in modern societies. Significant areas of land may be devoted to industrial activities. Water resources may be diverted over considerable distances to serve urban and/or industrial requirements.*	
Key concepts, examples, and related FEPs • *Water works* • *Urban and industrial environments* • *Water extraction through wells* • *Water extraction for irrigation* • *De-salination of water* • *Human water extraction*	
Application to E-Area: *Not relevant to the E-Area PA analyses conducted for exposures under DOE M 435.1-1 Chg 2. Resident farmer scenario is considered to be sufficiently bounding (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Not applicable.*	

Leisure and other uses of environment	2.4.11
Definition: FEPs related to leisure activities, the effects on the surface environment, and implications for contaminant exposure pathways.	
Comment: *Significant areas of land, water, and coastal areas may be devoted to leisure activities. e.g., water bodies for recreational uses and mountains/wilderness areas for hiking and camping activities.*	
Key concepts, examples, and related FEPs • *Recreational land use* • *Impoundment of water for bathing* • *Beach development*	
Application to E-Area: *Not relevant to the E-Area PA analyses conducted for exposures under DOE M 435.1-1 Chg 2 (DOE 2011a). Resident farmer scenario is considered to be sufficiently bounding (see Section TBD of the PA).* ***Potentially deleterious FEP:*** *Not applicable.*	

RADIONUCLIDE/CONTAMINANT FACTORS	3
Definition: FEPs that take place in the disposal system domain that directly affect the release and migration of radionuclides and other contaminants or directly affect the dose to members of a critical group from given concentrations of radiotoxic and chemotoxic species in environmental media.	
Comment: *" Radionuclide/Contaminant Factors" is a category in the International FEP List and is divided into subcategories.*	

CONTAMINANT CHARACTERISTICS	3.1
Definition: The characteristics of the radiotoxic and chemotoxic species that might be considered in a post-closure safety assessment.	
Comment: *"Contaminant Characteristics" is a subcategory in the International FEP List and is divided into individual FEPs.*	

Radioactive decay and ingrowth	3.1.01
Definition: Radioactivity is the spontaneous disintegration of an unstable atomic nucleus resulting in the emission of subatomic particles. Radioactive isotopes are known as radionuclides. Where a parent radionuclide decays to a daughter radionuclide so that the population of the daughter radionuclide increases, this is known as ingrowth.	
Comment: *In post-closure assessment models, radioactive decay chains are often simplified, e.g., by neglecting the shorter-lived radionuclides in transport calculations or adding dose contributions from shorter-lived radionuclides to dose factors for the longer-lived parent in dose calculations.*	
Key concepts, examples, and related FEPs • *Production of aqueous progeny* • *Radon emanation*	
Application to E-Area: *Relevant to the E-Area PA.* ***Potentially deleterious FEP****: Not applicable—none identified. Decay and ingrowth are inherently included in the calculations (see Section TBD of the PA).*	

Chemical/organic toxin stability	3.1.02
Definition: FEPs related to chemical stability of chemotoxic species.	
Comment:	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Not relevant to the E-Area PA. Organics are insignificant due to limitations in waste acceptance criteria.* ***Potentially deleterious FEP:*** *Not applicable.*	

Inorganic solids/solutes	3.1.03
Definition: FEPs related to the characteristics of inorganic solids/solutes that may be considered.	
Comment:	
Key concepts, examples, and related FEPs • *Source terms content*	
Application to E-Area: *Relevant to the E-Area PA.* ***Potentially deleterious FEP:*** *Not applicable—none identified.*	

Volatiles and potential for volatility	3.1.04
Definition: FEPs related to the characteristics of radiotoxic and chemotoxic species that are volatile or have the potential for volatility in repository or environmental conditions.	
Comment: *Some radionuclides may be isotopes of gaseous elements (e.g., Kr isotopes) or may form volatile compounds. Gaseous radionuclides or species may arise from chemical or biochemical reactions, e.g., metal corrosion to yield hydrogen gas and microbial degradation of organic material to yield methane and carbon dioxide.*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Relevant to the E-Area PA. Addressed in screening level atmospheric release and radon release analyses (see Section TBD of the E-Area PA).* ***Potentially deleterious FEP:*** *Not applicable—none identified.*	

Organics and potential for organic forms	3.1.05
Definition: FEPs related to the characteristics of radiotoxic and chemotoxic species that are organic or have the potential to form organics in repository or environmental conditions.	
Comment:	
Key concepts, examples, and related FEPs • *Source term content*	
Application to E-Area: *Not relevant to the E-Area PA. Organics are insignificant due to restrictions in the waste acceptance criteria.* ***Potentially deleterious FEP:*** *Not applicable.*	

Noble gases	3.1.06
Definition: FEPs related to the characteristics of noble gases.	
Comment: *Radon and thoron are special cases (see FEP 3.3.08).*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Not relevant to the E-Area PA.* ***Potentially deleterious FEP***: *Not applicable—none identified.*	

CONTAMINANT RELEASE/MIGRATION FACTORS	3.2
Definition: The processes that directly affect the release and/or migration of radionuclides in the disposal system domain.	
Comment: *"Contaminant Release/Migration Factors" is a subcategory in the International FEP List and is divided into individual FEPs.*	

Dissolution, precipitation, and crystallisation, contaminant	3.2.01
Definition: FEPs related to the dissolution, precipitation, and crystallisation of radiotoxic and chemotoxic species under repository or environmental conditions.	
Comment: *Dissolution is the process by which constituents of a solid dissolve into solution. Precipitation and crystallisation are processes by which solids are formed out of liquids. Precipitation occurs when chemical species in solution react to produce a solid that does not remain in solution. Crystallization is the process of producing pure crystals of an element, molecule, or mineral from a fluid or solution undergoing a cooling process.*	
Key concepts, examples, and related FEPs • *Chemical reactions caused by dissolution and precipitation of radionuclides* • *Change in mineralization* • *Caused by chemical interaction of vault material with pore water* • *Caused by chemical interaction of backfill with pore water* • *Caused by chemical interaction of nonradioactive waste with radioactive waste* • *Caused by a change in temperature*	
Application to E-Area: *Relevant to the E-Area PA.* ***Potentially deleterious FEP***: *Potential rapid waste dissolution or oxidation may affect the safety function of the waste form. Pessimistic bias is used assuming immediate release for most waste forms as described in Section TBD of the PA. Justification is required for any special cases.*	

Speciation and solubility, contaminant	3.2.02
Definition: FEPs related to the chemical speciation and solubility of radiotoxic and chemotoxic species in repository or environmental conditions.	
Comment: *The solubility of a substance in aqueous solution is an expression of the degree to which it dissolves. Factors such as temperature and pressure affect solubility, as do the pH and redox conditions. These factors affect the chemical form and speciation of the substance. Thus, different species of the same element may have different solubilities in a particular solution. Pore water and groundwater speciation and solubility are very important factors affecting the behavior and transport of radionuclides.*	
Key concepts, examples, and related FEPs • *Species equilibrium change caused by change in temperature* • *Solubility change caused by change in temperature* • *Solubility* • *Solubility change caused by chemical interaction between waste and pore water*	
Application to E-Area: *Limited relevance for the E-Area PA for a small number of solubility controlled waste forms and radionuclides (see Section TBD of the PA).* ***Potentially deleterious FEP****: Uncertainties in chemical behavior may affect the chemical safety functions. Pessimistic bias is generally applied assuming all species are soluble.*	

Sorption/desorption processes, contaminant	3.2.03
Definition: FEPs related to sorption/desorption of radiotoxic and chemotoxic species in repository or environmental conditions.	
Comment: *Sorption describes the physico-chemical interaction of dissolved species with a solid phase. Desorption is the opposite effect. Sorption processes are very important for determining the transport of radionuclides in groundwater. Sorption is often described by a simple Kd which is the ratio of solid phase radionuclide concentration to that in solution. This assumes that sorption is reversible, reaches equilibrium rapidly, and is independent of variations in water chemistry or mineralogy along the flow path, the solid-water ratio, or concentrations of other species. More sophisticated approaches involve the use of sorption isotherms.*	
Key concepts, examples, and related FEPs • *Sorption* • *Chemical reactions caused by adsorption or desorption* • *Anion exclusion effects* • *Effect of sorption* • *Caused by chemical interaction of waste with pore water* • *Caused by chemical interaction of nonradioactive waste with radioactive waste* • *Sorption change caused by change in temperature*	
Application to E-Area: *Relevant to the E-Area PA for chemical behavior of contaminants in specific wastes (see Section TBD of the PA).* ***Potentially deleterious FEP****: Uncertainties in chemical behavior may affect the chemical safety functions and variability in Kd for key radionuclides is addressed with pessimistic bias and sensitivity and uncertainty analyses.*	

Colloids, contaminant interactions, and transport with	3.2.04
Definition: FEPs related to the transport of colloids and interaction of radiotoxic and chemotoxic species with colloids in repository or environmental conditions.	
Comment: *Colloids are particles in the nanometer to micrometer size range that can form stable suspensions in a liquid phase. Metastable solid phases are unstable thermodynamically but exist due to the very slow kinetics of their alteration into more stable products. Colloids are present in groundwaters and may also be produced during degradation of the wastes or engineered barrier materials.* *Colloids may influence radionuclide transport in a variety of ways: retarding transport by sorption of aqueous radionuclide species and subsequent filtration or enhancing transport by sorption and transport with flowing groundwater.*	
Key concepts, examples, and related FEPs • *Colloid formation* • *Caused by chemical interaction of waste with pore water* • *Caused by chemical interaction of backfill with pore water* • *Colloid transport* • *Caused by chemical interaction of nonradioactive waste with radioactive waste*	
Application to E-Area: *Not relevant to the E-Area PA for transport behavior of contaminants.* ***Potentially deleterious FEP****: Potential for accelerated transport facilitated by colloids has been studied for SRS subsurface sediments. The number of colloids would need to increase by a couple orders of magnitude before it is likely that the groundwater concentration of strongly sorbing contaminants, such as Pu, Ac, Am, Cm, Eu, or Th, would increase due to the rise of their association with colloids.*	

Chemical/complexing agents, effects on contaminant speciation/transport	3.2.05
Definition: FEPs related to the modification of speciation or transport of radiotoxic and chemotoxic species in repository or environmental conditions due to association with chemical and complexing agents.	
Comment: *This FEP refers to any chemical agents that are present in the repository system and the effects that they may have on the release and migration of radionuclides from the repository environment. Chemical agents may be present in the wastes or in repository materials or introduced, e.g., from spillage during repository construction and operation, e.g., oil, hydraulic fluids, organic solvents. Chemical agents may be used during construction and operation, e.g., in drilling fluids, as additives to cements and grouts, etc.*	
Key concepts, examples, and related FEPs • *Effects of chelating agents* • *Caused by chemical interaction of waste with pore water* • *Caused by chemical interaction of backfill with pore water* • *Caused by chemical interaction of nonradioactive waste with radioactive waste* • *Microbial*	
Application to E-Area: *Potentially relevant to the E-Area PA for chemical safety functions but of minimal effect owing to low concentrations of organic material in residual waste.* ***Potentially deleterious FEP****: Not applicable.*	

Microbial/biological/plant-mediated processes, contaminant	3.2.06
Definition: FEPs related to the modification of speciation or phase change due to microbial/biological/plant activity.	
Comment: *Microbial activity may facilitate chemical transformations of various kinds.*	
<u>Key concepts, examples, and related FEPs</u> • *Microbial-enhanced mobility*	
<u>Application to E-Area:</u> *Potentially relevant to the E-Area PA for chemical safety functions but of minimal effect owing to low concentrations of organic material, providing negligible energy source for microbes.* ***<u>Potentially deleterious FEP</u>****: Not applicable.*	

Water-mediated transport of contaminants	3.2.07
Definition: FEPs related to transport of radiotoxic and chemotoxic species in groundwater and surface water in aqueous phase and as sediments in surface water bodies.	
Comment: *Water-mediated transport of radionuclides includes all processes leading to transport of radionuclides in water. Radionuclides may travel in water as aqueous solutes (including dissolved gases), associated with colloids (see FEP 3.2.04), or, if flow conditions permit, with larger particulates/sediments.*	
<u>Key concepts, examples, and related FEPs</u> • *Multiphase transport processes* • *Surface water aqueous transport* • *Transport by surface run-off* • *Transport in water bodies* • *Percolation* • *Capillary rise* • *Groundwater transport* • *Infiltration* • *Dual flow systems* • *Advection, i.e., movement with the bulk movement of the fluid (in fractures, failed joints, and matrix)* • *Molecular diffusion, i.e., random movement of individual atoms or molecules within the fluid* • *Dispersion, i.e., the spread of spatial distribution with time due to differential advection* • *Matrix diffusion, i.e., the diffusion or micro-advection of solute/colloids, etc., into non-flowing pores* • *Transport of colloids* • *Percolation, i.e., movement of the fluid under gravity* • *Transport processes between surface water and porous media* • *Isotopic dilution* • *Mass dilution* • *Discharge of radionuclides to sea* • *Fracture-matrix interaction* • *Discharge of radionuclides to foreshore* • *Transport of suspended sediment*	
<u>Application to E-Area:</u> *Relevant and addressed in the E-Area PA (see Section TBD).* ***<u>Potentially deleterious FEP</u>****: Uncertainties may lead to decrease in effectiveness of safety functions. Considered with assumptions in base case and sensitivity and uncertainty analyses.*	

Solid-mediated transport of contaminants	3.2.08
Definition: FEPs related to transport of radiotoxic and chemotoxic species in solid phase, for example, large-scale movements of sediments, landslide, solifluction, and volcanic activity.	
Comment:	
<u>Key concepts, examples, and related FEPs</u> • *Resuspension/deposition* • *Landslides* • *Rock falls* • *Rain splash* • *Transport by suspended sediments (sedimentation)* • *Erosion* • *Solid material release* • *Solid phase transport by water* • *Wet deposition* • *Washout*	
<u>Application to E-Area:</u> *Not relevant to the E-Area PA owing to depth of disposal and facility stability.* ***<u>Potentially deleterious FEP</u>****: Not applicable.*	

Gas-mediated transport of contaminants	3.2.09
Definition: FEPs related to transport of radiotoxic and chemotoxic species in gas or vapor phase or as fine particulate or aerosol in gas or vapor.	
Comment: *Radioactive gases may be generated from the wastes, e.g., C-14-labeled carbon dioxide or methane. Radioactive aerosols or particulates may be transported along with nonradioactive gases, or gases may expel contaminated groundwater ahead of them*	
<u>Key concepts, examples, and related FEPs</u> • *Gas mediated water flow* • *Gaseous release* • *Atmospheric gas transport* • *Gas-phase processes* • *Diffusion* • *Atmospheric aerosol transport* • *Barometric pumping* • *Overpressurization*	
<u>Application to E-Area:</u> *Relevant and addressed in the E-Area PA using relatively bounding assumptions (see Section TBD of the PA).* ***<u>Potentially deleterious FEP</u>****: Not applicable—none identified.*	

Atmospheric transport of contaminants	3.2.10
Definition: FEPs related to transport of radiotoxic and chemotoxic species in the air as gas, vapor, fine particulate, or aerosol.	
Comment: *Radionuclides may enter the atmosphere from the surface environment as a result of a variety of processes, including transpiration, suspension of radioactive dusts and particulates, or as aerosols. The atmospheric system may represent a significant source of dilution for these radionuclides. It may also provide exposure pathways, e.g., inhalation and immersion.*	
<u>Key concepts, examples, and related FEPs</u> • *Sea spray* • *Aerosol transport due to waves, wind*	

Application to E-Area: *Relevant and addressed in the E-Area PA using relatively bounding assumptions for base case and inadvertent intruder (see Sections TBD of the PA).*

Potentially deleterious FEP*: Not applicable—none identified.*

Animal, plant, and microbe-mediated transport of contaminants — 3.2.11

Definition: FEPs related to transport of radiotoxic and chemotoxic species as a result of animal, plant, and microbial activity.

Comment: *Burrowing animals, deep-rooting species, and movement of contaminated microbes are included.*

Key concepts, examples, and related FEPs

- *Discharge of radionuclides to soil layer (biotic intrusion)*
- *Animal/plant intrusion*
- *Transport mediated by flora and fauna*
- *Uptake and desorption*
- *Bioturbation*
- *Intake and emission by animals*

Application to E-Area: *Potentially relevant and addressed in the E-Area PA biotic transport screening analysis showing minimal impacts (see Section TBD).*

Potentially deleterious FEP*: Not applicable—none identified.*

Human-action-mediated transport of contaminants — 3.2.12

Definition: FEPs related to transport of radiotoxic and chemotoxic species as a direct result of human actions.

Comment: *Human-action-mediated transport of contaminants includes processes such as drilling into or excavation of the repository; the dredging of contaminated sediments from lakes, rivers, and estuaries; and placing them on land. Earthworks and dam construction may result in the significant movement of solid material from one part of the biosphere to another. Plowing results in the mixing of the top layer of agricultural soil, usually on an annual basis.*

Key concepts, examples, and related FEPs

- *Dredging of sediments*
- *Plowing*
- *Water abstraction*

Application to E-Area: *Addressed in the E-Area PA exposure analysis in a stylized manner consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance.*

Potentially deleterious FEP*: Not applicable.*

Foodchains, uptake of contaminants — 3.2.13

Definition: FEPs related to incorporation of radiotoxic and chemotoxic species into plant or animal species that are part of the possible eventual food chain to humans.

Comment: *Plants may become contaminated either as a result of direct deposition of radionuclides onto their surfaces or indirectly as a result of uptake from contaminated soils or water via the roots. Animals may become contaminated with radionuclides as a result of ingesting contaminated plants or directly as a result of ingesting contaminated soils, sediments, and water sources, or via inhalation of contaminated particulates, aerosols, or gases.*

Key concepts, examples, and related FEPs

- *Plant/animal uptake in a marine/estuarine*
- *External contamination of animals*
- *Crops and natural and semi-natural flora and fauna*
- *Internal transfer of radionuclides within animals*

Application to E-Area: *Addressed in the E-Area PA exposure analysis in a stylized manner consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance (see Section TBD).*

Potentially deleterious FEP*: Not applicable.*

EXPOSURE FACTORS	3.3

Definition: Processes and conditions that directly affect the dose to members of the critical group, from given concentrations of radionuclides in environmental media.

Comment: *"Exposure Factors" is a subcategory in the International FEP List and is divided into individual FEPs.*

Drinking water, foodstuffs, and drugs, contaminant concentrations	3.3.01

Definition: FEPs related to the presence of radiotoxic and chemotoxic species in drinking water, foodstuffs, or drugs that may be consumed by humans.

Comment:

Key concepts, examples, and related FEPs

- *Internal transfer of radionuclides within animals*
- *Crops and natural and semi-natural flora and fauna*

Application to E-Area: *Addressed in the E-Area PA exposure analysis in Section TBD in a stylized manner consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance.*

Potentially deleterious FEP*: Not applicable.*

Environmental media, contaminant concentrations	3.3.02

Definition: FEPs related to the presence of radiotoxic and chemotoxic species in environmental media other than drinking water, foodstuffs, or drugs.

Comment: *The comparison of calculated contaminant concentrations in environmental media with naturally occurring concentrations of similar species or species of similar toxic potential may provide alternative or additional criteria for assessment less dependent on assumptions of human behavior.*

Key concepts, examples, and related FEPs

- *None*

Application to E-Area: *Addressed in the E-Area PA exposure analysis in Section TBD in a stylized manner consistent with DOE M 435.1-1 Chg 2 and related guidance.*

Potentially deleterious FEP*: Not applicable.*

Non-food products, contaminant concentrations	3.3.03
Definition: FEPs related to the presence of radiotoxic and chemotoxic species in human-manufactured materials or environmental materials that have special uses, e.g., clothing, building materials, and peat.	
Comment: *Contaminants may be concentrated in non-food products to which humans are exposed, e.g., building materials, natural fibers or animal skins used in clothing, and peat used for fuel.*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Not relevant to the E-Area PA. Not considered in DOE O 435.1 Chg 1 (DOE 2007) PAs. Resident farmer is considered to be reasonably bounding.* ***Potentially deleterious FEP****: Not applicable.*	

Exposure modes	3.3.04
Definition: FEPs related to the exposure of man (or other organisms) to radiotoxic and chemotoxic species.	
Comment:	
Key concepts, examples, and related FEPs • *Direct radiation from airborne plumes of radioactive materials* • *Injection through wounds* • *Cutaneous absorption of some species.* • *External exposure through water or sediment* • *Dermal exposure* • *Immersion in contaminated water bodies* • *Ingestion (internal exposure) from drinking or eating contaminated water or foodstuffs* • *Inhalation (internal exposure) from inhaling gaseous or particulate radioactive materials* • *External exposure as a result of direct irradiation from radionuclides deposited on, or present on, the ground, buildings, or other objects.*	
Application to E-Area: *Addressed in the E-Area PA exposure analysis in Section TBD in a stylized manner consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance.* ***Potentially deleterious FEP****: Not applicable.*	

Dosimetry	3.3.05
Definition: FEPs related to the dependence between radiation or chemotoxic effect and amount and distribution of radiation or chemical agent in organs of the body.	
Comment: *Dosimetry involves the estimation of radiation dose to individual organs, tissues, or the whole body as a result of exposure to radionuclides. The radiation dose will depend on: the form of exposure, e.g., ingestion or inhalation of radionuclides leading to internal exposure or proximity to concentrations of radionuclides leading to external exposure; the metabolism of the radioelement and physico-chemical form if inhaled or ingested, which will determine the extent to which the radionuclide may be taken up and retained in body tissues; and the energy and type of radioactive emissions of the radionuclide, which will affect the distribution of energy within tissues of the body.*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Addressed in the E-Area PA exposure analysis in Section TBD in a stylized manner consistent with DOE O 451 Chg 3, DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance.* ***Potentially deleterious FEP****: Not applicable.*	

Radiological toxicity/effects	3.3.06
Definition: FEPs related to the effect of radiation on man or other organisms.	
Comment: *Radiation effects are classified as somatic (occurring in the exposed individual), genetic (occurring in the offspring of the exposed individual), stochastic (the probability of the effect is a function of dose received), and non-stochastic (the severity of the effect is a function of dose received and no effect may be observed below some threshold).*	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Considered consistent with requirements in DOE M 435.1-1 Chg 2 and related guidance (see Section TBD).* ***Potentially deleterious FEP****: Not applicable.*	

Non-radiological toxicity/effects	3.3.07
Definition: FEPs related to the effects of chemotoxic species on man or other organisms.	
Comment:	
Key concepts, examples, and related FEPs • *None*	
Application to E-Area: *Not relevant to radiological endpoints in DOE O 435.1 Chg 1 (DOE 2007) PAs.* ***Potentially deleterious FEP****: Not applicable.*	

Radon and radon daughter exposure	3.3.08
Definition: FEPs related to exposure to radon and radon daughters.	
Comment: *Radon and radon daughter exposure is considered separately from exposure to other radionuclides, because the behavior of radon and its daughter, and the modes of exposure, are different from other radionuclides.* *Rn-222 is the immediate daughter of Ra-226. Rn-222 is a noble gas with a half-life of about 4 days and decays through a series of very short-lived radionuclides (radon daughters), with half-lives of 27 minutes or less, to a lead isotope (Pb-210) with a half-life of 21 years. The principal mode of exposure is through the inhalation of radon daughters attached to dust particles, which may deposit in the respiratory system.*	
Key concepts, examples, and related FEPs *Radon emanation*	
Application to E-Area: *Evaluated as radon flux endpoint in the E-Area PA consistent with DOE M 435.1-1 Chg 2 (DOE 2011a) and related guidance (see Section TBD of the PA).* ***Potentially deleterious FEP****: Not applicable.*	

This page intentionally left blank.

Distribution:

alex.cozzi@srnl.doe.gov
david.crowley@srnl.doe.gov
a.fellinger@srnl.doe.gov
samuel.fink@srnl.doe.gov
connie.herman@srnl.doe.gov
dennis.jackson@srnl.doe.gov
patricia.lee@srnl.doe.gov
Joseph.Manna@srnl.doe.gov
daniel.mccabe@srnl.doe.gov
Gregg.Morgan@srnl.doe.gov
frank.pennebaker@srnl.doe.gov
Amy.Ramsey@srnl.doe.gov
William.Ramsey@SRNL.DOE.gov
michael.stone@srnl.doe.gov
Boyd.Wiedenman@srnl.doe.gov

sebastian.aleman@srnl.doe.gov
paul.andrews@srs.gov
dan.burns@srs.gov
tom.butcher@srnl.doe.gov
kerri.crawford@srs.gov
Thomas.Danielson@srnl.doe.gov
kenneth.dixon@srnl.doe.gov
James.Dyer@srnl.doe.gov
peter.fairchild@srs.gov
Scott.Germain@srs.gov
luther.hamm@srnl.doe.gov
thong.hang@srnl.doe.gov
daniel.kaplan@srnl.doe.gov
Dien.Li@srs.gov
steven.mentrup@srs.gov
verne.mooneyhan@srs.gov
ralph.nichols@srnl.doe.gov
Virgina.Rigsby@srs.gov
Jansen.Simmons@srs.gov
Ira.Stewart@srs.gov
Tad.Whiteside@srnl.doe.gov
Jennifer.Wohlwend@srnl.doe.gov

Rogerseitz5@gmail.com

Terry.Foster@srnl.doe.gov
Records Administration (EDWS)