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ANL-WIS-MD-000024 REV 01

February 2008

Postclosure Nuclear Safety Design Bases

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Change History

10. Revision No. and Addendum No.	11. Description of Change
REV 00	Initial issue.
REV 01	Complete revision. Revised to reflect transition of work scope to the Lead Lab including development of Rev 01 of ANL-WIS-MD-000024 with improved feeds to Safety Analysis Report Sections 1.9 and 2.1.

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FIGURES

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ACRONYMS

BSC	Bechtel SAIC Co. LLC
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EBS	Engineered Barrier System
FEPs	features, events, and processes
HLW	high-level (radioactive) waste
ITBC	important to barrier capability
ITWI	important to waste isolation
LNB	Lower Natural Barrier
NRC	U.S. Nuclear Regulatory Commission
PGV	peak ground velocity
PoNSDB	Postclosure Nuclear Safety Design Basis
RMEI	reasonably maximally exposed individual
SSC	structure, system, and component
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
TSPA	total system performance assessment
TWP	technical work plan
UNB	Upper Natural Barrier
YMP	Yucca Mountain Project

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1. PURPOSE

This report, the Postclosure Nuclear Safety Design Basis (PoNSDB) has been prepared to meet regulatory requirements of the 10 CFR 63.113(a) and 63.115 [DIRS 180319]), and to provide a risk-informed analysis of the postclosure technical basis for multiple barriers. Specifically, 10 CFR 63.113(a) [DIRS 180319] provides requirements for multiple barriers as part of performance objectives for the geologic repository after permanent closure; and 10 CFR 63.115 [DIRS 180319] provides requirements for the identification of, description of, and technical basis for the multiple barriers.

This document provides extensive lists of features of the barriers and rationale as to why these barriers are important to waste isolation (ITWI) and why the features important to barrier capability (ITBC) may support such an ITWI classification (if that feature/component contributes significantly to barrier capability relative to the other features/components of the barrier). It also describes some features that are ITBC that are not significant enough to support that feature being classified as ITWI. The methodology for the identification of ITBC core and control parameter characteristics and ITWI barrier features/components is described in this document. The process starts with the examination of features, events, and processes (FEPs) and their screening justifications. As the FEPs form the basis of technical support for the TSPA, this approach is efficient and comprehensive for this purpose. The description of the FEPs and screening justifications suggest a division of the repository system into barriers, and barriers into features/components. Parameter characteristics associated with each FEP relative to the features/components of each barrier are identified. The FEP screening justification supports the further identification of parameter characteristics that are ITBC relative to each barrier feature/component. Finally, if the features/components are associated with at least one ITBC parameter characteristic, and that feature/component contributes significantly to the barrier capability relative to the other features/components of the barrier, then that feature/component is ITWI. All barriers are ITWI and are associated with one or more ITWI feature/components.

This document identifies features/components of barriers that are important to waste isolation as well as features/components and parameter characteristics that are important to barrier capability (definitions developed specifically for use in this report are contained in Section 6.1.1). Capability as used in this document is not synonymous with performance. Performance, as defined in this report, is the realization of a capability as modeled in the Total System Performance Assessment (TSPA). Capability is broadly used to refer to the ability or potential of a feature/component to contribute to a function of a barrier. The identification of a parameter characteristic as contributing to the capability of a barrier's feature/component is not intended to suggest any importance of the capability or to suggest that the feature/component is important to waste isolation. The importance of the capability is instead identified through its ITBC status, and the importance of the barrier and its features/components are identified through their ITWI status. While the features/components of all ITWI barriers and their associated ITBC parameter characteristics are considered in the Performance Assessment, some capabilities and features/components may not necessarily be fully realized in the TSPA because some reasonable conservative assumptions are invoked during TSPA implementation or because a capability may be masked by the performance of another capability. Features of the engineered system are identified as structure, system, and component (SSC) in design. For this report, the term features/components will be used to maintain uniformity of terminology between the barriers, some of which are natural. Parameter characteristics are aspects of the barrier feature/component that contribute to the feature/component capability, and support the technical basis of the TSPA. Parameter characteristics are categorized into two groups. The first group, 'core parameter characteristics,' contains those characteristics that are not controlled or manipulated by design, construction, or operations and contribute to barrier capability. The second group, 'control parameter characteristics,' contains those characteristics that are able to be manipulated, controlled, and monitored by design, construction, or operations and contribute to barrier capability. A core and control parameter characteristic is further specified to be ITBC if it 1) prevents or substantially reduces the rate of movement of water from the repository to the accessible environment; 2) prevents the release or substantially reduces the release rate of radionuclides from the waste; 3) prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment, or 4) prevents or substantially reduces the consequences of disruptive events (e.g. criticality).

The major activities documented in this report are two: (1) conduct the barrier analysis, and (2) develop core parameter characteristics and analyze control parameter characteristics. For natural and engineered barriers that are ITWI, the tasks associated with these two activities:

1. Describe the three ITWI barriers (Upper Natural Barrier (UNB), the Engineered Barrier System (EBS), and the Lower Natural Barrier (LNB)).

2. Evaluate barrier capability, including assessment of the technical bases, and evaluation of ITBC parameter characteristics and supporting the ITWI determination.

This report serves as a companion document to *Nuclear Safety Design Bases for License Application* (BSC 2005 [DIRS 175546]). A second report, *Postclosure Modeling and Analyses Design Parameters* (BSC 2008 [DIRS 183627]), complements this report because of its emphasis on derived requirements and interface control parameters related to postclosure design components. This scientific analysis was conducted consistent with the *Technical Work Plan for: Postclosure Nuclear Safety Design Bases* (SNL 2007 [DIRS 182648]) except as noted in Section 2.

This analysis is intended to identify and document technical interfaces between postclosure analyses and repository design regarding the safety classification of systems, structures and components, and the design bases for SSCs classified as important to waste isolation.

2. QUALITY ASSURANCE

The analysis documented herein is subject to the Office of Civilian Radioactive Waste Management Quality Assurance Program as documented in the relevant technical work plan (TWP) TWP-WIS-MD-000015 (SNL 2007 [DIRS 182648], Section 8.1). This work constitutes an analysis report, therefore, the document was prepared in accordance with SCI-PRO-005, *Scientific Analyses and Calculations.* Approved quality assurance procedures and guidance documents were used to conduct and document the activities described in this report as outlined in the TWP (SNL 2007 [DIRS 182648], Section 4.1). The TWP (SNL 2007 [DIRS 182648], Section 8.4) also identifies applicable controls for the electronic management of data during the analysis and documentation activities. There are three deviations from the TWP. The first deviation is that a methodology for determination of features, events, and processes that are important to performance is now covered in an addendum to the *Performance Confirmation* Plan (SNL 2008 [DIRS 184797], Appendix A). The methodology (specifically important to dose, and significance to uncertainty) as originally intended in the TWP (SNL 2007 [DIRS 182648]) for this product is now covered in that document (SNL 2008 [DIRS 184797], Appendix A). The second deviation is that, the TWP stated: “Finally, the PoNSDB document will identify performance confirmation activities, as applicable, for FEPs that are ITBC.” That information is now better presented in the *Performance Confirmation Plan* (SNL 2008 [DIRS 184797], Appendix A) and is not presented in this document. The third deviation is that, because changes are so extensive in this revision, all comments from November 2006 LP 7.5Q OCRWM review of ANL-WIS-MD-000024 were not directly addressed. Technical issues were considered and resolved. Editorial comments were overcome by completely new text and could not be mapped directly to the new text.

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3. USE OF SOFTWARE

No software required to be qualified in accordance with IM-PRO-003, *Software Management* was used in developing this report. Standard functions of Microsoft Excel 2000 commercial-off-the-shelf software were used, but only for organizational purposes.

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4. INPUTS

This report uses the information and decisions developed in other reports as references and utilizes professional judgment. This work does not involve separate modeling or analyses using previously developed models and, as such, this report does not require model validation.

All direct inputs (data, parameters, and other information) used in this scientific analysis are identified in Section 4.1. Direct inputs used in this analysis report were obtained from controlled source documents and other sources in accordance with SCI-PRO-004, *Managing Technical Product Inputs*. NUREG-1804 (NRC 2003 [DIRS 163274]) lists some specific acceptance criteria that are addressed in this report which are identified in Section 4.2.

4.1 DIRECT INPUTS

Direct inputs used in the analyses are listed in Table 4-1. Indirect inputs are described in Section 6. These sources are appropriate for this analysis because they are dedicated to the technical understanding of processes and/or events that act on the features comprising the three barriers (UNB, EBS, and LNB) considered in this analysis. This type of input is directly applicable to the analysis discussed in Section 6 and Appendix A.

All data used from external sources and non-conclusion sections of direct input sources have either been qualified for intended use in *Features, Events, and Processes for the Total System Performance Assessment: Analyses* (SNL 2008 [DIRS 183041]) or other Analysis/Model Reports, as cited. The only use in this report is to analyze barrier capabilities, not to present any new information.

Table 4-1. Source of Inputs

Citation	Source Title	Specifically Used From	Specifically Used In (this AMR)	Input Description
NAC 534, 2006 [DIRS 151873]	NAC (Nevada Administrative Code) 534	NAC 534.4371	Table A-1	Existing open site investigation boreholes are expected to be backfilled and plugged to the upper 10 ft with cement according to NAC 534.4371
BSC 2004 [DIRS 166107]	Drift Degradation Analysis	Sections 6.3, 6.3.1.2, 6.4.2.2, 6.3.1.2, and 6.4.2.2	Table A-2	Thermal-hydrologic effects from drift collapse induced by a seismic event include an increase in the temperature and an increase in the probability and magnitude of seepage
BSC 2004 [DIRS 169987]	CSNF Waste Form Degradation: Summary Abstraction	Sections 6.1, 6.2, 6.2.1, 6.3.1	Table A-2	FEP not only encompasses the structure and composition of the CSNF, it also addresses alteration, degradation, and dissolution of the waste form. These processes can influence the mobilization of radionuclides
		Sections 6.3.1, Table 6-2	Table A-2	Release from the gap and grain boundaries is a small fraction of the total inventory
BSC 2004 [DIRS 169988]	Defense HLW Glass Degradation Model	Section 6.9	Table A-2	Differences in waste inventory of the different waste forms have been included in the evaluation of barrier capability
BSC 2004 [DIRS 170035]	Conceptual Model and Numerical Approaches for Unsaturated Zone Flow and Transport	Sections 6.2.5 and 6.3.6.3	Table A-3	Dispersive processes tend to be ineffective in the unsaturated zone in spreading short-term transient releases from the EBS
Craig, R.W. 2001 [DIRS 171411]	Excavation-Induced Fracture Study	p. 16	Table A-2	The extent of excavation damage in repository drifts will not affect mechanical response
BSC 2004 [DIRS 171764]	Seepage Calibration Model and Seepage Testing Data	Sections 6.3.2, 6.3.3.2, and 6.6.3.1	Table A-1	Key parameters affecting flow diversion, and the associated parameter uncertainties, are included in the performance assessment
BSC 2005 [DIRS 172232]	Drift-Scale Coupled Processes (DST and TH Seepage) Models	Sections 6.1.1, 6.2.4, 8.1	Table A-1	Effects of resaturation of host rock around emplacement drifts due to waste cooling are only significant for first several hundred to a few 1,000 years, and are insignificant over the period of geologic stability
BSC 2004 [DIRS 172453]	DSNF and Other Waste Form Degradation Abstraction	Section 6.3	Table A-2	An upper-bound model is used in TSPA to model degradation of all of the DSNF fuel types other than Naval SNF
SNL 2008 [DIRS 173869]	Screening Analysis of Criticality Features, Events, and Processes for License Application	Section 6.3	Table A-2	Conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with In-Package Criticality (degraded configuration) do not substantially effect the release of radionuclides or impact the barrier capability
		Section 6.3	Table A-2	Effects of radioactive gases in the EBS were analyzed and were found to be inconsequential to repository performance
		Sections 6.4, 6.5 and 6.6	Table A-2	Conditions required to lead to near-field criticality are not likely to occur, and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier

Table 4-1. Source of Inputs (Continued)

Citation	Source Title	Specifically Used From	Specifically Used In (this AMR)	Input Description
SNL 2007 [DIRS 176828]	Seismic Consequence Abstraction	Sections 6.11.1.3 and 6.11.2	Table A-2	Lithophysal host rock is expected to collapse into the emplacement drifts for unlikely peak ground velocities above 2 m/s
		Section 6.11.4	Table A-2	It is not expected that faults will significantly affect the degradation of the EBS, at annual recurrence intervals of about 10−7 per year and less
		Section 6.11.5	Table A-2	Potential damage to waste packages and drip shields from displacement on these faults is included in the TSPA Model
		Section 6.7	Table A-2	Barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package
		Sections 6.7.3.1, 6.7.3.2, 6.8, and 6.8.5	Table A-2	Axial separation of adjacent drip shields is excluded from the TSPA model because a kinematic study indicates that small static loads from rubble or frictional loads between EBS components are sufficient to eliminate axial separation of drip shields
		Sections 6.1.2, 6.1.3	Table A-2	Changes configuration of EBS components within the emplacement drifts
SNL 2007 [DIRS 177391]	Saturated Zone Site-Scale Flow Model	Section 6.6.4.1	Table A-3	Climate change alters the flux through the saturated zone by increasing the regional recharge and causing the water table to rise
SNL 2007 [DIRS 177396]	Radionuclide Transport Models Under Ambient Conditions	Sections 6.7.5 and 6.8.1.2	Table A-3	Faults are important to unsaturated zone transport because they provide fast pathways for radionuclide transport to the water table
		Sections 6.1.1and 6.1.2	Table A-3	Fracture-related transport processes/properties include fracture permeability, porosity, frequency, active fracture model, matrix diffusion coefficient, sorption, and colloid filtration
SNL 2007 [DIRS 177407]	EBS Radionuclide Transport Abstraction	Section 6.2.1.1	Table A-1	Discussion of two-phase buoyant flow included in models of thermal seepage and thermal hydrology
		Section 5, 6	Table A-2	Seepage or condensation processes are significant mode of release that substantially impacts the transport of radionuclides
		Section 6.3.1.1	Table A-2	Advective releases are more significant from a system performance perspective because releases occur into the fractures of the unsaturated zone below the repository, while diffusive releases are released to the slower transport in the matrix of the unsaturated features
		Section 6.3.1.2	Table A-2	Colloids and associated radionuclides are immobilized, and true colloids may dissolve becoming subject to aqueous transport if conditions are not stable
		Section 6.3.1.2	Table A-2	The process of decay and ingrowth of radionuclides is included in the TSPA
		Section 6.3.2.4	Table A-2	Thermal environment has a direct effect on temperature and humidity in the emplacement drifts, which control the corrosion environment, and the conditions for radionuclide mobilization and release
		Section 6.3.3	Table A-2	Flow diversion, when combined with the lack of advection through the waste package, results in only the potential for diffusive releases from the waste form and waste package if the waste package has degraded features
		Section 6.3.4	Table A-2	Diffusive transport is conservatively specified to occur through a continuous water film on the surfaces of the EBS features

Table 4-1. Source of Inputs (Continued)

Citation	Source Title	Specifically Used From	Specifically Used In (this AMR)	Input Description
SNL 2007 [DIRS 177407] (Continued)	EBS Radionuclide Transport Abstraction (Continued)	Section 6.3.4, Table 6.6-1	Table A-2	Diffusion of colloids is not a significant mode of release
		Section 6.3.4.4	Table A-2	If drip shield and waste package are not breached, advective transport of colloids through the invert is more significant than diffusive
		Section 6.5.2.6	Table A-2	Partitioning of released radionuclides from the EBS to the LNB is sensitive to advective flow, but is relatively insensitive to hydrologic properties of the invert
		Section 6.5.2.6, Table 6.4-1	Table A-2	Unsaturated flow occurs through the invert as a result of seepage or drift-wall condensation, imbibition from the host rock, or capillary condensation, and affects the release of radionuclides from the EBS to the LNB features
		Sections 5, 6	Table A-2	Unsaturated flow has been included in the abstractions for flow and transport through the EBS features
		Sections 6.1.1, Table 6.3-2	Table A-2	Only the smallest of colloidal particles, together with any associated radionuclides, may be transported significantly by diffusion in the EBS. Advection is a more significant method of transport in the invert
		Sections 6.3.1.1, 6.3.1.2	Table A-2	If drip shield and waste package are not breached, advective releases are more significant than diffusive from a system performance perspective
		Sections 6.4.1, 6.6.1	Table A-2	Release pulses caused by bathtub behavior of the waste package have been analyzed
SNL 2007 [DIRS 177412]	Engineered Barrier System: Physical and Chemical Environment	Sections 6.8, 6.8.4, 6.13, 6.13.4, 6.14, and 6.15	Table A-2	Chemical characteristics of water in the drift affect the likelihood of potential degradation, deterioration, and alteration of the other EBS components, as well as affecting the transport characteristics of any radionuclides released from the waste package to the invert
SNL 2007 [DIRS 177418]	Dissolved Concentration Limits of Elements with Radioactive Isotopes	Section 8.1	Table A-2	Uncertainty in these solubilities and the effects of waste package internal chemistry variability and uncertainty have been included in the models of waste form release
SNL 2007 [DIRS 177423]	Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations	Sections 4.1.2, 6.3.1, 6.5.1, 6.6.8, 6.3.9	Table A-2	Corrosion product colloids included in the colloid models environment
		Section 6.6.8	Table A-2	Colloid stability in the invert is a function of the aqueous chemical conditions
		Table 4-2; Sections 6.3.2.2, 7.0	Table A-2	Co-precipitation of colloids due to the degradation of HLW glass waste forms has been included in the assessment of total colloidal release from the codisposal waste packages environment
SNL 2007 [DIRS 177430]	Dike/Drift Interactions	Section 6.7	Table A-2	Following an unlikely magma intrusion into the repository, it is possible that the water chemistry in the emplacement drifts will be altered by basalt-water interactions

Table 4-1. Source of Inputs (Continued)

Citation	Source Title	Specifically Used From	Specifically Used In (this AMR)	Input Description
SNL 2007 [DIRS 177432]	Number of Waste Packages Hit by Igneous Events	Section 6	Table A-2	Potential consequence of an eruptive conduit, to the surface intersecting the repository is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the reasonably maximally exposed individual
		Section 7.2	Table A-3	Discussion of possibility of an eruptive conduit intersecting the repository and extending to surface
70 FR 53313 [DIRS 178394]	70 FR 53313. Implementation of a Dose Standard After 10,000 Years. Internet Accessible	10 CFR 63.305(b)	Table A-1	Future changes in agricultural and industrial activities are excluded based on regulatory requirements
SNL 2007 [DIRS 178519]	General Corrosion and Localized Corrosion of Waste Package Outer Barrier	Section 1	Table A-2	Stainless steel inner shell of waste package has been conservatively modeled to provide no delay of penetration of waste package once waste package Alloy 22 outer barrier has been breached
		Section 6.4.4	Table A-2	Possibility of localized corrosion also requires particular antecedent geochemical conditions that are generally not present
		Section 6.4	Table A-2	Uncertainty in these corrosion
10 CFR 63. 2007 [DIRS 180319]	10 CFR 63	10 CFR 63.51(a)(3)(i−iii), 10 CFR 63.72(a), and 10 CFR 63.72(b)(1−11)	Table A-1	To preclude any potential deleterious effects, construction and operational management, and administrative controls will be developed
SNL 2007 [DIRS 180472]	Initial Radionuclide Inventories	Section 6	Table A-2	Within the waste package, radioactive decay and ingrowth contribute to the waste inventory, which defines the amount of different radionuclides present in different waste forms
		Section 6.1	Table A-2	Other radionuclides have moderate half-lives and decay to products that may be released from the waste
		Section 6.1	Table A-2	Waste inventory defines the amount of different radionuclides present in different waste forms
		Section 6.1.10	Table A-2	Any change to inventory will be managed by the change evaluation process
		Section 6.3	Table A-2	The process of decay and ingrowth of radionuclides is included in the TSPA
		Sections 6.4, 6.6.2 and 6.6	Table A-2	Differences in waste inventory of the different waste forms have been included in the evaluation of barrier capability
SNL 2007 [DIRS 180778]	General Corrosion and Localized Corrosion of the Drip Shield	Section 6	Table A-2	General corrosion rates of titanium in the range of likely environmental conditions are low during the regulatory period. This process has been included in models of drip shield degradation

Table 4-1. Source of Inputs (Continued)

Citation	Source Title	Specifically Used From	Specifically Used In (this AMR)	Input Description
SNL 2008 [DIRS 184748]	Particle Tracking Model and Abstraction of Transport Processes	Section 6.8.2.2	Table A-2	The process of decay and ingrowth of radionuclides
		Section D.2	Table A-2	Other radionuclides have moderate half-lives and decay to products that may be released from the waste
		Section 8.2.2	Table A-3	Processes are included in the UZ Transport Abstraction Model
		Sections 6.5.12, 6.5.13 and 6.6.2	Table A-3	Small fraction of the colloids are conservatively modeled to be unretarded in the unsaturated zone. Sorption of colloidal transport of radionuclides is included in the UZ Transport Abstraction Model
SNL 2007 [DIRS 181244]	Abstraction of Drift Seepage	Sections 6.1[a] and 6-12[a]	Table A-1	Uncertainty in flow focusing has been included in the assessment of the likelihood and magnitude of seepage into the emplacement drifts
		Section 6.4.3.3	Table A-1	Effects of resaturation of the host rock around the emplacement drifts due to waste cooling are dependent on location of the repository
		Section 6.5	Table A-1	Effects of dryout of the host rock around the emplacement drifts due to waste heat depends on location of the repository
		Sections 6.6, 6.6.5.2, and 6.7	Table A-1	Representativeness of the seepage parameter distributions used in PA within repository host rock is considered important to capability of upper natural barrier
		Section 6.4	Table A-2	Thermal-hydrologic effects from drift collapse induced by a seismic event include an increase in the temperature and an increase in the probability and magnitude of seepage
SNL2008 [DIRS 184433]	Multiscale Thermohydrologic Model	Section 6.2.1[a]	Table A-2	Temperature resulting from heat generation also affects the initiation of waste form alteration and radionuclide transport processes dependent on the presence of an aqueous film
		Section 6.2[a]	Table A-2	Nonuniform heat has been considered in the models of in-drift thermal hydrology
		Section 6.3.17[a]	Table A-2	Thermal-hydrologic effects from drift collapse induced by a seismic event include an increase in the temperature and an increase in the probability and magnitude of seepage
		Sections 6.2.15[a], 6.2.17[a]	Table A-2	Preclosure ventilation removes heat and moisture from the host rock during the ventilation period
		Section 6.3.3	Table A-2	Effect of wicking (without seepage) slightly increases the advective flux through the invert

Table 4-1. Source of Inputs (Continued)

Citation	Source Title	Specifically Used From	Specifically Used In (this AMR)	Input Description
SNL 2007 [DIRS 181648]	In-Drift Natural Convection and Condensation	Executive Summary	Table A-2	Thermal environment has a direct effect on temperature and humidity in the emplacement drifts, which control the corrosion environment, and the conditions for radionuclide mobilization and release
		Executive Summary, Table 6.1.2-1, Sections 6.1, 6.2, 6.3 and 6.4	Table A-2	Convective flow of air and moisture in the emplacement drifts has been included in models of in-drift thermal hydrology. However, it does not create an additional source of moisture
		Section 6.2.1	Table A-2	Flow diversion, when combined with the lack of advection through the waste package, results in only the potential for diffusive releases from the waste form and waste package if the waste package has degraded features
SNL 2007 [DIRS 181953]	Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials	Section 6.8.6	Table A-2	Stress cracks are sufficiently small and tight to allow only the diffusive transport of radionuclides through the cracks
		Section 6.2	Table A-2	The potential for and resultant consequences of early failure of the waste package by manufacturing defects or weld flaws exists, and has been considered in the TSPA Nominal Scenario Class
		Section 6.8.6	Table A-2	Stress cracks are sufficiently small and tight to allow only the diffusive transport of radionuclides through the cracks
BSC 2007 [DIRS 182131]	Basis of Design for the TAD Canister-Based Repository Design Concept.	Section 8.2.3.1.1	Table A-2	Requirements for Naval waste packages emplacement standoff distance from mapped faults
		Section 8.2.3.1.1	Table A-2	Naval waste packages that requires an 8.2-ft (2.5-m) minimum emplacement standoff distance from mapped faults
SNL 2008 [DIRS 183041]	Features, Events, and Processes for the Total System Performance Assessment: Analyses	Section 6, by individual FEP	Table A-1	Discussion of FEP related to the Upper Natural Barrier as either an included or excluded screening decision.
		Section 6, by individual FEP	Table A-2	Discussion of FEP related to the Engineered Barrier System as either an included or excluded screening decision.
		Section 6, by individual FEP	Table A-3	Discussion of FEP related to the Lower Natural Barrier as either an included or excluded screening decision.
SNL 2008 [DIRS 183478]	Total System Performance Assessment Model /Analysis for the License Application	Section 6.5 and Table 6.5-2	Table A-2	The probability of igneous an igneous event compromising waste emplacement drifts is very small
SNL 2008 [DIRS 183750]	Saturated Zone Flow and Transport Model Abstraction	Section 6.7.2	Table A-2	Other radionuclides have moderate half-lives and decay to products that may be released from the waste
		Sections 7.4.2, 6.7.2	Table A-3	Radioactive decay and ingrowth

Table 4-1. Source of Inputs (Continued)

Citation	Source Title	Specifically Used From	Specifically Used In (this AMR)	Input Description
SNL 2007 [DIRS 184614]	UZ Flow Models and Submodels	Section 7.7.4.2	Table A-1	Perched-water conditions do not presently exist in the unsaturated zone above the repository, and are not expected even under future climate changes
		Sections 6.1.2, 6.2.4, 6.1.2; Table 4.1-1	Table A-3	Fracture-related transport processes/properties include fracture permeability, porosity, frequency, active fracture model, matrix diffusion coefficient, sorption, and colloid filtration
SNL 2007 [DIRS 180506]	In-Package Chemistry Abstraction	Section 6.3.1.3.4	Table A-2	The different characteristics of these waste forms (in particular the hygroscopic nature of the HLW glass) have been considered in the waste form alteration models and is not found to substantially impact barrier capability of this feature
		Section 6.3.1.1	Table A-2	Chemistry effects of voids in the waste package internals are included in models of in-package chemistry
		Sections 6.10.8 and 8.1	Table A-2	The chemical characteristics of the water in contact with the waste package internals, including void spaces, and the waste form, affect the degradation characteristics of the waste form, the solubility of radionuclides in the dissolved phase, and the stability of colloidal particles
		Table 6-1a	Table A-2	The in-package redox state is assumed to be set by the oxidation state in the emplacement drifts once the waste package is breached and therefore set to 0.2
		Section 6.3.1.3.3	Table A-2	The chemistry of the water that comes into contact with the waste form and waste package internals is altered by reaction with the exposed metallic and waste form surfaces inside the waste package. Results of analyses indicate that the chemistry is more affected by the rate and amount of water interacting with the waste package internals than the chemistry of this water

4.2 CRITERIA

Technical requirements to be satisfied by this document are based on 10 CFR 63.113(a) [DIRS 180319] and 10 CFR 63.115(a)-(c) [DIRS 180319]; as shown in Table 4-2. The acceptance criteria that will be used by the U.S. Nuclear Regulatory Commission (NRC) to determine whether the technical requirements have been met are identified in NUREG-1804 (NRC 2003 [DIRS 163274], Section 2.2.1.1.3) and *Technical Work Plan for: Postclosure Nuclear Safety Design Bases* (SNL 2007 [DIRS 182648]), Section 3.4). This document meets Criterion 1. Part of Criteria 2 and 3, the quantitative analysis and technical basis, are met by the TSPA (SNL 2008 [DIRS 183478]). These acceptance criteria are included below:

- Acceptance Criterion 1—Identification of Barriers Is Adequate

Barriers relied on to achieve compliance with 10 CFR 63.113(b) [DIRS 180319], as demonstrated in the Total System Performance Assessment, are adequately identified, and are clearly linked to their capabilities. The barriers identified include at least one from the engineered system and one from the natural system.

- Acceptance Criterion 2—Description of Barrier Capability to Isolate Waste Is Acceptable

The capability of the identified barriers to prevent or substantially reduce the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or prevent the release or substantially reduce the release rate of radionuclides from the waste is adequately identified and described:

(1) The information on the time period over which each barrier performs its intended function, including any changes during the compliance period, is provided

(2) The uncertainty associated with barrier capabilities is adequately described

(3) The described capabilities are consistent with the results from the Total System Performance Assessment

(4) The described capabilities are consistent with the definition of a barrier in 10 CFR 63.2 [DIRS 180319].

- Acceptance Criterion 3—Technical Basis for Barrier Capability Is Adequately Presented

The technical bases are consistent with the technical basis for the Performance Assessment. The technical basis for assertions of barrier capability is commensurate with the importance of each barrier's capability and their associated uncertainties.

The information presented in Table 4-2 summarizes the information category and the corresponding regulatory requirements of 10 CFR Part 63 [DIRS 180319].

Table 4-2. Cross Reference for Information Categories in 10 CFR Part 63

Information Category	10 CFR Part 63 Reference
System Description and Demonstration of Multiple Barriers	63.113(a) 63.115(a)-(c)
Identification of Barriers	63.113(a) 63.115(a)
Barrier Capability Description	63.113(a) 63.115(b)
Technical Bases for Barrier Capability	63.115(c)
Identifying Postclosure Performance Assessment Controlling Parameters and Classifying ITWI Structures, Systems and Components.	63.21(c)(9) 63.21(c)(10) 63.21(c)(14) 63.21(c)(15)

NOTE: Meeting 10 CFR 63.115(c) [DIRS 180319] regulations also requires that the technical basis for each barrier capability shall be based on, and consistent with, the technical basis for the performance assessments used to demonstrate compliance with 10 CFR 63.113(b) and 10 CFR 63.113(c) [DIRS 180319], which also invoke 10 CFR 63.114 [DIRS 180319] and other requirements from Subpart L of 10 CFR Part 63 [DIRS 180319].

4.3 CODES, STANDARDS, AND REGULATIONS

Other than the regulatory requirements and Yucca Mountain Review Plan acceptance criteria identified in Section 4.2, no other codes, standards, or regulations are used in this report.

5. ASSUMPTIONS

The only assumptions in this scientific analysis that are used in the ITBC evaluations of FEPs are the enabling assumptions identified in Section 6.1.

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6. SCIENTIFIC ANALYSIS DISCUSSION

This report has been prepared to meet regulatory requirements of 10 CFR 63.113(a) and 63.115 [DIRS 180319]), and to provide a risk-informed analysis of the postclosure technical basis for multiple barriers. Specifically, 10 CFR 63.113(a) [DIRS 180319] provides requirements for multiple barriers as part of performance objectives for the geologic repository after permanent closure, and 10 CFR 63.115 [DIRS 180319] provides requirements for the identification of, description of, and technical basis for the multiple barriers.

The major activities documented in this report that address, in part, the above regulations are two: conduct the barrier analysis, and develop core and control parameter characteristics. For natural and engineered barriers that are ITWI, the tasks associated with these two activities include:

1. Describing the three ITWI barriers (UNB, EBS, and LNB)
2. Evaluating barrier capability, including assessment of the technical bases, evaluation of ITBC parameter characteristics and supporting the ITWI determination.

The approach used to identify parameter characteristics that support the postclosure technical basis, the TSPA and contribute to barrier capability, begins by analyzing the FEP descriptions and screening justifications. The barrier analysis uses supporting information from FEP screening reports, which document the processes and events that are included in or excluded from performance assessment models; it also uses information from process models and model abstraction reports that describe the technical basis for implementation of processes and events in the performance assessment models. The use of information from these reports to support the barrier analysis ensures that the technical basis for barrier capability is consistent with the technical basis for the performance assessment models. Direct inputs supporting this analysis are listed in Table 4-1. Indirect inputs are listed in Table 6-1.

Table 6-1. Source of Indirect Inputs

Reference and DIRS	Citation Name
10 CFR 63. 2007 [DIRS 180319]	10 CFR 63
70 FR 49014 [DIRS 177357]	40 CFR 197
70 FR 53313 [DIRS 178394]	70 FR 53313. Implementation of a Dose Standard After 10,000 Years
ASME B46.1-2002. 2003 [DIRS 166013]	Surface Texture (Surface Roughness, Waviness and Lay). New York, New York: American Society of Mechanical Engineers. TIC: 257359.
ASTM B 575-99a. 1999 [DIRS 147465]	Standard Specification for Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Plate, Sheet, and Strip
BSC 2004 [DIRS 166107]	Drift Degradation Analysis
BSC 2004 [DIRS 167652]	Seepage Model for PA Including Drift Collapse
BSC 2004 [DIRS 168138]	Estimation of Mechanical Properties of Crushed Tuff for Use as Ballast Material in Emplacement Drifts

Table 6-1. Source of Indirect Inputs (Continued)

Reference and DIRS	Citation Name
BSC 2004 [DIRS 169218]	Natural Analogue Synthesis Report
BSC 2004 [DIRS 169987]	CSNF Waste Form Degradation: Summary Abstraction
BSC 2004 [DIRS 169988]	Defense HLW Glass Degradation Model
BSC 2004 [DIRS 169989]	Characterize Framework for Igneous Activity at Yucca Mountain, Nevada
BSC 2004 [DIRS 170002]	Future Climate Analysis
BSC 2004 [DIRS 170035]	Conceptual Model and Numerical Approaches for Unsaturated Zone Flow and Transport
BSC 2004 [DIRS 171764]	Seepage Calibration Model and Seepage Testing Data
BSC 2004 [DIRS 172452]	Performance Confirmation Plan
BSC 2004 [DIRS 172453]	DSNF and Other Waste Form Degradation Abstraction
BSC 2005 [DIRS 170137]	Peak Ground Velocities for Seismic Events at Yucca Mountain, Nevada
BSC 2005 [DIRS 175150]	Postclosure Nuclear Safety Design Basis Document: Features, Events and Processes Control Parameters and Proposed Technical Specifications Candidates
BSC 2005 [DIRS 175546]	Nuclear Safety Design Bases for License Application
BSC 2007 [DIRS 182131]	Basis of Design for the TAD Canister-Based Repository Design Concept
BSC 2007 [DIRS 183743]	IED Subsurface Facilities Layout Geographical Data
BSC 2008 [DIRS 183627]	Postclosure Modeling and Analyses Design Parameters
CRWMS M&O 1996 [DIRS 100116]	Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada
CRWMS M&O 1998 [DIRS 103731]	Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada
DOE 2002 [DIRS 155970]	Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada
DOE 2007 [DIRS 181403]	Transportation, Aging and Disposal Canister System Performance Specification
DOE 2007 [DIRS 169992]	Waste Acceptance System Requirements Document.
MO0712DELNPCCA.001 [DIRS 184172]	Delineation of Postclosure Controlled Area. Submittal date: 12/03/2007.
NRC 1997 [DIRS 101903]	Standard Review Plan for Dry Cask Storage Systems. NUREG-1536
NRC 2000 [DIRS 149756]	Standard Review Plan for Spent Fuel Dry Storage Facilities. NUREG-1567
NRC 2003 [DIRS 163274]	Yucca Mountain Review Plan, Final Report
Pan, L.; Wu, Y-S.; and Zhang, K. 2004 [DIRS 169760]	A Modeling Study of Flow Diversion and Focusing in Unsaturated Fractured Rock
SNL 2007 [DIRS 174109]	Hydrogeologic Framework Model for the Saturated Zone Site-Scale Flow and Transport Model
SNL 2007 [DIRS 174260]	Characterize Eruptive Processes at Yucca Mountain, Nevada
SNL 2007 [DIRS 176828]	Seismic Consequence Abstraction
SNL 2007 [DIRS 177391]	Saturated Zone Site-Scale Flow Model
SNL 2007 [DIRS 177396]	Radionuclide Transport Models Under Ambient Conditions
SNL 2007 [DIRS 177399]	Biosphere Model Report
SNL 2007 [DIRS 177407]	EBS Radionuclide Transport Abstraction
SNL 2007 [DIRS 177411]	In-Drift Precipitates/Salts Model
SNL 2007 [DIRS 177412]	Engineered Barrier System: Physical and Chemical Environment
SNL 2007 [DIRS 177418]	Dissolved Concentration Limits of Elements with Radioactive Isotopes

Table 6-1. Source of Indirect Inputs (Continued)

Reference and DIRS	Citation Name
SNL 2007 [DIRS 177422]	MOX Spent Nuclear Fuel and LaBS Glass for TSPA-LA
SNL 2007 [DIRS 177423]	Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations
SNL 2007 [DIRS 177430]	Dike/Drift Interactions
SNL 2007 [DIRS 177431]	Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada
SNL 2007 [DIRS 177432]	Number of Waste Packages Hit by Igneous Events
SNL 2007 [DIRS 178519]	General Corrosion and Localized Corrosion of Waste Package Outer Barrier
SNL 2007 [DIRS 178765]	Analysis of Mechanisms for Early Waste Package/Drip Shield Failure
SNL 2007 [DIRS 178851]	Mechanical Assessment of Degraded Waste Packages and Drip Shields Subject to Vibratory Ground Motion
SNL 2007 [DIRS 179347]	Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada
SNL 2007 [DIRS 179354]	Total System Performance Assessment Data Input Package for Requirements Analysis for Engineered Barrier System In-Drift Configuration.
SNL 2007 [DIRS 179394]	Total System Performance Assessment Data Input Package for Requirements Analysis for Transportation Aging and Disposal Canister and Related Waste Package Physical Attributes Basis for Performance Assessment
SNL 2007 [DIRS 179466]	Total System Performance Assessment Data Input Package for Requirements Analysis for Subsurface Facilities
SNL 2007 [DIRS 179545]	Calibrated Unsaturated Zone Properties
SNL 2007 [DIRS 179567]	Total System Performance Assessment Data Input Package for Requirements Analysis for DOE SNF/HLW and Naval SNF Waste Package Physical Attributes Basis for Performance Assessment
SNL 2007 [DIRS 180472]	Initial Radionuclide Inventories
SNL 2007 [DIRS 180506]	In-Package Chemistry Abstraction
SNL 2007 [DIRS 180616]	Cladding Degradation Summary for LA
SNL 2007 [DIRS 180778]	General Corrosion and Localized Corrosion of the Drip Shield.
SNL 2007 [DIRS 181244]	Abstraction of Drift Seepage
SNL 2007 [DIRS 181267]	Analysis of Dust Deliquescence for FEP Screening
SNL 2008 [DIRS 184433]	Multiscale Thermohydrologic Model
SNL 2007 [DIRS 181648]	In-Drift Natural Convection and Condensation
SNL 2007 [DIRS 181953]	Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials
SNL 2007 [DIRS 182648]	Technical Work Plan for: Postclosure Nuclear Safety Design Bases
SNL 2007 [DIRS 184614]	UZ Flow Models and Submodels
SNL 2008 [DIRS 184797]	Performance Confirmation Plan
SNL 2008 [DIRS 173869]	Screening Analysis of Criticality Features, Events, and Processes for License Application
SNL 2008 [DIRS 179476]	Features, Events, and Processes for the Total System Performance Assessment: Methods
SNL 2008 [DIRS 182145]	Simulation of Net Infiltration for Present-Day and Potential Future Climates
SNL 2008 [DIRS 183041]	Features, Events, and Processes for the Total System Performance Assessment: Analyses
SNL 2008 [DIRS 183478]	Total System Performance Assessment Model /Analysis for the License Application
SNL 2008 [DIRS 183750]	Saturated Zone Flow and Transport Model Abstraction

Table 6-1. Source of Indirect Inputs (Continued)

Reference and DIRS	Citation Name
SNL 2008 [DIRS 184806]	Site-Scale Saturated Zone Transport
Wu, Y-S.; Zhang, W.; Pan, L.; Hinds, J.; and Bodvarsson, G.S. 2000 [DIRS 154918]	Capillary Barriers in Unsaturated Fractured Rocks of Yucca Mountain, Nevada
Wu, Y-S.; Zhang, W.; Pan, L.; Hinds, J.; and Bodvarsson, G.S. 2002 [DIRS 161058]	Modeling Capillary Barriers in Unsaturated Fractured Rock
YMP 1993 [DIRS 100520]	Evaluation of the Potentially Adverse Condition “Evidence of Extreme Erosion During the Quaternary Period” at Yucca Mountain, Nevada
YMP 2001 [DIRS 154386]	Reclamation Implementation Plan

Section 6.1 introduces the barrier analysis consistent with the tasks outlined above and in Section 1. Section 6.2 provides a detailed discussion of the barrier analysis, which demonstrates the concept of multiple barriers. This discussion includes identification of the three ITWI barriers, description of barrier capability, and the technical bases for barrier capability. Each of the three barriers—UNB, EBS, and LNB—is considered ITWI based on this analysis. As defined in 10 CFR 63.2 [DIRS 180319], barrier means “any material, structure, or feature” that: “prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment” or “prevents the release or substantially reduces the release rate of radionuclides from the waste.”

The technical bases for barrier capability involve a description of the numerous process models applied to each of the three barriers to analyze their respective capabilities. It should be noted that not all capability of the barriers is implemented into the TSPA. Although TSPA is largely dependent on technical feeds from process models, not all barrier capability is realized in the subsequent abstraction process. Some conservative assumptions are made in the TSPA that result in a tendency to overestimate release and subsequent dose. Additionally, full barrier capabilities may be masked in the systems level TSPA model. This occurs because redundancy may lead to downstream barrier capabilities being unrealized by upstream barrier performance. The barrier analysis presented in Section 6.2 utilizes information from the FEP screening reports to identify processes and events that can influence barrier capability. The analysis demonstrates that the three barriers (one engineered and two natural) are interrelated in the repository system.

This report emphasizes a qualitative analysis of barrier capability, evaluated at the conceptual or process level, as opposed to a total system approach that emphasizes the quantitative assessment of the performance of the repository as measured by dose to the reasonably maximally exposed individual (RMEI). Therefore, an understanding of process behavior is sufficient for the evaluations of barrier capabilities.

6.1 BARRIER ANALYSIS

Section 6.1.1 contains definitions that are useful to the understanding of the evaluation of barrier capability and waste isolation potential. Section 6.1.2 identifies three ITWI barriers (UNB, EBS, and LNB) and the consideration contributing to their selection. Section 6.1.3 identifies the features of each that contribute to that barrier’s capability. Section 6.1.3 also describes processes and events that act upon the natural and engineered features and influence the barrier capability. Section 6.1.4 describes the methodology used to evaluate the barrier capability for each ITWI barrier. Section 6.1.4 describes the methodology used to identify ITBC core parameter and control parameter characteristics for the feature/components of each ITWI barrier.

6.1.1 Definitions

Features/components of the engineered barrier are each identified within the preclosure design as being part of the postclosure system. Administrative and procedural controls will be developed to ensure ITWI barriers function as intended and as described in the postclosure technical baseline during the repository regulatory period. These control processes will pertain to waste acceptance, procurement, construction, operations, and closure activities that affect ITWI barriers and corresponding control parameter characteristics.

Barrier—10 CFR 63.2 [DIRS 180319] defines a barrier as “any material, structure, or feature that, for a period to be determined by the U.S. Nuclear Regulatory Commission, prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or prevents the release or substantially reduces the release rate of radionuclides from the waste. For example, a barrier may be a geologic feature, an engineered structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around the waste, provided that the material substantially delays movement of water or radionuclides.”

Control Parameter—A quantity or variable that defines or supports a contribution to barrier capability or a model (conceptual, mathematical, or numerical) describing that capability. A control parameter supports the postclosure technical bases and is controlled or manipulated during design, construction, or operations in such a fashion as to provide a reasonable expectation that the barrier’s capability will be as described. Control parameters are generally associated with the EBS, however, they can, in some circumstances, be associated with the natural barriers as well.

Control Parameter Characteristics—The specific aspects of the contribution to barrier capability that are defined or supported by logical groupings of control parameters that are controlled or manipulated during design, construction, or operations. A control parameter characteristic may include, but not limited to, fit, form, and functionality of the materials of a barriers feature/component. For example, Reclamation of Lands Disturbed by Repository, Waste Package Outer Barrier Material Specification, and Waste Package Surface Finish are examples of control parameter characteristics. Infiltration rate, coefficients defining general corrosion, and depth of scratches are examples of control parameters that may correspond to these characteristics.

Core Parameter—A quantity or variable that defines or supports a contribution to barrier capability or a model (conceptual, mathematical, or numerical) describing that capability. A core parameter supports the postclosure technical bases and is not controlled or manipulated during, design, construction, or operations.

Core Parameter Characteristics—The specific aspects of the contribution to barrier capability that are defined or supported by logical groupings of core parameters. In-drift chemical environment, infiltration and seepage properties, properties of host rock unit, and radionuclide inventory and source term properties are examples of core parameter characteristics. Ionic strength and pH in the invert, horizontal permeability of the TSw, thermal conductivity of the TSw, and solubility limit of Pu are examples of core parameters that may correspond to these characteristics. Core parameter characteristics are candidates for monitoring during Performance Confirmation.

Design Bases—10 CFR 63.2 [DIRS 180319] defines design bases as "that information that identifies the specific functions to be performed by a structure, system, or component of a facility and the specific values or ranges of values chosen for controlling parameters as reference bounds for design. These values may be constraints derived from generally accepted "state-of-the-art" practices for achieving functional goals or requirements derived from analysis (based on calculation or experiments) of the effects of a postulated event under which an SSC must meet its functional goals. The values for controlling parameters for external events include:

1. Estimates of severe natural events to be used for deriving design bases that will be based on consideration of historical data on the associated parameters, physical data, or analysis of upper limits of the physical processes involved.

2. Estimates of severe external human-induced events to be used for deriving design bases that will be based on analysis of human activity in the region, taking into account the site characteristics and the risks associated with the event."

Event—A natural or human-caused phenomenon that has a potential to affect disposal system performance [repository performance] and that occurs during an interval that is short compared to the period of performance (NRC 2003 [DIRS 163274], Section 3).

Important to Barrier Capability—A determination assigned to a parameter or parameter characteristic based on an evaluation of the ability of the characteristic to be capable of preventing or substantially reducing the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or preventing the release or substantially reducing the release rate of radionuclides from the waste. A feature is also ITBC if it is associated with one or more ITBC characteristic.

Important to Waste Isolation—The following definitions apply to the concepts of ITWI:

Barriers/Systems Important to Waste Isolation – With reference to addressing 10 CFR 63.113(a) [DIRS 180319], means specifically the Engineered Barrier System, the Upper Natural Barrier, and the Lower Natural Barrier. This usage is analogous with the preclosure usage of "system" in "structures, systems, and components important to safety.

Features/Components Important to Waste Isolation—With reference to addressing 10 CFR 63.115(a) [DIRS 180319], the subdivision of the Barriers Important to Waste Isolation/Systems Important to Waste Isolation into physical entities that are credited in the postclosure safety analysis to prevent or substantially reduce the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or prevents the release or substantially reduces the release rate of radionuclides from the waste.

Items Important to Waste Isolation—With reference to addressing 10 CFR 63.142 [DIRS 180319] and NUREG-1804 2.5.1.3 AC 2(1) (a) (and 10 CFR 63.114 (d) (e) and (f) [DIRS 180319]) includes Barriers / Systems Important to Waste Isolation, Features / Components Important to Waste Isolation *and also includes*:

- Those engineered features/components of the geologic repository whose function is to prevent or mitigate the consequences of potential disruptive events (e.g., criticality)
- Consumable materials to be incorporated into any engineered item important to waste isolation during fabrication of that item.

A feature is classified as ITWI if it meets two conditions. The first condition is that the feature is associated with one or more parameter characteristic classified as important to barrier capability (ITBC). The second condition is that the feature is a significant contributor to the barrier capability relative to the other features of the barrier. Consistent with 10 CFR 63.2 and 10 CFR 63.142(a) [DIRS 180319], a parameter characteristic is classified as ITBC if it: 1) prevents or substantially reduces the rate of movement of water from the repository to the accessible environment; 2) prevents the release or substantially reduces the release rate of radionuclides from the waste form; 3) prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment, or 4) prevents or substantially reduces the potential for criticality.

Process—A natural or human-caused phenomenon that has the potential to affect disposal system performance [repository performance], and that operates during all or a significant part of the period of performance (NRC 2003 [DIRS 163274], Section 3).

Q-List—A list of the set of structures, systems, and components (SSCs) that are Important to Safety and the barriers and barrier SSCs that are Important to Waste Isolation.

Figure 6-1 illustrates schematically the relationship between FEPs, core parameter characteristics, control parameter characteristics and engineered SSCs. Figure 6-2 illustrates schematically the relationship between Important to Safety, Important to Waste Isolation, Important to Barrier Capability, Control Parameter Characteristics, Core Parameter Characteristics and their controlling or monitoring mechanisms.

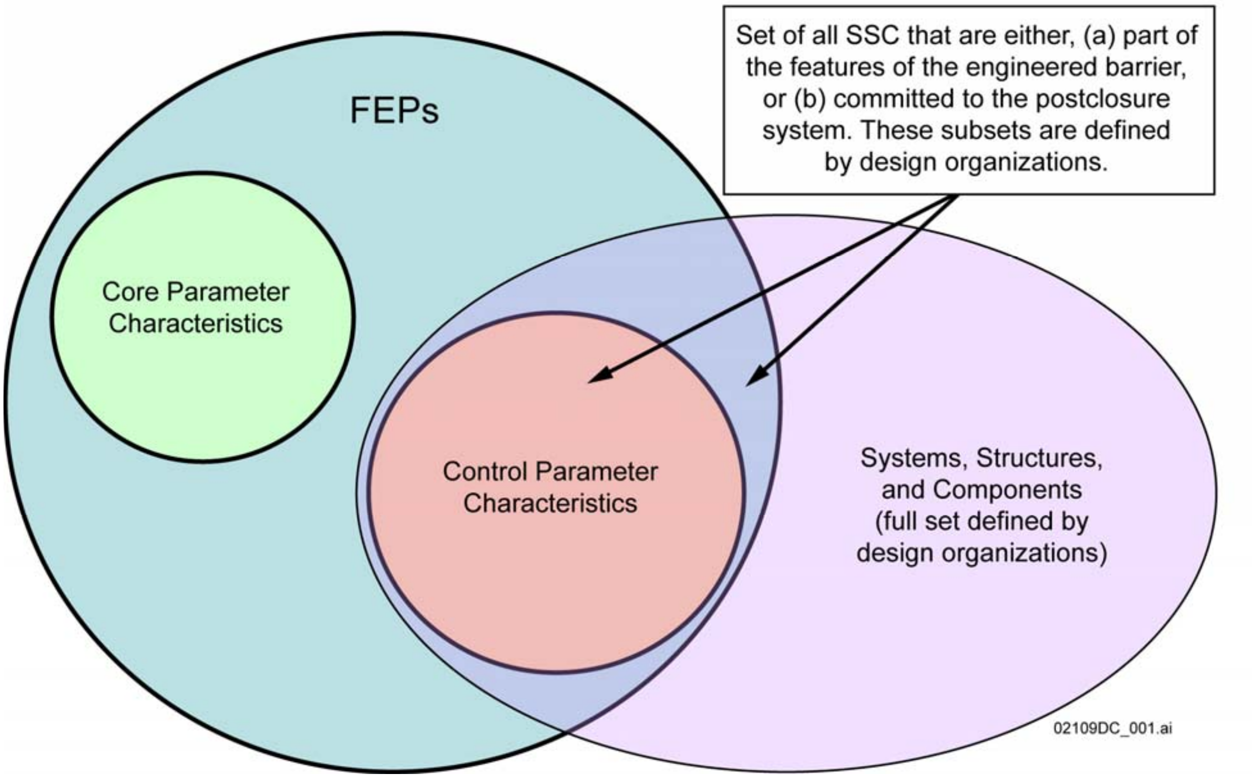


Figure 6-1. Relationship between FEPs; Core Parameter Characteristics; Control Parameter Characteristics; and Design-Related Systems, Structures, and Components

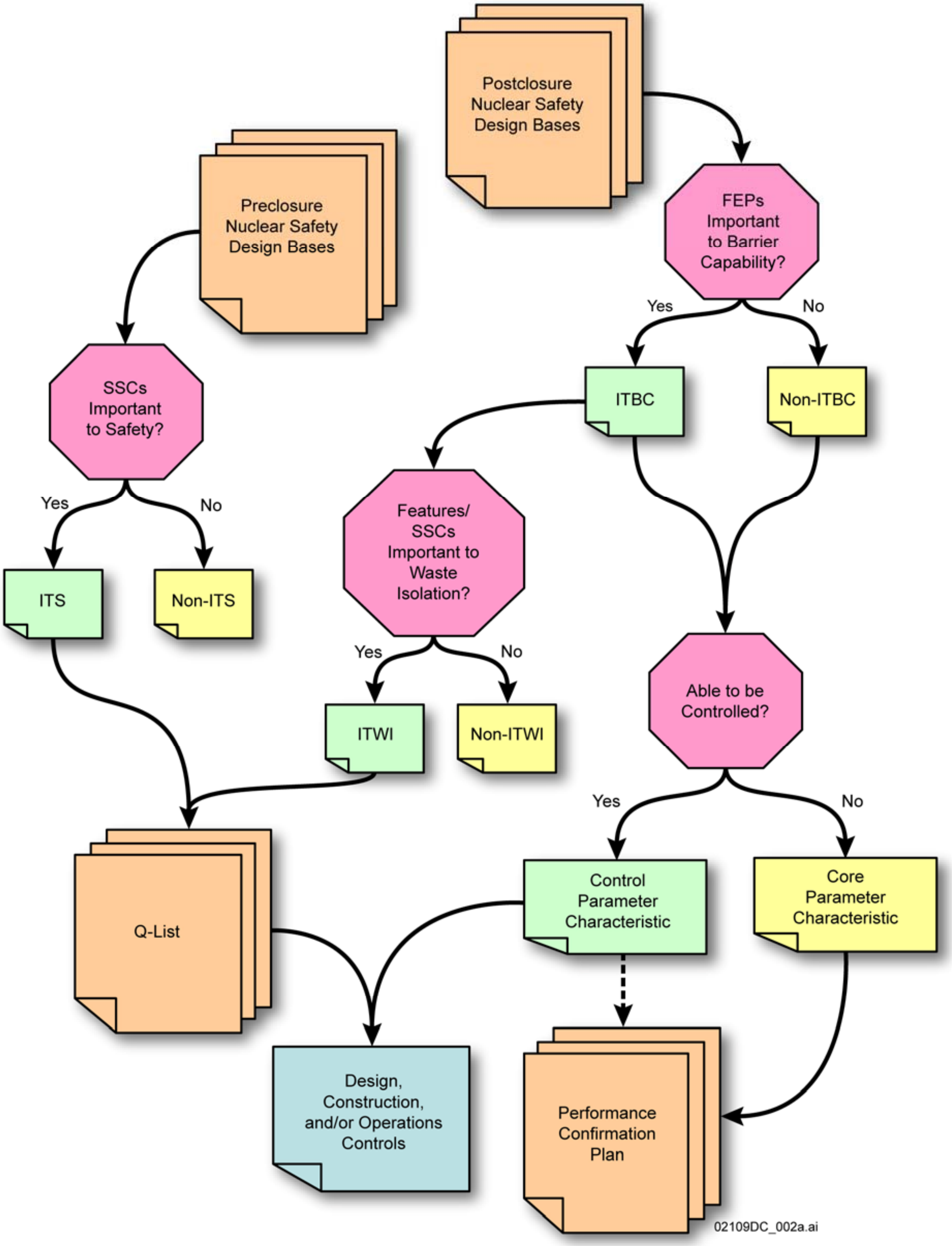


Figure 6-2. Relationship between ITS, ITWI, ITBC and Control Parameter Characteristics and Core Parameter Characteristics and Their Controlling or Monitoring Mechanisms

6.1.2 Identification of Barriers

The barriers should include at least one barrier associated with the natural system and at least one associated with the engineered system. The barrier accomplishes or contributes to one or more of the following functions:

1. Prevents or substantially reduces the rate of movement of water from the repository to the accessible environment.

2. Prevents the release or substantially reduces the release rate of radionuclides from the waste.

3. Prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment.

Based on the definitions in Section 6.1.1, and the relevant sections of 10 CFR Part 63 [DIRS 180319] outlined at the start of Section 6, the following considerations helped formulate the process for the ITWI determination of the barriers.

- The technical basis for barrier capability is that the capability is consistent with the technical basis of performance assessment or differences clearly and defensively explained. Realization of the capabilities is quantifiable with respect to performance criteria in performance assessment or process modeling. The capability considers and is treated with uncertainty as is demonstrated in the performance assessment modeling of the barrier behavior as acted upon by relevant and significant events. Finally, it is important that the capabilities of the barrier be capable of demonstration through monitoring and testing in the Performance Confirmation Program in site characterization.

Other considerations in the barrier selection process are that the barrier and its capabilities are readily understood and described and documented in a transparent fashion. In order to provide for redundancy in system wide capability and for defense in depth, the selection of barriers should be diverse in terms of features and processes. There should be multiple features contributing to a given barrier and there should be multiple barriers that complement the capabilities of each other when viewed at the total system level.

Based on these considerations and the analyses presented in remainder of Section 6.1 and the results of the analysis presented in Appendix A, the following three barriers are determined to be ITWI:

- The UNB prevents or substantially reduces the rate of downward movement of water to the repository.

- The EBS prevents or substantially reduces the rate of movement of water, prevents or substantially reduces the release rate of radionuclides from the waste, and prevents or substantially reduces the rate of movement of radionuclides.

- The LNB prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment.

6.1.2.1 Technical Justification for Barrier Selection

6.1.2.1.1 Upper Natural Barrier

The soils and rock above the repository serve as a barrier to restrict water flow into the emplacement drifts and, ultimately, to the waste form. A significant reduction in the amount of precipitation that falls to the surface is achieved through the processes of run off, evaporation, and plant transpiration within the surficial soils. Precipitation moderated by these processes results in infiltration. Net infiltration then becomes percolation. At the interface with the Paintbrush non-welded (PTn) unit, transient percolation pulses are damped such that the magnitude of episodic flow into the emplacement drifts is substantially reduced (attenuated) (SNL 2007 [DIRS 184614], Section 6.1.2). An additional reduction in percolation flux occurs as a result of the capillarity of the unsaturated fractured tuffs around the repository drifts. These processes result in a diversion of percolation around the drift thus reducing the net flow that can seep into the emplacement drifts and potentially contact the Engineered Barrier System.

6.1.2.1.2 Engineered Barrier

The EBS consists of several engineered components although the barrier capability is considered at the system level, which accounts for barrier feature/component interactions. These components include the emplacement drift, drip shield, waste package, cladding, waste package internals, waste form, waste package pallet, and the invert. Each component contributes to the overall barrier capability; however, the predominant features are the drip shield, waste package, and waste form. These are briefly summarized below. A more detailed discussion is presented in Section 6.2.

Drip Shield—The drip shield prevents or substantially reduces water flow that could contact the waste package and, in the event of a waste package failure, contacts the waste form. The drip shield's contribution to the Engineered Barrier capability is through its integrity and resistance to damage by chemical and mechanical means. Some control parameter characteristics that support the drip shield capabilities include Drip Shield Design and Installation, Drip Shield Fabrication, Drip Shield Materials and Thickness, Drip Shield Seismic Performance, and Drip Shield Thermal Expansion. Some core parameter characteristics include Drip Shield Corrosion and Drip Shield Materials, Properties, and Configuration, Even in the situation where the drip shield becomes degraded, it still has a capability to limit water contacting the waste package.

Waste Package—The waste package prevents or reduces the flow of water that could contact the waste form. In conjunction with the drip shield, the waste package is exposed only to humid air conditions and the outer barrier of the waste package prevents water from contacting the waste form until the waste package is degraded. The waste package in its intact condition prevents the release of radionuclides. The waste package in its degraded form is still capable of reducing the rate of release of radionuclides. This ability to prevent or reduce water flow and prevent or reduce the rate of radionuclide release is the property that makes the waste package function as part of the EBS.

As long as they remain intact, waste packages prevent contact between water and the waste form and prevent the release of radionuclides. Should water contact the waste packages, corrosion of waste package outer barrier is expected to proceed slowly and the degraded waste package still limits the movement of water that could potentially contact the waste form and limits the release rate of radionuclides from the waste packages. The waste package design and materials of construction contribute to its resistance to mechanical damage during seismic events. Some control parameter characteristics that support the waste package capabilities are Waste Package Dimensions and Component Masses, Waste Package Fabrication, Waste Package Outer Barrier, Seismic Design of the Waste Package, and Waste Package Handling and Emplacement. Some core parameter characteristics are Waste Package Materials, Properties, and Configuration and Waste Package Temperature Limits.

Waste Form—The radionuclides in the waste form are generally of a form that are highly insoluble to water and are not likely to mobilize, except for a limited number of radionuclides, thus significantly reducing the radionuclide release rate. Some control parameter characteristics that support the waste form capabilities are Waste Form Moisture Removal and Inerting, Loading of Waste Forms, and Handling of Waste Forms. Some core parameter characteristics are Waste Form Degradation, and Waste Form/Package Internal Materials, Properties, and Configuration.

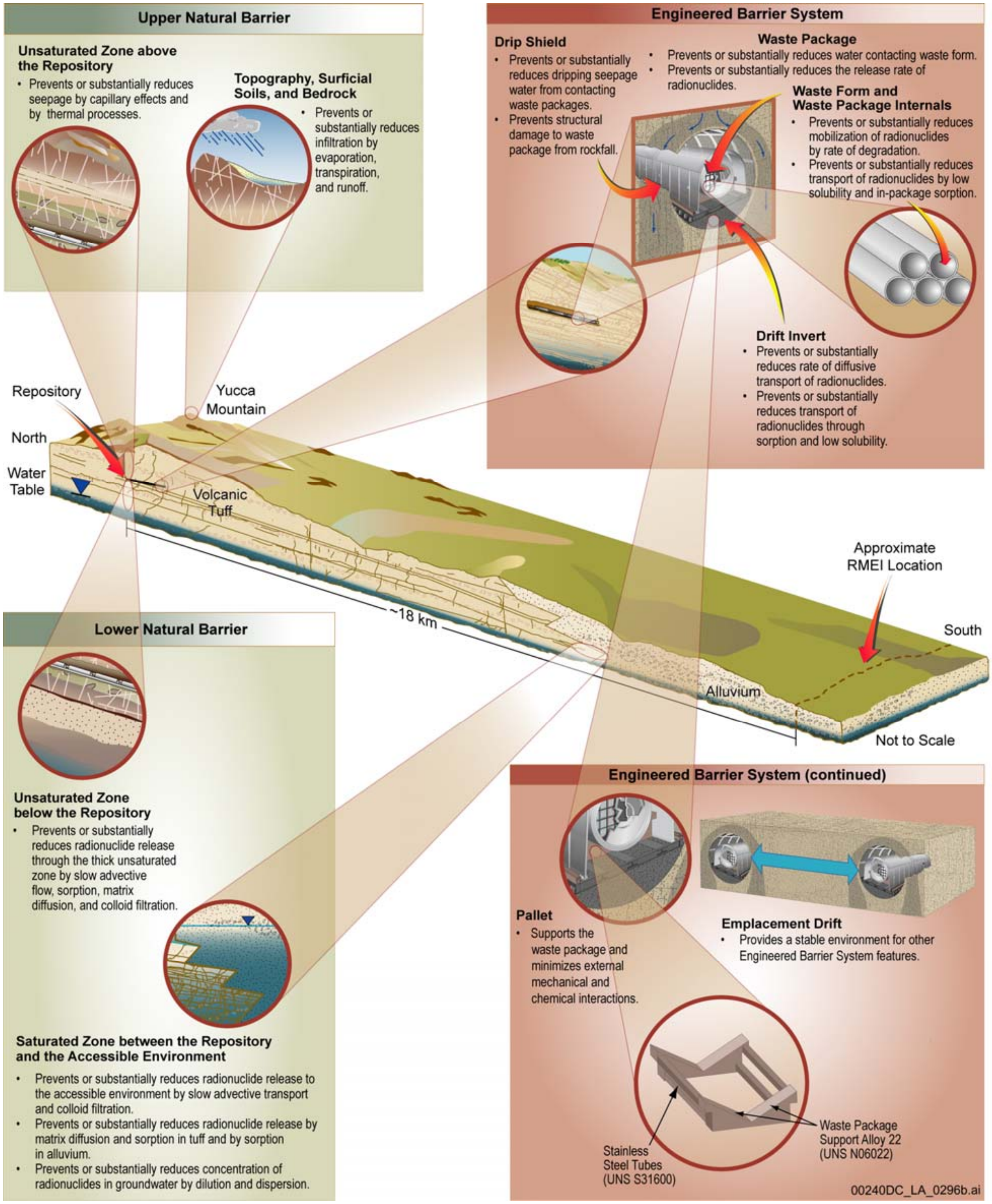
6.1.2.1.3 Lower Natural Barrier

The volcanic rock below the repository and in the downgradient portion of the saturated zone has properties that prevent or reduce the release rate of radionuclides to the accessible environment. The reduction in release of radionuclides is due to diffusion from the fractures into the rock matrix. Further, the volcanic tuff and the alluvial material have the capability of sorption of radionuclides, thus slowing the release rate of the radionuclides to the accessible environment. The rock below and downgradient from the repository also have the capability to filter colloids, again reducing the rate of release of those radionuclides potentially attached to colloids. These properties of matrix diffusion, sorption, and colloid filtering combine to provide the barrier capability for the LNB.

6.1.2.2 Representation of the Barriers in Relation to the Overall System

Figure 6-3 schematically shows the three ITWI barriers of the repository system. The geologic and hydrologic features and characteristics of the Yucca Mountain site form effective natural barriers to the flow of water and to the potential movement of radionuclides. The underground environment within the natural setting is conducive to the design and construction of features of the EBS that prevent or substantially reduce the potential release of radionuclides from the waste. The barrier analysis presented in Section 6.2 describes how each of the ITWI barriers work, individually and together, to prevent or substantially reduce the rate of movement of water and/or radionuclides to the accessible environment and the release rate of radionuclides from the waste.

Figure 6-4 is a schematic representation of the approach used to identify the postclosure nuclear safety design bases associated with these three ITWI barriers. The approach is described in the remainder of this section.



Upper Natural Barrier

Unsaturated Zone above the Repository

- Prevents or substantially reduces seepage by capillary effects and by thermal processes.

Topography, Surficial Soils, and Bedrock

- Prevents or substantially reduces infiltration by evaporation, transpiration, and runoff.

Engineered Barrier System

Drip Shield

- Prevents or substantially reduces dripping seepage water from contacting waste packages.
- Prevents structural damage to waste package from rockfall.

Waste Package

- Prevents or substantially reduces water contacting waste form.
- Prevents or substantially reduces the release rate of radionuclides.

Waste Form and Waste Package Internals

- Prevents or substantially reduces mobilization of radionuclides by rate of degradation.
- Prevents or substantially reduces transport of radionuclides by low solubility and in-package sorption.

Drift Invert

- Prevents or substantially reduces rate of diffusive transport of radionuclides.
- Prevents or substantially reduces transport of radionuclides through sorption and low solubility.

Lower Natural Barrier

Unsaturated Zone below the Repository

- Prevents or substantially reduces radionuclide release through the thick unsaturated zone by slow advective flow, sorption, matrix diffusion, and colloid filtration.

Saturated Zone between the Repository and the Accessible Environment

- Prevents or substantially reduces radionuclide release to the accessible environment by slow advective transport and colloid filtration.
- Prevents or substantially reduces radionuclide release by matrix diffusion and sorption in tuff and by sorption in alluvium.
- Prevents or substantially reduces concentration of radionuclides in groundwater by dilution and dispersion.

Engineered Barrier System (continued)

Pallet

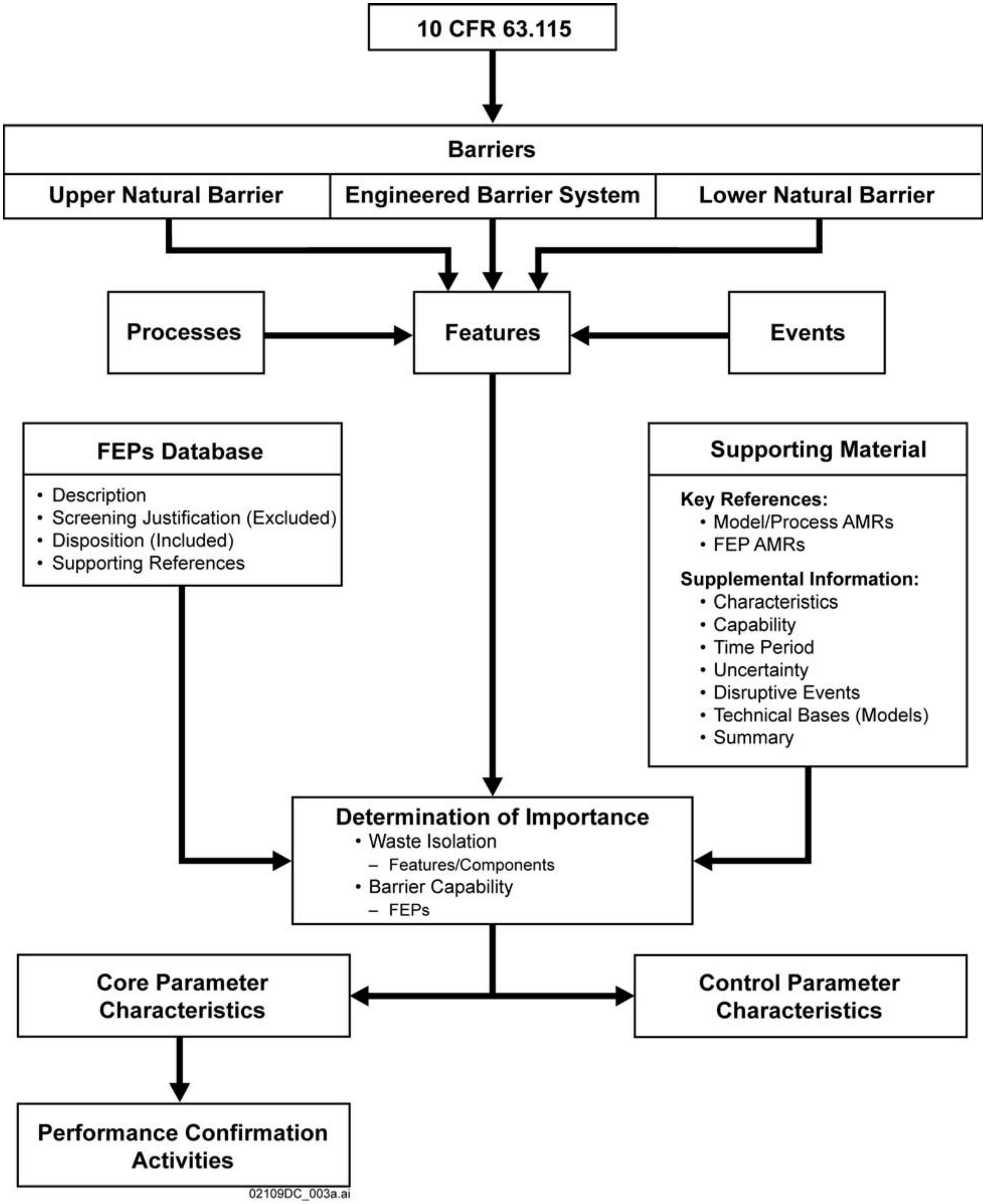
- Supports the waste package and minimizes external mechanical and chemical interactions.

Emplacement Drift

- Provides a stable environment for other Engineered Barrier System features.

NOTE: Some of the SSCs shown are not important to barrier capability, but are illustrated here for completeness. The approximate RMEI location is the southern-most edge of the controlled area at 36°40′13.6661″ North latitude. This is approximately 18 km south of the repository along the predominant direction of groundwater flow.

Figure 6-3. Schematic Illustration of the Multiple Barrier Repository System



NOTE: Processes and/or events, acting on features within a barrier are described by FEPs. The ITBC evaluations are tabulated in Appendix A. Corresponding core parameter characteristics and control parameter characteristics, and Performance Confirmation activities are also tabulated in this appendix.

Figure 6-4. Schematic of ITBC/ITWI Process with Ties to Performance Confirmation Activities

6.1.3 Identification of Features

The three barriers (UNB, EBS, and LNB) are composed of features/components. All physical attributes of the repository system, whether natural or engineered, are called features/components, and can be associated with core parameter characteristics or control parameter characteristics. The principal features/components of the repository system are identified in Table 6-2 (SNL 2008 [DIRS 179476], Section 6.1.3 and Table 6-1). This list includes the features within the barriers plus those features that support the capability of the barrier functions or that contribute to barrier capability in the unlikely occurrence of a disruptive event. For the natural system, the features identified represent a logical deviation of the processes and barrier capability that falls out of the analysis documents in this report. For the EBS, these features are consistent with the SSCs identified in *Nuclear Safety Design Bases for License Application* (BSC 2005 [DIRS 175546], Section 5.6.1.4). For the remainder of this document, the term 'features' as used to describe the EBS is considered to implicitly include features and SSCs. FEPs necessary to address repository performance but not directly related to the capability of barriers are discussed in Section 6.3. Table 6-2 is presented in the order of the features along the likely path that water takes in reaching the waste, and then the path that radionuclides take from the repository to the accessible environment.

Table 6-2. Features/Components for Each of the Three Barriers

Barrier	Features/Components
UNB	Topography and surficial soils Unsaturated zone above the repository
EBS	Emplacement drift Drip shield Waste package Waste package internals Naval SNF Structure Cladding Waste form Waste package pallet Invert
LNB	Unsaturated zone below the repository Saturated zone

NOTE: FEPs related to human intrusion, ramp or drift backfill, biosphere, and systems are not considered in this scientific analysis because they are non-barrier-specific (Section 6.3).

The principal features that correspond to the three ITWI barriers are described further as part of the barrier analysis in Section 6.2.

Features may have various processes and events act upon them that contribute to or potentially detract from the ability of the features to perform one or more functions related to barrier capability (Table 6-3). To evaluate the capability of the barriers, the impact of different processes and events, acting on the features that make up the barrier are assessed. For example, as shown in Table 6-3, all processes and events act on the waste package and influence the waste package ability to perform the barrier function. Therefore, the barrier capability analysis described in Section 6.2 is evaluated in the context of the processes and events that act upon the features.

The approach for identifying specific processes and events relevant to the principal features of the repository system is documented in *Features, Events, and Processes for the Total System Performance Assessment*: *Methods* (SNL 2008 [DIRS 179476], Sections 6.1, 6.2, and 6.3). This systematic FEP identification effort produced a total of 374 FEPs. The list of 374 FEPs represents the complete list of processes and events that could potentially affect the Yucca Mountain repository system (SNL 2008 [DIRS 179476], Table 7-1). Each of the 374 FEPs was evaluated (screened) for inclusion into the performance assessment on the basis of probability, consequence (i.e., whether it could significantly affect the magnitude and timing of radiological exposure to the RMEI or radionuclide releases to the accessible environment), or regulatory specification. The disposition of the FEPs in the performance assessment and the rationale for excluding those FEPs that do not meet the criteria above are documented in the FEP report (SNL 2008 [DIRS 183041], Section 6).

The barrier capability analysis presented in Section 6.2 utilizes the FEP screening information to support the demonstration of barrier capability. Some FEPs apply to more than one feature of a barrier. Rationale for the association of parameter characteristics and the determination of ITBC and non-ITBC are presented in Appendix A, Table A-1 (UNB), Appendix A, Table A-2 (EBS), and Appendix A, Table A-3 (LNB).

Table 6-3. Mapping of Processes and Events to Features/Components of the Three Barriers

Yucca Mountain FEP Matrix			Processes							Events				
			Hydrologic and Thermal-Hydrologic	Chemical and Thermal-Chemical	Mechanical and Thermal-Mechanical	Microbiological	Radiological	Characteristics	Transport	Igneous	Seismic	Criticality	Human Intrusion[4]	Early Failure
Features / Components	Upper Natural Barrier	Topography and Surficial Soils	✓	✓	✓			✓		✓	✓			
		Unsaturated Zone Above Repository	✓	✓	✓	✓		✓	✓	✓	✓			
	Engineered SSCs of the Engineered Barrier System	Emplacement Drifts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
		Drip Shield	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
		Waste Package	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Cladding[1]	✓	✓	✓	✓	✓	✓		✓	✓			
		Waste Form[2] and Waste Package Internals[3]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
		Waste Package Pallet	✓	✓	✓	✓	✓	✓		✓	✓			
		Invert	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	Lower Natural Barrier	Unsaturated Zone Below Repository	✓	✓	✓	✓		✓	✓	✓	✓	✓		
		Saturated Zone	✓	✓	✓	✓		✓	✓	✓	✓	✓		

Source: SNL 2008 [DIRS 179476], Table 6-1.

NOTES:

[1] Potential capability of cladding is not considered in TSPA for CNSF and DOE SNF. For Naval SNF Structure, the cladding is considered as an integral part of the structure.

[2] The waste form for Naval SNF is called Naval SNF Structure, and includes the fuel as well as the integral cladding.

[3] Waste form and waste package internals includes SSCs such as the TAD canister, naval canister, DOE SNF canister and HLW canister and also includes the criticality control measures (absorber plates, etc) that are identified in Table 7-1.

[4] Human intrusion event is an evaluation of system resiliency and is not part of the barrier evaluation required by 10 CFR 63.115 [DIRS 180319].

6.1.4 Description of Processes and Events

Table 6-3 maps processes and events to features/components of the three barriers. A brief description of the processes and events follows.

Hydrologic flow processes include climate change, precipitation, infiltration, runoff, unsaturated zone flow, flow diversion, capillarity, matrix imbibition, evaporation, condensation, and saturated zone flow.

Chemical processes include the geochemical environment and those processes that affect the degradation mechanisms of engineered features, which include dissolution, precipitation, reduction, oxidation, salt deliquescence, general corrosion, and localized (or crevice) corrosion.

Mechanical processes include drift degradation and those that affect the degradation of engineered features, which include rockfall, drift collapse, stress corrosion cracking, hydrogen embrittlement, buckling, and floor heave, among others.

Thermal processes may affect the hydrologic (e.g., flow), chemical, and mechanical environments. The radioactive wastes to be placed in the repository will generate varying amounts of heat from the time of emplacement. This decay heat flux decreases with time. Even though the heat flux decreases with time, certain effects of heat will be present after repository closure. The thermal processes operating within the repository include conduction, radiation, and convection. These thermal processes affect flow through evaporation, condensation, and vapor and liquid flow. The thermal effects on chemistry occur through evaporation, mineral precipitation, dissolution, and on thermal-chemical properties. The thermal effects on the mechanical environment occur through thermal stresses and corresponding effects on rock mass strength and degradation. In general, for the purposes of FEP analysis, thermal processes are not treated separately, but instead, are coupled with the process that is affected by thermal conditions. For example, the processes will be generally referred to as thermal-hydrologic, thermal-chemical, or thermal-mechanical to indicate the principal couplings considered.

Microbiological processes include the potential effects of microorganisms on other processes relevant to performance, such as microbial effects on chemistry.

Radiological processes include the potential effects of ionizing radiation from the decay of radioactive materials on other processes potentially relevant to performance, such as chemistry. Specific radiological processes include radiolysis. As in the case of thermal effects, the radiological processes are generally addressed through their coupling with other processes that in turn could potentially affect repository performance.

Transport processes include advection, diffusion, dispersion, matrix diffusion, sorption /desorption and colloid filtration. These processes occur within the EBS and the LNB. In addition, radionuclide transport due to atmospheric transport processes following an eruptive volcanic event is also considered in this category.

Processes also include "characteristics" that are not physical-chemical-biological processes but are properties of the features that need to be evaluated for their inclusion in abstraction models of the processes and events. For example, tectonic processes are included in the characteristics category. In addition, a number of FEPs relate to geologic characteristics of the features (e.g., fractures or faults).

Natural disruptive events that may affect the repository include igneous intrusion intersecting the repository, volcanic eruption from a volcanic vent that intersects the repository, seismic activity that produces vibratory ground motion affecting the repository and the EBS, and potential seismic activity, including fault displacement, that affects the repository and the EBS.

Igneous intrusion considers the possibility that magma in the form of a dike could intrude into repository drifts, destroying drip shields and waste packages in those drifts, exposing the waste forms to percolating water that could mobilize radionuclides from the waste forms and transport them through the unsaturated and saturated zones. Volcanic eruption considers that a volcanic conduit (or conduits) invades the repository, destroys waste packages, and erupts at the land surface. The volcanic eruption disperses volcanic tephra and entrained waste under atmospheric conditions, and deposits the contaminated tephra on land surfaces where the contaminated tephra becomes subject to redistribution by soil and near surface hydrogeologic processes.

Seismic ground motion concerns damage to waste packages and drip shields due to vibrating ground motion, potentially resulting in rockfall and drift collapse. Seismic fault displacement includes the effects of fault displacement on waste packages and drip shields.

Criticality events include initiators of sequences of events or processes that could lead to configurations that have potential for criticality in the repository. For a criticality event to occur, the appropriate combination of materials (neutron moderators, fissile materials, or isotopes) and geometric configurations favorable to criticality must exist. Neutron absorbers are included to reduce the probability of criticality. The waste package is designed such that the initial emplaced configuration of the waste form remains subcritical, even under flooded conditions. The initial fuel geometry is considered to bound the various limiting configurations that would result for each of the criticality FEP scenarios (nominal, rockfall, seismic, igneous). Therefore, for a configuration to have potential for criticality, all of the following conditions must occur in the same location at the same time: (1) sufficient mechanical or corrosive damage to the waste package outer corrosion barrier to cause a breach, (2) presence of a moderator (i.e., water), (3) separation of fissionable material from the neutron absorber material or an absorber material selection error during the canister fabrication process, and (4) the accumulation (external) or presence of a critical mass and geometry of fissionable material.

The human intrusion event is a stylized calculation that simulates a future drilling operation in which an intruder drills a land-surface borehole using a drilling apparatus operating under the common techniques and practices currently employed in exploratory drilling for groundwater in the region around Yucca Mountain. During drilling, the drilling apparatus directly intersects a degraded drip shield and waste package, causing a release of waste and continues subsequently into the saturated zone underlying Yucca Mountain. In the human intrusion event, potential releases caused by unlikely natural processes and events are exempt from consideration by regulation (Subpart E of 10 CFR Part 63 ([DIRS 180319], Technical Criteria)).

Early failure addresses the potential for drip shield and waste package early failure in the absence of disruptive events. The early-failure scenarios include drip shields and waste packages that fail prematurely due to material defects or improper manufacturing conditions or pre-emplacement operations and practices, such as improper heat treatment or welding flaws.

Table 6-4 relates the ITWI Barriers to specific models, sub-models, and abstractions in the TSPA and to the Analysis Reports that support these aspects of the TSPA. References are provided. One point of note in the table is that only the Principle Model Component, "Events" only impacts the Engineered Barrier in the TSPA. While event related FEPs (seismic and igneous FEPs) are associated with both natural barriers, these FEPs are screened out of further consideration in the performance assessment (SNL 2008 [DIRS 183041], Section 6).

All barriers and features/components that are identified as ITWI are included in the postclosure technical baseline and the TSPA model. The parameters and models used in the quantification of barrier capability are the same as those developed for use in the TSPA for evaluation of performance of the natural and engineered barriers in the assessment of the individual and groundwater protection. Although uncertainty exists in the parameters and models of the relevant processes that affect the assessment of barrier capability and TSPA, this uncertainty has been appropriately included in the assessments. As a result, the description of the repository system and the demonstration of multiple barriers increase the confidence that the postclosure performance objectives specified in 10 CFR 63.113(b) and (c) [DIRS 180319] will be achieved.

Table 6-4. Relationship among TSPA Model Components, Submodels, and Abstraction/Process Model(s)/Analysis(es)

Barrier	TSPA-LA Principal Model Components		Submodel for TSPA-LA	Abstraction/Process Model(s)/Analysis(es)	Reference[1]
Upper Natural Barrier	Unsaturated Zone Flow Model Component	Site-Scale UZ Flow	UZ Flow Fields Abstraction	UZ Flow Fields Abstraction	1
				Site-Scale UZ Flow Process Model	
				Active Fracture Model	
				Dual-Permeability UZ Flow Model	
		Infiltration Analysis	Infiltration Submodel	Infiltration Model Abstraction	2
				Infiltration Process Model	2
		Climate Analysis	Climate Submodel	Future Climate Analysis	3
		Drift Seepage	Drift Seepage Submodel	Drift Seepage Abstraction	4,5
				Drift Seepage Abstraction including Drift Collapse	
				TH Seepage Process Model	
Engineered Barrier System	EBS Environment Model Component	Drift Wall Condensation	Drift Wall Condensation Submodel	In-Drift Natural Convection and Condensation Process Model	7
				Drift Wall Condensation Abstraction	
		EBS Thermal-Hydrologic Environment	EBS TH Environment Submodel	MSTHM Process Model	6
				MSTHM Abstraction	
		EBS Chemical Environment	EBS Chemical Environment Submodel	EBS P&CE Abstraction	8
				IDPS Process Model	15
	WP and DS Degradation Model Component	WAPDEG	WP and DS Degradation Submodel	WP General Corrosion Abstraction	10,11,12
				WP MIC Abstraction	
				WP SCC Abstraction	
				DS General Corrosion Abstraction	
		Localized Corrosion on WP Outer Surface	Localized Corrosion Initiation Submodel	Localized Corrosion Initiation Abstraction	
				Localized Corrosion Penetration Rate Abstraction	

Table 6-4 Relationship among TSPA Model Components, Submodels, and Abstraction/Process Model(s)/Analysis(es) (Continued)

Barrier	TSPA-LA Principal Model Components		Submodel for TSPA-LA	Abstraction/Process Model(s)/Analysis(es)	Reference[1]
Engineered Barrier System (Continued)	Waste Form Degradation and Mobilization Model Component	Radionuclide Inventory	Radionuclide Inventory Submodel	Initial Radionuclide Inventory Screening Analysis	20,35
				Initial Radionuclide Inventory Abstraction	20,35
		In-Package Chemistry	In-Package Chemistry Submodel	In-Package Chemistry Abstraction	21
		Cladding Degradation	Cladding Degradation	Cladding Degradation Abstraction	22
		CSNF, DSNF, HLW Degradation	Waste Form Degradation Submodel	CSNF WF Degradation Abstraction	23
				DSNF WF Degradation Abstraction	24
				HLW Glass Degradation Abstraction	25
		Dissolved Radionuclide Concentration Limits	Dissolved Concentration Limits Submodel	Dissolved Concentration Limits Abstraction	26
		WF and EBS Colloids	Engineered Barrier System Colloids Submodel	WF and In-Drift Colloid Concentration Abstraction	27
	EBS Flow and Transport Model Component	EBS Flow	EBS Flow Submodel	EBS Flow Abstraction	13
		EBS Transport	EBS Transport Submodel	EBS Transport Abstraction	13
				Single Continuum Invert Abstraction	
				Mass of Corrosion Products Abstraction	
				Waste Form Water Volume Abstraction	22,25
			EBS-UZ Interface Submodel	EBS-UZ Interface Abstraction	13
Lower Natural Barrier	Unsaturated Zone Transport Model Component	UZ Transport (Particle Tracking)	UZ Transport Submodel	Active Fracture Model Abstraction	14
				Particle Tracking Model Abstraction	
				Dual-Continuum Transport Model Abstraction	
				UZ Transport Abstraction	

Table 6-4 Relationship among TSPA Model Components, Submodels, and Abstraction/Process Model(s)/Analysis(es) (Continued)

Barrier	TSPA-LA Principal Model Components		Submodel for TSPA-LA	Abstraction/Process Model(s)/Analysis(es)	Reference[1]
Lower Natural Barrier (Continued)	SZ Flow and Transport Model Component	3-D SZ Flow and Transport	SZ Flow and Transport Submodel	3-D SZ Flow and Transport Process Models	17,18
				3-D SZ Flow and Transport Abstraction	16
		1-D SZ Flow and Transport		SZ Convolute Abstraction	
				1-D SZ Flow and Transport Abstraction	
N/A	Biosphere Model Component	Nominal BDCFs	Biosphere Submodel	Biosphere Process Model	19
		Groundwater Protection Conversion Factors		Groundwater Exposure Case Abstraction	
		Disruptive Events BDCFs		Volcanic Ash Exposure Case Abstraction	
Engineered Barrier System	Events	Early Failure	DS Early Failure Submodel	Abstraction of DS Failures from Undetected Defects	28
			WP Early Failure Submodel	Abstraction of WP Failures from Undetected Defects	28
		Igneous Activity	Igneous Intrusion Submodel	Igneous Activity Analysis	29
			Igneous Event Time and Probability Submodel	Annual Frequency Abstraction	
			Igneous Intrusion EBS Damage Submodel	Number of WP Hit by Igneous Intrusion Abstraction	30
			EBS TH Environment Submodel Modifications for Igneous Intrusion	Dike Drift Interactions Analysis	9
			EBS Chemical Environment Submodel Modifications for Igneous Intrusion	Unevaporated Seepage Chemistry Abstraction	
				Basalt Chemistry Abstraction	
			Mean Annual Dose for Igneous Intrusion	Calculation of Expected Dose	Section 6.1.2 Appendix J

Table 6-4 Relationship among TSPA Model Components, Submodels, and Abstraction/Process Model(s)/Analysis(es) (Continued)

Barrier	TSPA-LA Principal Model Components		Submodel for TSPA-LA	Abstraction/Process Model(s)/Analysis(es)	Reference[1]
Engineered Barrier System (Continued)	Events (Continued)	Igneous Activity (Continued)	Volcanic Eruption Submodel	Eruptive Processes Analysis	31,32
			Volcanic Interaction with the Repository Submodel	Number of WP Hit by Eruptive Conduits Analysis	30
			Atmospheric Transport Submodel	Atmospheric Dispersal and Deposition of Tephra Analysis	32,33
				ASHPLUME Model Abstraction	
			Tephra Redistribution Submodel	Redistributed Tephra Abstraction	
			Volcanic Ash Exposure Submodel	Mean Annual Dose for Volcanic Eruption Abstraction	31
		Seismic Activity	Ground Motion Damage	Seismic Damage Abstraction	34
			Fault Displacement Damage		
			Drift Seepage Submodel and Drift Wall Condensation Submodel Modifications for Seismic Disruption	Drift Seepage Abstraction including Drift Collapse	4,5
			EBS TH Environment Submodel Modifications for Seismic Disruption	Collapsed Drift TH Abstraction	6
			WP and DS Degradation Submodel Modifications for Seismic Disruption	WP and DS Degradation Submodel	10,11,12

Table 6-4 Relationship among TSPA Model Components, Submodels, and Abstraction/Process Model(s)/Analysis(es) (Continued)

Barrier	**TSPA-LA Principal Model Components**		**Submodel for TSPA-LA**	**Abstraction/Process Model(s)/Analysis(es)**	**Reference[1]**
Engineered Barrier System (Continued)	Events (Continued)	Seismic Activity (Continued)	WP Localized Corrosion Initiation Submodel for Seismic Disruption	Localized Corrosion Initiation Analysis	10
N/A	TSPA-LA	Human Intrusion	Human Intrusion Submodel	10CFR Part 63.322 and 63.321	36

NOTES: Modified from Table 1-1 (SNL 2008 [DIRS 183478]).

[1] References are listed by number that is contained in the “Key to References” list below (as a continuation of the table).

Table 6-4 Key to References in Last Column of "Relationship among TSPA Model Components, Submodels, and Abstraction/Process Model(s)/Analysis(es)" (Continued)

Number	Reference
1	*UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614])
2	*Simulation of Net Infiltration for Present-Day and Potential Future Climates* (SNL 2008 [DIRS 182145])
3	*Future Climate Analysis* (BSC 2004 [DIRS 170002])
4	*Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244])
5	*Seepage Model for PA Including Drift Collapse* (BSC 2004 [DIRS 167652])
6	*Multiscale Thermohydrologic Model* (SNL 2008 [DIRS 184433])
7	*In-Drift Natural Convection and Condensation* (SNL 2007 [DIRS 181648])
8	*Engineered Barrier System: Physical and Chemical Environment* (SNL 2007 [DIRS 177412])
9	*Dike/Drift Interactions* (SNL 2007 [DIRS 177430])
10	*General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519])
11	*Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007 [DIRS 181953])
12	*General Corrosion and Localized Corrosion of the Drip Shield* (SNL 2007 [DIRS 180778])
13	*EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407])
14	*Particle Tracking Model and Abstraction of Transport Processes* (SNL 2007 [DIRS 184748])
15	*In-Drift Precipitates/Salts Model* (SNL 2007 [DIRS 177411])
16	*Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750])
17	*Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391])
18	*Site-Scale Saturated Zone Transport* (SNL 2008 [DIRS 184806])
19	*Biosphere Model Report* (SNL 2007 [DIRS 177399])
20	*Initial Radionuclides Inventory* (SNL 2007 [DIRS 180472])
21	*In-Package Chemistry Abstraction* (SNL 2007 [DIRS 180506])
22	*Cladding Degradation Summary for LA* (SNL 2007 [DIRS 180616])
23	*CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004 [DIRS 169987])
24	*DSNF and Other Waste Form Degradation Abstraction* (BSC 2004 [DIRS 172453])
25	*Defense HLW Glass Degradation Model* (BSC 2004 [DIRS 169988])
26	*Dissolved Concentration Limits of Radioactive Elements* (SNL 2007 [DIRS 177418])
27	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (SNL 2007 [DIRS 177423])
28	*Analysis of Mechanisms for Early Waste Package/Drip Shield Failures* (SNL 2007 [DIRS 178765])
29	*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989])
30	*Number of Waste Packages Hit by Igneous Events* (SNL 2007 [DIRS 177432])
31	*Characterize Eruptive Processes at Yucca Mountain, Nevada* (SNL 2007 [DIRS 174260])
32	*Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 177431])
33	*Redistribution of Tephra and Waste by Geomorphic Processes Following a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 179347])
34	*Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828])
35	*MOX Spent Nuclear Fuel and LaBS Glass for TSPA-LA* (SNL 2007 [DIRS 177422])
36	NRC Proposed Rule at 10 CFR 63.321 [DIRS 178394] and 10 CFR 63.322 [DIRS 180319]

6.1.5 Methodology for Important to Barrier Capability/Important to Waste Isolation Evaluation

The bases for ITBC evaluations consist of FEP disposition and FEP screening justification, corresponding analysis and/or model reports, professional judgment, and the following enabling assumptions:

1. ITBC is evaluated in the context of the current design (including waste package, drip shield, thermal loading, repository location, etc.).

2. ITBC is evaluated in the context of all controls necessary to support the analyzed basis.

3. ITBC is evaluated in the context of two regulatory compliance durations. Based on the interpretation of regulations and consistency with the performance assessment, barrier capability, as such, is limited to considerations during the initial ten thousand years for those FEPs excluded from the performance assessment. FEPs involving seismicity, igneous scenario, general corrosion, and climate change are included for both 10,000 years and the period of geologic stability. For these exceptions and for those barriers, features, events, and processes associated with FEPs included in the performance assessment, the compliance duration is the period of geologic stability (approximately one million years) as proposed by 40 CFR Part 197 [DIRS 177357].

4. ITBC evaluations consider only the primary feature, event, or process associated with each FEP – the evaluation does not consider secondary coupled processes.

5. ITBC evaluations consider all TSPA scenario classes and disruptive events: Nominal (expected corrosion failure), Early Failure (waste package and drip shield), Igneous (intrusion and eruption), and Seismic (fault displacement and ground motion).

Once the barriers are selected as described in Section 6.1.2, the process starts with a review of each FEP's (included and excluded) description and screening justification. The FEP description and screening justification can lead to an association with a barrier and a specific barrier feature/component. The resulting features/components are associated with each of the barriers. For the EBS, the resulting features/components are consistent with the preclosure SSCs identified in *Nuclear Safety Design Bases for License Application* (BSC 2005 [DIRS 175546]). For each barrier, the list created from this first step identifies a FEP with each relevant feature/component. Some FEPs are repeated because they may be associated with more than one feature/component of a barrier.

Once the list of FEPs is organized according to associated barrier feature/component, each FEP is reviewed for its relationship to core and control parameter characteristics using the definitions presented in Section 6.1.1. The identified core and control parameter characteristics are then evaluated for their impacts to the capability of a specific barrier feature/component.

For each barrier feature/component, the ITBC evaluations are based on the following two criteria linked closely to the definition of a barrier in 10 CFR 63.2 [DIRS 180319]:

1. Does the parameter characteristic prevent or substantially reduce the rate of movement of water from the Yucca Mountain repository to the accessible environment?

2. Does the parameter characteristic FEP prevent or substantially reduce the rate of movement of radionuclides from the Yucca Mountain repository to the accessible environment or prevent the release or substantially reduce the release rate of radionuclides from the waste?

The term substantially in the above criteria is relative to all features that comprise a barrier. For example, the engineered barrier is comprised of eight features including the waste package and invert. Because of the relative importance of the waste package compared to the invert, FEPs involving the waste package are more likely to be associated with parameter characteristics that are ITBC than the FEPS that are associated with the Invert.

The determination of the ITBC status cannot rely solely on the FEP screening decision regarding its inclusion or exclusion from the TSPA. There are instances where a FEP has been demonstrated to be excluded from the performance assessment but is associated with a parameter characteristic that is determined to be ITBC. This situation may arise when the justification for the exclusion of the FEP relies upon the parameter characteristic.

The bases for ITBC evaluations were implemented with rigor by soliciting participation from members of the Performance Assessment System Integration Team and several other subject matter experts in the review of the FEP descriptions and screening justifications. This cadre of experts conducted evaluations and subsequent discussions to solidify the final decisions regarding the ITBC status of 374 FEP/feature-component combinations listed in Appendix A.

A feature/component is ITWI if it is associated with an ITBC parameter characteristic, and if the feature is judged to be a significant contributor to barrier capability, relative to the other features of the barrier or the feature functions to prevent or significantly mitigate the consequences of potential disruptive events (e.g., criticality). All three barriers, UNB, LNB, and the EBS are determined to be ITWI by this analysis. In addition to the ITBC/ITWI evaluations described above, the barrier capability analysis presented in Section 6.2 also includes identification of the following:

- Process Models Used—A summary of each model used to characterize and assess the capability of the ITWI barriers

- Characteristics—A summary of the general characteristics of each ITWI barrier (and its associated features) that support the discussion of barrier capability

- Capabilities—A discussion of specific characteristics and processes associated with each barrier/feature. Separate discussions are provided for each applicable barrier function.

- Temporal Considerations—A discussion of possible changes to the barriers, features, and their capability due to nominal processes that may occur after closure
- Impact of Disruptive Events—A discussion of possible changes to the barriers, features, and their capability due to disruptive events
- Uncertainties—A discussion of uncertainties as they affect barrier capability.

The use of the FEP information in the barrier capability analysis addresses the following issues related to meeting the intent of 10 CFR 63.115 [DIRS 180319]:

- The complete list of FEPs (included and excluded) that might potentially affect features and barrier capability is considered in Section 6.2
- Uncertainties considered during FEP screening are also considered in the barrier capability analysis
- The analysis and understanding, of the barrier capability are consistent with the technical bases of the performance assessment used to demonstrate compliance with 10 CFR 63.113 (b) and (c), [DIRS 180319] as they are based on results from the FEP screening analyses. This is strictly true for included FEPs. FEPs whose exclusion from the TSPA results in conservative estimates of dose may still contribute to barrier capability even though they do not contribute to performance.

Total System Performance Assessment Data Input Packages were used for consistency evaluations of the control parameters used in the TSPA and the analyses in this report. These included the *Total System Performance Assessment Data Input Package for Requirements Analysis for Engineered Barrier System In-Drift Configuration* (SNL 2007 [DIRS 179354]), *Total System Performance Assessment Data Input Package for Requirements Analysis for DOE-OWNED SNF/HLW and Naval SNF Waste Package Physical Attributes Basis for Performance Assessment* (SNL 2007 [DIRS 179567]), *Total System Performance Assessment Data Input Package for Requirements Analysis for Subsurface Facilities* (SNL 2007 [DIRS 179466]), and the *Total System Performance Assessment Data Input Package for Requirements Analysis for TAD Canister and Related Waste Package Overpack Physical Attributes Basis for Performance Assessment* (SNL 2007 [DIRS 179394]).

6.1.6 Core and Control Parameter Characteristics

Core parameter characteristics were identified from knowledge of defining processes and features relevant to FEP screening justifications and dispositions. They were selected by a group of postclosure technical leads who reviewed each FEP in the context of specific barrier features/components. The group had working knowledge and expertise in all the areas relevant to postclosure science and design integration. The group used information contained in the AMRs to supplement the information contained in the FEP disposition and justification. The group identified the high-level processes and informational areas that are needed to implement the inclusion of the FEP into performance assessment or related to the FEP screening justifications based upon their knowledge of these processes as supported by the AMRs. If a core parameter characteristic was essentially the same as a control parameter, the core parameter characteristic was eliminated and the control parameter characteristic retained.

Core parameter characteristics are listed in Table 6-5 and cited in Appendix A.

Core parameter characteristics are defined in Section 6.1.1. They are associated with core parameters that contribute to barrier capability, support the postclosure technical baseline, and are candidates for performance confirmation. They are related to the events and/or processes that act on a feature as described by a FEP screening justification or report. Core parameter characteristics are generalized, and they include the materials, properties, configurations, and/or orientations.

Table 6-5. Core Parameter Characteristics

Core Parameter Characteristic[1]
Characterization of Fault Displacement
Characterization of Igneous Events
Characterization of Seismic Events
Closure Materials
Corrosion Products Properties
Criticality Characteristics
Drip Shield Corrosion
Drip Shield Materials, Properties, and Configuration
Drip Shield Seismic Performance
Emplacement Drift Configuration
Emplacement Pallet Materials, Properties, and Configuration
Extent of Saturated Zone
Extent of Unsaturated Zone
Geothermal Gradient
In-Drift Chemical Environment
In-Drift Chemical Environment Properties
In-Drift Thermal Environment, Convection, Condensation, and Evaporation
Infiltration and Seepage
Infiltration and Seepage Properties
In-Package Chemical Environment
In-Package Thermal Environment,
Inside Waste Package Waste Forms
Interpretation of Fault Displacement
Invert Materials Properties, and Configuration
Pallet Materials, Properties, and Configuration
Preclosure Ventilation
Properties of corrosion products
Properties of the Host Rock Unit
Properties of Unsaturated Zone
Radionuclide Inventory and Source Term Properties
Radionuclide Properties
Repository: location and depth; layout and geometry; construction, operation, and closure
Saturated Zone Chemical Environment
Saturated Zone Flow

Table 6-5. Core Parameter Characteristics (Continued)

Core Parameter Characteristic
Saturated Zone Properties
Saturated Zone Transport
Backfill Materials, Properties, and Configuration
Seepage Water Chemistry
Seepage Water Properties
Surface Soil Properties (Including Vegetation)
Thermal Loading and Distribution
Unsaturated Zone Chemical Environment
Unsaturated Zone Flow
Unsaturated Zone Properties
Unsaturated Zone Transport
Waste Form Degradation
Waste Form, Properties, and Configuration
Waste Form/Package Internals Materials, Properties, and Configuration
Waste Package Materials, Properties, and Configuration
Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat
Waste Package Temperature Limit

NOTE: [1] Core Parameter Characteristics are the specific aspects of the contribution to barrier capability that are defined or supported by logical groupings of a quantity or variable that defines or supports a contribution to barrier capability or a model (conceptual, mathematical, or numerical) describing that capability. A core parameter supports the postclosure technical bases and is not controlled or manipulated during, design, construction, or operations. These parameters were developed for use in this document.

Control parameter characteristics are defined in Section 6.1.1 and listed in Table 6-6. They are associated with control parameters that contribute to barrier capability, support the postclosure technical baseline, and are controlled, or manipulated during design, construction, or operations. They are associated with features/components in such a fashion as to provide a reasonable expectation that the feature/component capability will be as described in the postclosure technical baseline, the TSPA, and the Safety Analysis Report. A control parameter characteristic may include, but is not limited to, fit, form, and functionality of the materials of a barrier feature/component. Control parameter characteristics are that information that identifies the specific functions to be performed by a feature/component (or SSC) so that the nuclear safety design bases of a feature within an engineered barrier (based on the core characteristics for the engineered barrier) will be as analyzed. These control parameter characteristics are consistent with *Postclosure Modeling and Analyses Design Parameters* (BSC 2008 [DIRS 183627]). Control parameter characteristics include the application of process controls during design, construction, and operation. For example, control parameter characteristics constrain the design of the EBS to ensure the performance objectives of 10 CFR 63.113 [DIRS 180319] are achieved. Any changes to the controls or the design will be evaluated through an established change evaluation process (Section 6.1.8), which will include an evaluation of the impacts.

Focusing on core and control parameter characteristics will better ensure that the performance objectives of 10 CFR 63.113 [DIRS 180319] can be achieved. Core and control parameter characteristics are listed in Tables 6-5 and 6-6 and cited in Appendix A.

As stated in Section 6.1.1, core and control parameter characteristics may be determined to be ITBC if the characteristic prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain repository to the accessible environment, or prevents the release of or reduces the release rate of radionuclides from the waste.

Parameter characteristics were identified from consideration of the following categories of parameters: the initial set of control parameters (BSC 2005 [DIRS 175150], Table 2), the performance assessment parameters, performance confirmation activities and candidate parameters (BSC 2004 [DIRS 172452], Table 3-2), and professional judgment. These candidate parameter characteristics were edited, generalized, and consolidated to produce the working set of core and control parameter characteristics shown in Table 6-5 and 6-6. In Table 6-6, the unique number in the first column is the identifier used in the *Postclosure Modeling and Analyses Design Parameters* (BSC 2008 [DIRS 183627]). These core and control parameter characteristics are generalized into broad categories for this report. This generation of broad categories of parameter characteristics ensures proper categorization. Subdivision will be included in the Performance Confirmation test plans where more specific parameter characteristics or parameters with corresponding ranges and values will be identified.

Table 6-6. Control Parameter Characteristics

Number	Control Parameter Characteristic
01-01	Repository Geographic and Geologic Location
01-02	Repository Layout
01-03	Repository Geologic Location
01-04	Repository Elevation – Standoff from Water Table
01-05	Repository Standoff from Quaternary Fault
01-06	Repository Elevation – Overburden Thickness
01-07	Repository Standoff from Perched Water
01-08	Orientation of Emplacement Drifts
01-09	Excavation Methods
01-10	Emplacement Drift Configuration
01-11	Emplacement Drift Gradient
01-12	Non-Emplacement Opening Gradient
01-13	Emplacement Drift Spacing
01-14	Verification of Design Rock Properties
01-15	Design of Ground Support System
01-16	Air Circulation through Ground Support
01-17	Emplacement Drift Ground Support
01-18	Unheated Drift Length
01-19	Flood Protection
01-20	Repository Standoff from Paintbrush Nonwelded Hydrogeologic Unit
01-21	Minimum Thickness of the Paintbrush Nonwelded Hydrogeologic Unit above the Repository
01-22	Repository Standoff from Calico Hills Nonwelded Hydrogeologic Unit
02-01	As-Emplaced Waste Configuration
02-02	As-Emplaced Waste Package-Drip Shield Configuration
02-03	Committed Materials
02-04	Invert and EBS Components In Situ Stress and Thermal Response
02-05	EBS In-Drift Materials Interactions

Table 6-6. Control Parameter Characteristics (Continued)

Number	Control Parameter Characteristic
02-06	EBS Material Interactions – Copper
02-07	Emplacement Drift Invert Function
02-08	Invert Materials
02-10	Emplacement Drift Invert Configuration
03-01	Waste Package Dimensions and Component Masses
03-02	Waste Package Quantities
03-03	Waste Package Outer Barrier Material and Thickness
03-04	Waste Package Radial Gap
03-05	Waste Package Longitudinal Gap
03-06	Waste Package Internal Pressurization
03-07	Waste Package Corrosion Allowance
03-08	Seismic Design of Waste Package
03-09	Waste Package Worst-Case Dose Rate
03-10	Waste Package Design Basis Bounding Dose Rate
03-11	Waste Package Decay Heat
03-12	Waste Package Fabrication
03-13	Waste Package Fabrication Weld Inspections
03-14	Waste Package Welding Materials
03-15	Waste Package Fabrication Welding Flaws
03-16	Waste Package Annealing
03-17	Waste Package Closure
03-18	Waste Package Surface Marring Prior to Emplacement
03-19	Waste Package Outer Barrier Material Specifications
03-20	Materials Contacting the Waste Package
03-21	Waste Package Handling
03-22	Waste Package Handling and Emplacement
03-23	Waste Package Surface Finish
03-24	Waste Package Surface Damage Prior to Closure
03-26	Waste Package Moisture Removal and Inerting
04-01	Loading of Waste Forms
04-02	Handling of Bare SNF
04-03	Waste Form CSNF Fuel Rod Maximum Burnup Limit
04-04	Waste Form Moisture Removal and Inerting
04-05	Cladding Temperature Limit -- Waste Form
04-06	Maximum Temperature of HLW Glass Canisters -- Waste Form
04-07	Waste Package Capacities
04-08	Handling of Waste Forms
04-09	Waste Package and TAD Canister Excluded Materials
05-01	Waste Package Handling and Emplacement
05-02	Waste Package Spacing
05-03	Waste Package Thermal Limits
05-04	No Backfill in Emplacement Drifts
06-01	Duration of Ventilation Period
06-02	Drift Wall Temperature

Table 6-6. Control Parameter Characteristics (Continued)

Number	Control Parameter Characteristic
06-03	Waste Package Temperature Limit
06-04	Cladding Temperature Limit -- Ventilation
06-05	Maximum Temperature of HLW Glass Canisters -- Ventilation
06-06	Average Airflow Rate for Preclosure Ventilation of Emplacement Drifts
07-01	Drip Shield Design
07-02	Drip Shield Design and Installation
07-03	Drip Shield Corrosion Allowance
07-04	Drip Shield Materials and Thicknesses
07-07	EBS Drip Shield / Emplacement Drift Invert Materials Interactions
07-08	Drip Shield Seismic Performance
07-09	Drip Shield Fabrication
07-10	Drip Shield Fabrication Weld Inspections
07-11	Drip Shield Fabrication Welding Flaws
07-12	Drip Shield Fabrication Weld Materials
07-13	Drip Shield Heat Treatment
07-14	Drip Shield Handling
07-15	Drip Shield Thermal Expansion Constraint
07-16	As-Emplaced Waste Configuration – Waste Package/Drip Shield Clearance
08-01	Emplacement Pallet Design
08-02	Emplacement Pallet Function
08-03	Emplacement Pallet Fabrication and Corrosion Allowance
08-04	EBS Materials Interactions – Emplacement Pallet Function
08-05	Waste Package and Emplacement Pallet Static Stresses
09-01	Closure of Shafts and Ramps
09-03	Closure of Boreholes
09-04	Reclamation of Lands Disturbed by Repository

Source: BSC 2008 [DIRS 183627], Table 1.

6.1.7 Integration of the Performance Confirmation Program

A completeness review was conducted to compare the results from this report and the TSPA to the activities in the *Performance Confirmation Plan* (SNL 2008 [DIRS 184797], Appendix A). This review used information extracted from this report to link the models and parameters identified in Appendix A of this report, to the analyzed basis of the barriers. It notes that this document identifies core parameter characteristics for feature/components important to barrier capability, which would be candidates for evaluation in the performance confirmation program.

Core parameter characteristics pertain to features/components included in models supporting performance assessment as well as to features, events and processes (FEPs) that have been excluded. Performance confirmation activities will evaluate both excluded and included FEPs. Core parameter characteristics deemed important to barrier capability (ITBC) and which are possible to test or monitor would be candidates for inclusion in the confirmation program. Some aspects of barrier capability identified in the PoNSDB are not significant in (or in some instances, excluded from) performance assessment models, but are compared to the Performance

Confirmation Plan activities. Thus, PoNSDB identifies all barrier capabilities, whereas, TSPA identifies which of these capabilities are represented in risk and performance determinations.

The activities identified in the Performance Confirmation Plan have been compared to the assumptions, data, and information that comprise the performance assessment models and results of the TSPA and the PoNSDB document. This exercise has confirmed that the existing performance confirmation activities provide a breadth of investigations sufficient to evaluate the performance basis of the license application. None of these activities is identified for deletion at this time (SNL 2008 [DIRS 184797]).

6.1.8 Methodology for Postclosure Change Evaluation

Repository design, engineering, construction, and operations activities may result in changes to design, materials, configurations, and processes that differ from the analyzed technical bases. In addition, advances in scientific research may result in information (data, models, and methodologies) that is different than the analyzed bases. Finally, the regulator may dictate change(s). The evaluation of such changes with respect to the postclosure technical basis and performance assessment is a necessary part of change control management, which involves integration among the preclosure safety analyses of the design organization (currently Bechtel SAIC Company, LLC (BSC)), Postclosure Analysis Organization (currently Sandia National Laboratories), the Department of Energy (DOE), and the Naval Nuclear Propulsion Program. The process of change evaluation and documentation for the Postclosure Analysis Organization will be captured in a new procedure.

10 CFR 63.44 [DIRS 180319] provides regulatory requirements associated with change control for the technical basis documented in the Safety Analysis Report, but is not invoked until after construction authorization is granted. It is prudent to design the preconstruction change evaluation process to be consistent with the information needs of the program that will be implemented to comply with 10 CFR 63.44 [DIRS 180319] when it is invoked. The process presented herein is primarily intended to provide evaluations of changes to postclosure activities and/or SSCs that will be required during the postclosure period during the presubmittal and preconstruction authorization time periods, although the process could additionally be used to address some of the requirements for 10 CFR 63.44 [DIRS 180319]. The requirements related to change control processes in 10 CFR 63.44 [DIRS 180319] addresses preclosure and postclosure changes.

Once the decision is made to initiate the postclosure change evaluation, the process, will be implemented. The process of evaluation remains the same regardless of the drivers for the change (e.g., design, operations, or science). Evaluations are made with respect to impacts on the postclosure compliance baseline and performance assessment. The technical basis is defined and documented in the TSPA analysis and/or model report, key supporting postclosure technical documents, the FEPs analysis and Database, and Total System Performance Assessment design interface documents that define the design input parameters and current ranges for those parameters as the required source for postclosure analyses. These documents summarize the postclosure technical bases and will be used as the basis from which to evaluate proposed changes.

A new procedure will establish the process and responsibilities for evaluating proposed changes to repository design, engineering, construction, and operations activities that could impact the postclosure safety analyses. The procedure may also be used to evaluate the potential inclusion of items in the *Q-List*, as necessary. Configuration management and change control of these elements are the responsibility of BSC, the managing and operating contractor for the Yucca Mountain facility.

Evaluations conducted pursuant to this new procedure will include programmatic decision activities, as defined in SCI-PRO-002, *Planning for Science Activities* as these evaluations consist of "what-if" studies of proposed changes to technical baseline parameters and processes. Approved design changes will be incorporated into the design and technical baseline using applicable procedures. Programmatic decision activities may involve alternative conceptual models, parametric changes, scientific analyses or calculations. Programmatic decision documentation shall fully describe the intended use of the product, and shall fully justify assumptions, inputs, and decisions with respect to this intended use.

The evaluation concludes with a report, which will include documentation of the analysis supporting the results, as well as the results, justifications and conclusions that document the results of the evaluations and any subsequent impacts. Also, the report will define, if warranted, a proposed path forward and any additional actions to be taken. The report will be provided to lead lab senior management for any further action, which includes notification of BSC and/or DOE, as necessary.

6.2 SYSTEM DESCRIPTION AND DEMONSTRATION OF MULTIPLE BARRIERS

A critical element for repository safety is a site and system that provides multiple barriers to the movement of water and radionuclides. A barrier is defined in 10 CFR 63.2 as any material, structure, or feature that, for a period to be determined by the NRC, prevents or substantially reduces the rate of movement of water or radionuclides from the Yucca Mountain Repository to the accessible environment, or prevents the release or substantially reduces the release rate of radionuclides from the waste.

The repository system is composed of natural and engineered features that are combined into two natural barriers and an engineered barrier, designated as the UNB, the LNB, and the EBS. These three barriers provide the following principal barrier functions:

- The UNB, by preventing or substantially reducing the amount and the rate of water seeping into the drifts, prevents or substantially reduces the rate of movement of water from the repository to the accessible environment and prevents or substantially reduces the release rate of radionuclides from the waste

- The EBS prevents or substantially reduces the release rate of radionuclides from the waste and prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment

- The LNB prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment, which is located approximately 18 km south of the repository.

As defined by 10 CFR 63.302, the accessible environment means any point outside of the controlled area, including: (1) the atmosphere (including the atmosphere above the surface area of the controlled area); (2) land surfaces; (3) surface waters; (4) oceans; and (5) the lithosphere. For the purposes of the TSPA, the accessible environment is considered to be accessed by the reasonably maximally exposed individual (RMEI) living 18 km south of the repository in the Amargosa Valley. Modeled groundwater flow paths cross the postclosure controlled area boundary only at the portion of the boundary located about 18 km south of the repository (DTN: MO0712DELNPCCA.001 [DIRS 184172]).

The three repository system barriers are important to waste isolation (ITWI) and function in a manner to provide a reasonable expectation that HLW can be disposed of consistent with 10 CFR 63.113(b) and (c) [DIRS 180319]. Accordingly, based upon the analysis performed, the three barriers are ITWI. The understanding of the barriers gained through site characterization and/or repository design permits a demonstration that the barriers work together to perform their postclosure functions. This section identifies and describes the features of the repository system that contribute to barrier performance. These features and the capability of each barrier are described in terms of the physical processes that contribute to repository system performance.

Section 6.2.1 identifies the features of the natural barriers and the EBS that contribute to barrier capabilities and considerations. This section also describes the relationships between the three barriers and the models utilized in the TSPA, as well as identifying the features that ensure waste isolation for 10,000 years after repository closure, and that prevent or substantially reduce the rate of movement of radionuclides for up to 1 million years. For the EBS, these features are described as SSCs.

Section 6.2.2 describes the capability of the barriers to perform one or more of the barrier functions and considers the impacts of likely and unlikely events. This section also demonstrates that the EBS and the two natural barriers, working in combination, result in a repository system with multiple barriers. Section 6.2.2 includes an evaluation of the time period over which the barriers function and the uncertainty associated with analyses of barrier capability. The demonstration of barrier capability considers both qualitative and quantitative information. Qualitative information includes a summary of the events and processes acting on each barrier feature that contribute to barrier capability. Quantitative information supporting barrier capability is developed using the TSPA model and is presented both for the time period up to 10,000 years after repository closure, and for the post-10,000-year period (i.e., after 10,000 years but through the period of geologic stability ending at 1,000,000 years).

It should be noted that, while all barrier capability important to waste isolation is included in TSPA model, some unrealized potential barrier capabilities related to excluded FEPs are not included in the TSPA model. Reasonably conservative model assumptions are sometimes made in the TSPA that result in the tendency of the TSPA model to overestimate release and subsequent dose. Such assumptions are made to reduce model complexity or data needs, or to account for uncertainty in processes. An example discussed in Section 6.2.1.2 is cladding. Although it is recognized that cladding on commercial spent nuclear fuel (SNF) may contribute to barrier capability, no credit is taken for its potential performance in the TSPA model. This assumption is made because the effort involved in inspection outweighs the potential barrier benefit that commercial SNF cladding will provide. The technical basis for the barrier capabilities discussed in Section 6.2.2 is consistent with the technical basis for the TSPA and is commensurate with the importance of each barrier's capability; any differences are identified and justified.

Section 6.2.3 summarizes and cross-references the extensive discussions of the technical basis for the models used to evaluate barrier performance and capability and abstracted for use in the TSPA to demonstrate compliance with the performance objectives of 10 CFR 63.113(b) and (c) [DIRS 180319]. The technical basis for the barrier capabilities discussed in Section 6.2.2 is consistent with the technical basis for the TSPA, and is commensurate with the importance of each barrier capability.

The information discussed in Section 6.2 is based on data and analyses described in the analysis and model reports referenced therein. These data and analyses are the same as those used to support the TSPA model and analyses presented in *Total System Performance Assessment Model/Analysis for the License Application* (SNL 2008 [DIRS 183478]).

The information presented in Table 6-7 summarizes the content of this section, the corresponding regulatory requirements, and the applicable acceptance criteria from NUREG-1804 (NRC 2003 [DIRS 163274]):

Table 6-7. NUREG-1804 and 10 CFR Part 63 Crosswalk Table

Section	Information Category	10 CFR Part 63 Reference	NUREG-1804 Reference
6.2	System Description and Demonstration of Multiple Barriers	63.113(a)	Section 2.2.1.1
6.2.1	Identification of Barriers	63.21(c)(14) 63.113(a) 63.115(a)	Section 2.2.1.1.3: Acceptance Criterion 1
6.2.2	Barrier Capability Description	63.21(c)(14) 63.113(a) 63.115(b)	Section 2.2.1.1.3: Acceptance Criterion 2
6.2.3	Technical Bases for Barrier Capability	63.115(c)	Section 2.2.1.1.3: Acceptance Criterion 3

6.2.1 Identification of Barriers

A multiple barrier system consisting of natural and engineered barriers derived from the characteristics of the site and the design of the repository system is an important element of the safety case. In addition, a thorough postclosure safety assessment based on a comprehensive characterization and testing program, and the use of other information including natural and man-made analogues that provide insight into potential repository performance, is needed. This technical basis for performance assessment is important to both the demonstration of safety and regulatory compliance. Sections 6.2.1, 6.2.2, and 6.2.3 will describe this information for each of the barriers in some detail.

The repository system is composed of three barriers: the UNB, the EBS, and the LNB. Figure 6-3 is a schematic representation of the repository system that shows the three barriers and the features making up each barrier. The geologic and hydrologic features and characteristics of the Yucca Mountain site form effective natural barriers to the flow of water and to the potential movement of radionuclides. The underground environment within the natural setting is conducive to the design and construction of EBS features that prevent or substantially reduce the potential release of radionuclides from the waste.

Each of the barriers in the repository system works individually and together to prevent or substantially reduce the rate of movement of water and/or radionuclides to the accessible environment and the release rate of radionuclides from the waste. Table 6-4 shows the relationship among the three barriers and the components used in the TSPA. These models provide the technical bases for the inputs and abstraction models that are implemented in the TSPA. Barriers are comprised of features. The features of the UNB are evaluated with respect to how they prevent or substantially reduce the rate and amount of water that may seep into the repository drifts and, in turn, the accessible environment. The features of the EBS are evaluated with respect to how they prevent or substantially reduce the release rate of radionuclides from the waste or how they prevent or substantially reduce the rate of movement of radionuclides from the repository. The features of the LNB are evaluated with respect to how they prevent or substantially reduce the rate of movement of radionuclides from the repository to the accessible environment.

Features have various processes acting on them that contribute to the ability of the feature to perform one or more functions related to the barrier capability. To evaluate the capability of the barriers, the impacts of different processes acting on the features that make up the barrier is assessed. For example, matrix diffusion and radionuclide retardation are processes acting within both features of the LNB (i.e., the unsaturated zone below the repository and the saturated zone) that contribute to preventing or substantially reducing the rate of movement of radionuclides away from the repository. It is, therefore, appropriate to evaluate the capability of barriers in the context of the processes that act within the features.

Features also have various events acting upon them that may affect their barrier function and capability. The evaluation of barrier capability provides information on the time period over which each barrier and feature performs its function, including the potential effects associated with events that are expected to occur. For example, the potential effect of seismic events on the capability of the EBS is considered in the evaluation of the EBS barrier capability. The impacts of seismic events on the EBS and its barrier function during the period of geologic stability (one million years) are potentially more significant than impacts during the 10,000-year period following repository closure. This result is based primarily on the fact that corrosion processes acting over long periods of time will degrade the EBS features and reduce their structural integrity, making them more susceptible to damage induced by vibratory ground motion. Igneous disruptive events are not evaluated with respect to barrier capability, even though such events are included in Section 6.2, because disruptive events, in general, disrupt the barriers and are not attributes of the capability of the physical feature itself.

In the following discussion, all physical attributes of the repository system, whether natural or engineered, are called features. In addition to the barrier function that many features provide, there are features that contribute to a barrier function by providing a stable environment in which other features perform their function.

The processes that act on the features, which allow the natural barriers to perform the functions of preventing or substantially reducing the rate of movement of water or radionuclides, are generally hydrologic and thermal-hydrologic processes or transport processes. The processes that act on the engineered features, which allow the EBS to perform the function of preventing or substantially reducing the release rate of radionuclides from the waste, are generally hydrologic and thermal-hydrologic, chemical and thermal-chemical, mechanical and thermal-mechanical, and transport processes. These include the degradation, deterioration, or alteration processes (evaluated in accordance with 10 CFR 63.114(f) [DIRS 180319]) that can affect the integrity of the EBS.

6.2.1.1 Upper Natural Barrier

The UNB consists of (1) surface topography and surficial soils, and (2) the unsaturated zone above the repository. Figure 6-5 presents a schematic of Upper Natural Barrier. Both these features are important to waste isolation. Surface topography and surficial soils act to limit infiltration into the unsaturated zone through a combination of evaporation, transpiration, and runoff (SNL 2008 [DIRS 182145]). The unsaturated zone above the repository horizon prevents or limits seepage into emplacement drifts by attenuating episodic flow and diverting percolation laterally. At the drift walls, flow is diverted around the drift opening through a combination of capillarity and thermal processes (SNL 2007 [DIRS 181244]).

The location and elevation of the repository take advantage of the characteristics of the geologic and hydrogeologic setting of Yucca Mountain. These characteristics include:

- A semiarid climate with limited precipitation and significant evapotranspiration
- A thickness of rock and soil above the repository everywhere greater than 200m and up to more than 400 m

- Geologic, geochemical, and geomechanical characteristics compatible with the design and construction of an effective EBS

- Geomechanical and thermal characteristics that provide a stable facility with adequate capacity for waste disposal.

At Yucca Mountain the majority of precipitation does not infiltrate into the unsaturated zone because of surface runoff, evaporation, and transpiration. On the basis of the values in the infiltration report (SNL 2008 [DIRS 182145], Section 6.5.7), the infiltration on average ranges up to about only 10% of the precipitation expected over the repository area, even for future wetter climates. This small amount of water infiltrates the ground surface and percolates downward as percolation flux, driven by gravity and capillary forces, through layers of welded and nonwelded tuff units. The major hydrogeologic units within the upper natural barrier include the Tiva Canyon welded (TCw) and the Paintbrush nonwelded (PTn) units located above the repository and the Topopah Spring welded (TSw) unit that hosts the repository (BSC 2004 [DIRS 170035], Section 6.1.2).

As water percolates downward through the unsaturated zone of the upper natural barrier it is redistributed between fractures and matrix, and by lateral flow along layer interfaces to faults (BSC 2004 [DIRS 170035], Section 6.1). Over the unsaturated zone flow model domain, a substantial portion of flow is laterally diverted in the PTn into faults, where fault flow increases from 1% to 2% at the top of the PTn to 12% to 32% at the repository level. However, within the repository footprint, fault flow is about 1% of the total at the top of the PTn and at the repository horizon, indicating less significant lateral flow in the PTn for this smaller area (SNL 2007 [DIRS 184614], Tables 6.6-1, 6.6-2, and 6.6-3). The PTn unit has high matrix permeability and high matrix porosity with low fracture density, and its matrix system has a large capacity for storing groundwater. The relatively high matrix permeability and porosity, and the low fracture density of the PTn unit, convert the predominant fracture flow in the TCw unit above the PTn to dominant matrix flow within the PTn unit, thus damping flow through the UZ. In contrast, water flow in the fractured welded tuffs that host the repository (i.e., the TSw hydrogeologic unit) occurs primarily in widely distributed fractures (SNL 2007 [DIRS 184614], Section 6.9).

The location of repository excavations in the unsaturated zone also limits the seepage of water as a result of capillary processes. Water moving through the rock matrix or in fractures in the unsaturated zone tends not to flow into large openings, such as drifts, but tends to continue to flow in the matrix and fractures in the rock around openings. These processes divert percolating water around the emplacement drifts and into the rock pillars between the drifts (SNL 2007 [DIRS 181244], Section 6.3.1). Seismic events and igneous intrusion events would tend to decrease the water flow diversion effect of drifts (SNL 2007 [DIRS 181244], Sections 6.5.1.5 and 6.5.1.7). Emplacement drifts degrade with time as a result of seismic activity, potentially leading to changes in drift shape, size, and filling of drift openings with rubble rock material. Igneous intrusion events potentially lead to magma-filled drifts. The impact of changes in shape, size, or filling the drifts in both of these events would tend to decrease the water flow diversion effect of drifts.

The design of the repository system also takes advantage of the heat generated by emplaced waste to increase the diversion of percolating water away from and around the emplacement drifts. As long as drift wall temperature exceeds the boiling point of water, no liquid water will be available to flow into emplacement drifts. Above-boiling temperatures will generally persist for several hundred to more than 1,000 years following closure, particularly in the drifts near the center of the repository footprint (SNL 2008 [DIRS 184433], Section 6.3.1).

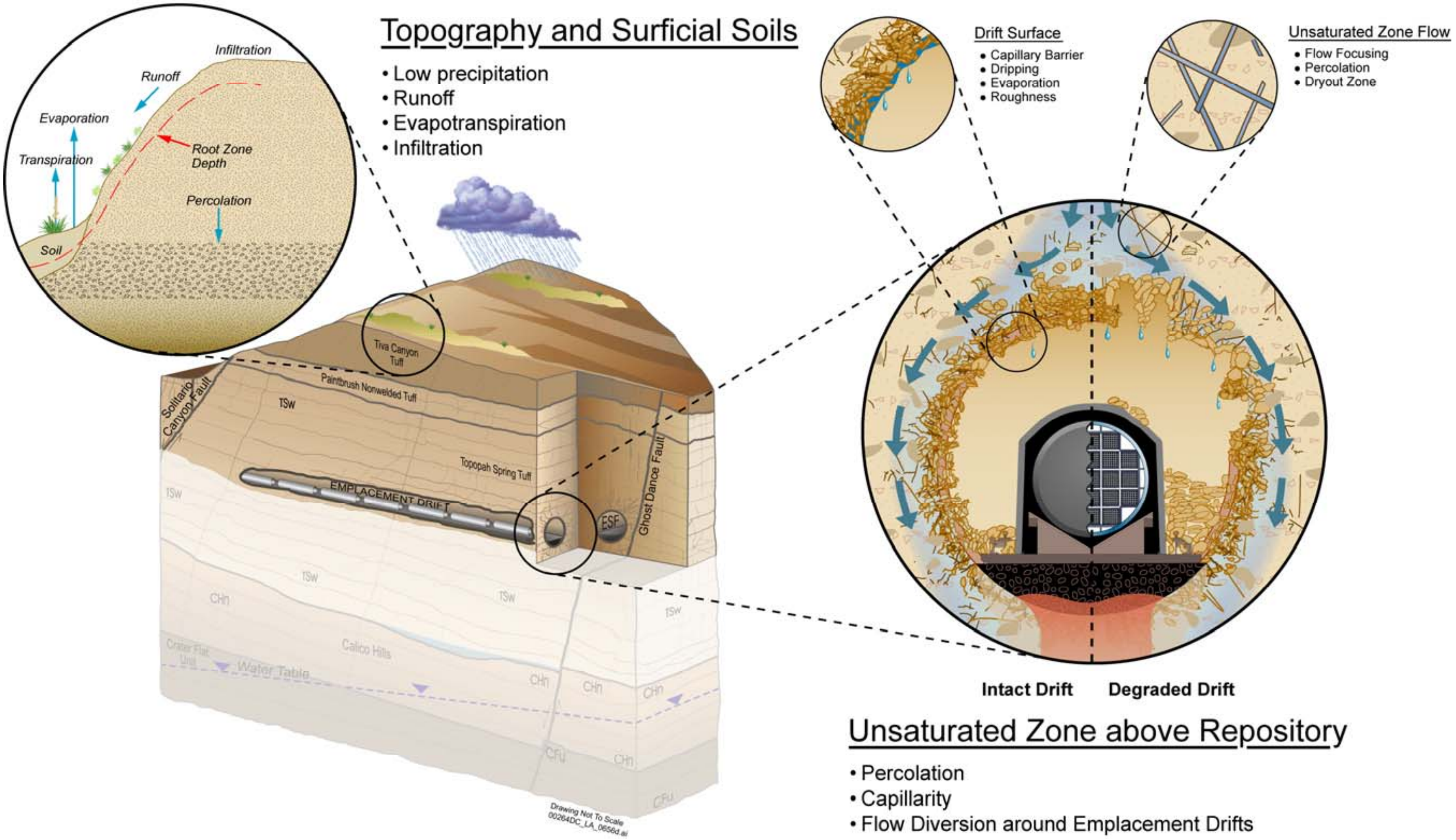


Figure 6-5. Schematic of the Upper Natural Barrier

6.2.1.2 Engineered Barrier System

The EBS is composed of features/components designed to work together and to complement the natural barriers by preventing or substantially reducing the release rate of radionuclides from the waste and preventing or substantially reducing the rate of movement of radionuclides from the repository to the accessible environment. Figure 6-6 presents a schematic of Engineered Barrier System. The EBS features/components that are important to waste isolation and that contribute to barrier capability are (1) emplacement drift, (2) drip shield, (3) waste package including inner vessel, (4) naval SNF structure, and (5) waste form and waste package internals including the transport, aging, and disposal (TAD) canister, naval canister, TAD and DOE SNF neutron absorber materials, and naval SNF canister system components.

Commercial SNF waste packages are used to represent the naval SNF waste packages in the TSPA. EBS features/components that are not important to waste isolation are, (1) the waste package pallet, and (2) invert. Commercial and DOE SNF cladding are also classified as not important to waste isolation.

The characteristics of the EBS include:

- A thermal, mechanical, hydrologic (including isolation of waste from moisture), and chemical environment favorable to waste isolation and affected principally by the thermal effects of radioactive decay

- Corrosion-resistant metals that are designed to perform and function in the thermal, mechanical, hydrologic, and chemical environments expected in the emplacement drifts

- Drip shield, waste package, and cladding materials with designs and fabrication methods that reduce the potential effects of stress corrosion cracking, creep, and other physical-chemical degradation processes

- Generally low radionuclide solubility and high sorption capacity of radionuclides thus delaying or preventing their release in the event that waste packages are breached.

- Delayed transport of radionuclides through the EBS due to insignificant advection through the EBS features for several hundreds of thousands of years and the slow diffusion of radionuclides through any continuous water film.

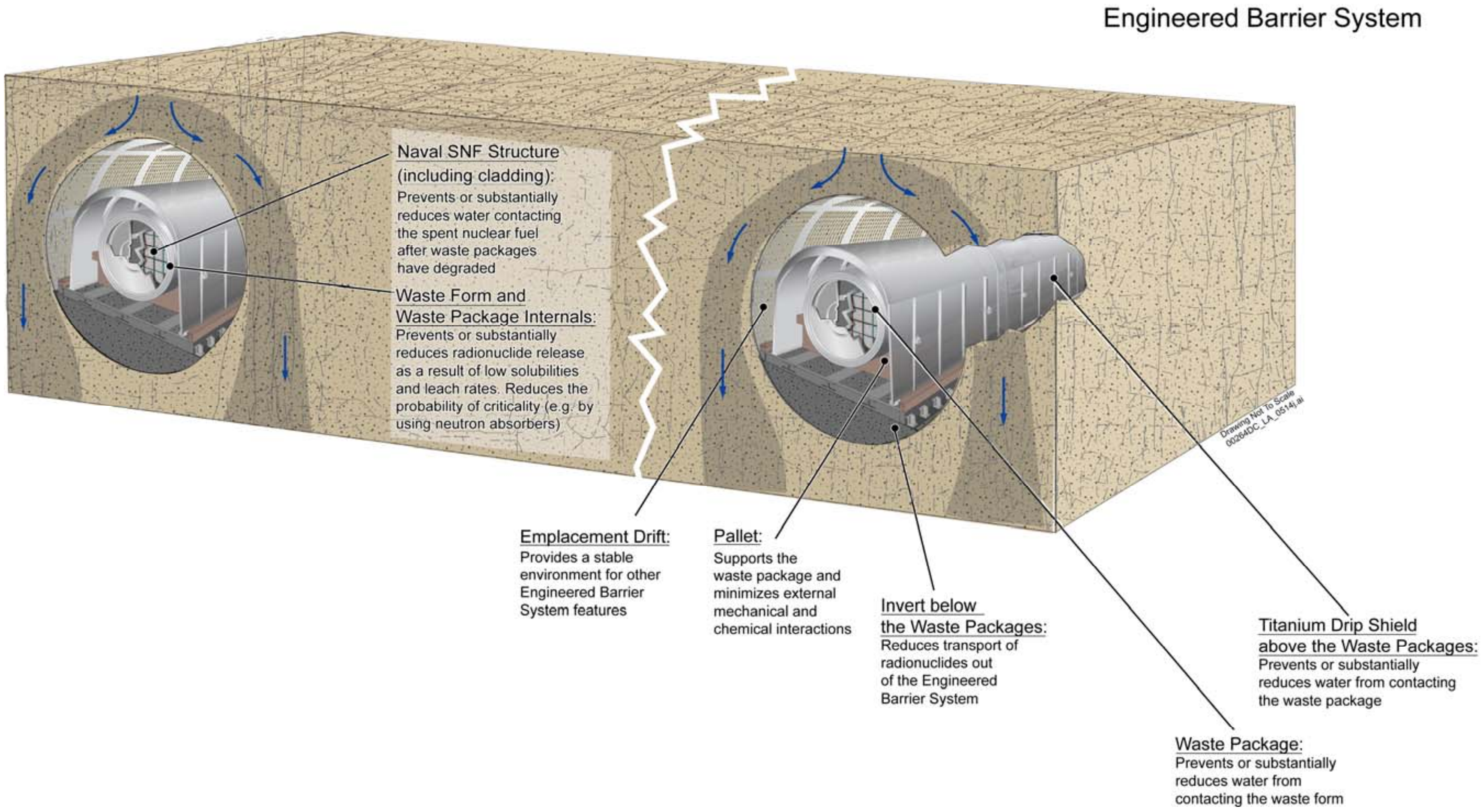


Figure 6-6. Schematic of the Engineered Barrier System

Evidence from natural and man-made openings in unsaturated underground environments indicates that such conditions effectively limit the seepage of water and often create in-drift conditions in which fragile materials may be preserved for tens of thousands of years. Seepage exclusion in underground openings (drifts) is consistent with processes that occur in caves, lava tubes, rock shelters, and surface structures, which indicate that underground openings provide a significant reduction in seepage compared to the amount of water infiltration that enters the unsaturated zone (BSC 2004 [DIRS 169218], Section 8.2). Emplacement drifts provide the thermal, mechanical, hydrologic, and chemical environment in which the rest of the EBS features function. These environments are affected by the heat caused by the decay of radioactive materials in the waste, in particular in the commercial SNF waste form, which makes up the bulk of the repository waste and therefore generates the most heat. Although these environments are expected to change with time, in the absence of low-probability events such as seismic or igneous events, the rate of change is very slow.

The drip shield is important to waste isolation. The drip shield, which will be placed over the waste packages, is fabricated from Titanium Grade 7 (UNS R52400), a commercially available, nearly pure titanium alloy containing a small addition of palladium to provide a higher degree of corrosion resistance. The structural components of the drip shield will be constructed using the higher-strength titanium alloy Titanium Grade 29 (UNS R56404), which has alloying elements aluminum and vanadium to provide the required strength and ruthenium to provide corrosion resistance. This titanium alloy is also highly corrosion resistant in a wide variety of chemical environments (SNL 2007 [DIRS 179354], Section 4.1.2).

The waste package is important to waste isolation. The waste package consists of two concentric cylinders: an inner vessel of Stainless Steel Type 316 (UNS S31600, with further compositional restrictions designed for structural support), and a corrosion-resistant outer shell made of Alloy 22 (UNS N06022, a nickel-chromium-molybdenum alloy with further compositional restrictions) (SNL 2007 [DIRS 179394], Sections 4.1.1 and 4.1.2).

Naval SNF structure is important to waste isolation. Naval SNF structure protects the radionuclides from contact with the surrounding environment and reduces the release of radionuclides from the SNF. Commercial cladding is not important to waste isolation. Commercial cladding provides protection for commercial SNF from the surrounding environment as long as it is intact. Commercial SNF cladding will fail by mechanical action from seismic or volcanic events, and/or by long-term chemical degradation. Commercial SNF cladding is modeled in the TSPA as being failed upon emplacement of the waste packages in the repository. Thus, no credit is taken for any barrier capability of the commercial SNF (and DOE SNF) cladding. Because of the robust design of naval SNF, the radionuclide releases from naval SNF waste packages are considerably less than releases from commercial SNF waste packages. The TSPA model does not explicitly include naval SNF, but represents naval SNF waste packages with commercial SNF waste packages that bound its behavior (SNL 2007 [DIRS 179567], Section 4.1.1).

Components of waste package internals that are ITWI include the transport, aging, and disposal (TAD) canister and neutron absorber materials in both the TAD canister and DOE SNF canister. Commercial SNF waste packages and naval SNF waste packages constitute approximately 70% of the waste packages that will be emplaced in the repository. Commercial SNF waste packages will contain a TAD canister. The approximately 400 naval SNF canisters (BSC 2007 [DIRS 182131], Section 3.2.1.6) are treated in the TSPA as Commercial SNF waste packages. The TAD canister is constructed of Type 300-series stainless steel (such as Stainless Steel Type 316) that fits within the inner vessel (SNL 2007 [DIRS 179394]). SNF assemblies in baskets fit within the TAD canister. The waste packages that contain canisters of naval SNF will contain only that waste form.

Codisposal waste packages, which constitute approximately 30% of the waste packages in the repository, contain both HLW canisters and DOE SNF canisters. These two canister types are not important to waste isolation.

The waste forms that are important to waste isolation include commercial SNF, naval SNF structure and HLW. DOE SNF is not classified as important to waste isolation. The types of waste to be placed in the repository include commercial SNF, U.S. Department of Energy (DOE) SNF (including naval SNF), and HLW. The waste forms are physically solid materials that degrade under moist, oxidizing conditions. Commercial SNF is primarily composed of uranium dioxide pellets that oxidize and hydrate. DOE SNF is composed of uranium metal (N Reactor) fuel and other DOE SNF waste forms. These fuel types decompose by several processes including dissolution, phase separation, selective leaching, and oxidation. HLW is composed of a borosilicate glass waste form that reacts with water and forms clays, zeolites, and oxides.

The waste package pallet and the emplacement drift invert are two features of the EBS that are not important to waste isolation. The emplacement pallet rests on the invert and is a platform that supports the waste package. The pallet is constructed of Alloy 22 end support piers and 316 SS connector tubes (SNL 2007 [DIRS 179354], Section 4.1.2). The emplacement drift invert is composed of two parts: a mild steel framework and ballast (or fill). The ballast material is crushed, graded and compacted tuff derived from tunneling operations (BSC 2004 [DIRS 168138], Section 8.2).

6.2.1.3 Lower Natural Barrier

The LNB consists of two natural features: (1) the unsaturated zone below the repository horizon, and (2) the saturated zone beneath the repository to the accessible environment (Figure 6-7). Both of these features are important to waste isolation. The characteristics of the LNB include:

- Depth to groundwater below repository emplacement drifts, from about 200 m to nearly 400 m (BSC 2007 [DIRS 183743]; SNL 2007 [DIRS 177391], Appendix C), for the present-day climate (estimated to decrease on average by up to 120 m for future climate states)

- Long transport distance from the repository to the accessible environment

- Hydrogeologic and geochemical characteristics that limit radionuclide movement.

The LNB below the repository horizon prevents or substantially reduces the rate of radionuclide movement to the accessible environment through a variety of natural processes and characteristics. In the unsaturated zone, these processes and characteristics include low percolation rates, matrix diffusion, and sorption of radionuclides onto mineral surfaces (SNL 2007 [DIRS 184748], Section 6). Percolating water may also be diverted horizontally over perched water bodies caused by permeability barriers (SNL 2008 [DIRS 184748], Section 6.2). Perched water bodies are found primarily below the northern part of the repository area, where low-permeability, sparsely fractured zeolitic rock units predominate. Perched water zones may laterally divert a considerable amount of flow to major faults (BSC 2004 [DIRS 170035], Section 6.1.4; SNL 2007 [DIRS 184614], Section 6.6.2.3), which are conservatively treated as localized fast flow paths that may focus flow downward to the water table. Vitric zones are located in the southern half of the area below the repository. These vitric layers have relatively high matrix porosity and permeability, and matrix flow dominates. The relatively fast flow down faults below the northern half of the repository results in faster mean transport times than in the southern half of the repository area (SNL 2008 [DIRS 184748], Section 6.2.2.1).

The LNB also includes the volcanic rock, zeolites, and alluvium in the saturated zone below the water table that delay the movement of most radionuclides. Saturated zone processes and characteristics that limit the movement of radionuclides include low groundwater flow rates, matrix diffusion, sorption, and filtration of colloids that could potentially transport radionuclides.

Certain aspects of the performance of the LNB are radionuclide-specific. Matrix diffusion and sorption within the LNB cause a delay between release of the radionuclides from the EBS and arrival at the accessible environment. In addition, radioactive decay reduces the radioactivity of the short-lived radionuclides to negligible levels.

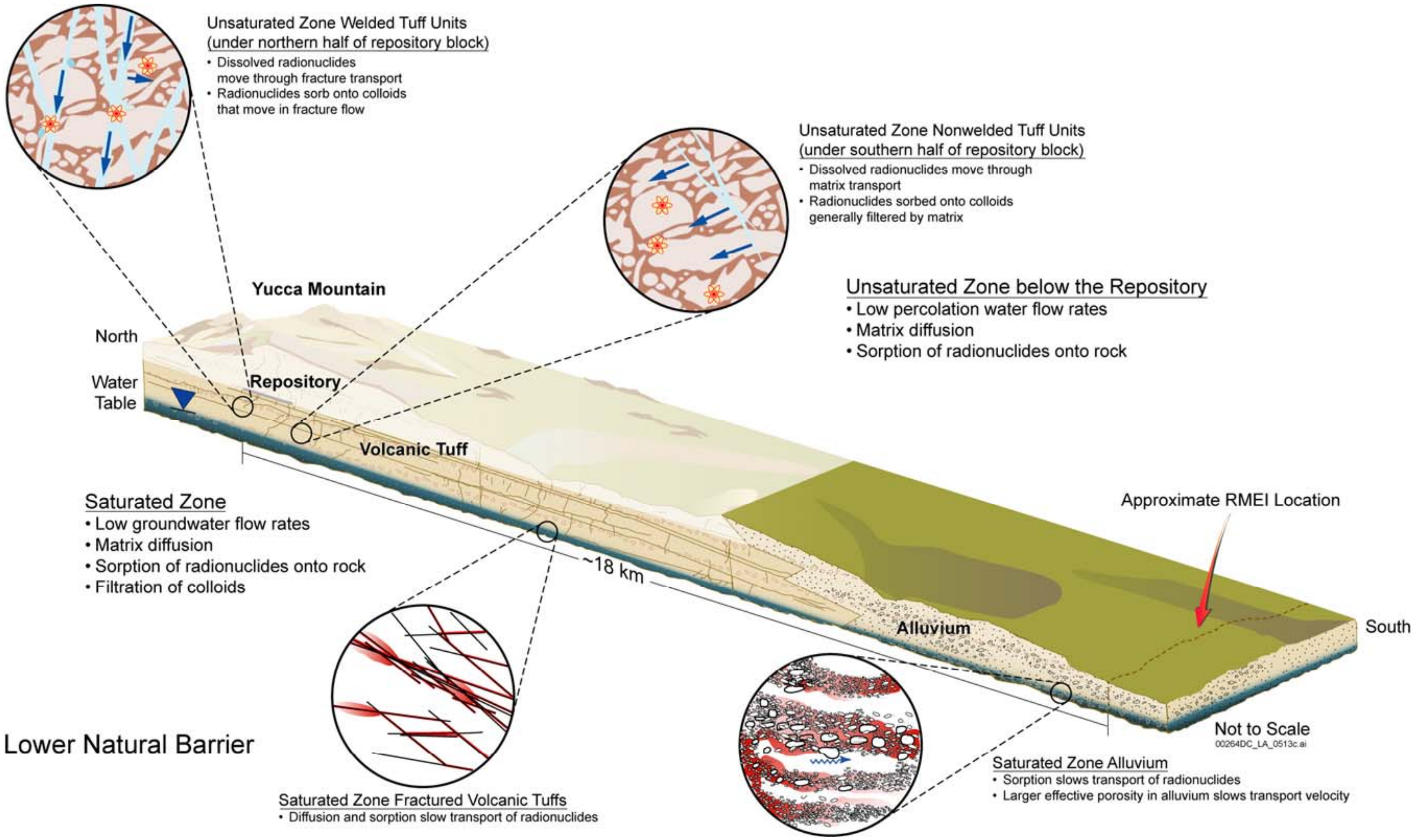


Figure 6-7. Schematic of the Lower Natural Barrier

6.2.2 Barrier Capability Description

This section describes the capability of the three barriers identified in Section 6.2.1. The description includes information on the time period over which each barrier performs. Uncertainties associated with each barrier's capability are also described. The analysis and understanding of the capability of the barriers are consistent with the results from the TSPA model as they are based on results from process models and abstraction models that provide the technical bases for the TSPA. Because the TSPA analyses extend beyond 10,000 years but within the period of geologic stability ending at 1 million years after disposal as prescribed by proposed 10 CFR Part 63 (70 FR 53313 [DIRS 178394]), the barrier capability analyses presented in this section also extend up to 1 million years after closure (proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394])).

The barriers are described in the sequence in which water flowing through the repository system encounters them: the UNB, the EBS, and finally, the LNB.

6.2.2.1 Upper Natural Barrier

The topography and surficial soils, as part of the UNB, substantially reduce the amount of precipitation that can infiltrate into and percolate through the underlying unsaturated zone. In addition, capillary retention and the low permeability of the unsaturated zone prevent water from entering the emplacement drifts over about 30% to 60% of the repository during the post-10,000-year climate. These processes prevent or substantially reduce the rate of movement of water from the repository to the accessible environment, and prevent or substantially reduce the release rate of radionuclides from the waste.

The UNB is composed of two natural features: (1) the topography and surficial soils and (2) the unsaturated zone above the repository. The unsaturated zone above the repository is composed of three hydrogeologic units with distinct properties that play an important role in limiting the flow of water: the Tiva Canyon welded tuff (TCw), the Paintbrush non-welded tuff (PTn) and the Topopah Spring welded tuff (TSw). These features are illustrated in Figure 6-8. These features have different processes and characteristics that influence their ability to prevent or substantially reduce the rate of movement of water into the repository. The hydrologic processes that affect the rate of water movement to the repository for both the topography and surficial soils and the unsaturated zone above the repository feature, are tabulated in Appendix A, Table A-1.

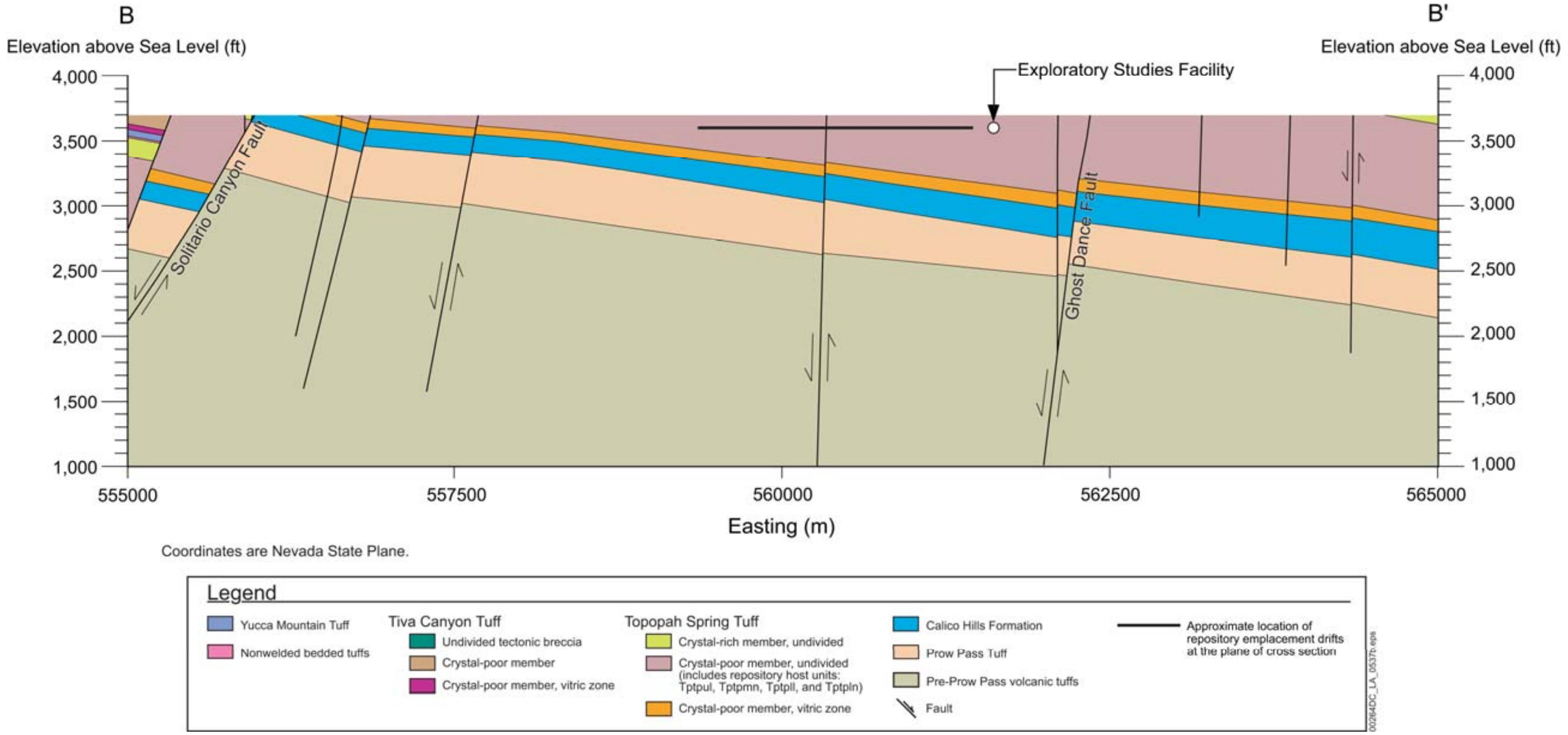


Figure 6-8. Unsaturated Zone below the Repository Horizon

As identified in Appendix A, Table A-1, some processes are important contributors to the overall capability of the UNB to prevent or substantially reduce the rate of water movement. In the evaluation of the important features and processes related to the capability of the UNB, consideration is given to both the beneficial as well as the potentially deleterious processes that act on each of the features of the barrier. Beneficial processes generally result in (a) reducing the amount of water from precipitation that is available for infiltration (e.g., runoff and evapotranspiration), (b) preventing the movement of water, or (c) substantially reducing the rate of movement of water from the surface to the repository, therefore preventing the movement of water or substantially reducing the rate of movement of water that could transport radionuclides from the repository to the accessible environment. The presence of a potentially deleterious process, on the other hand, could result in an increase in the rate of movement of water. The evaluation of both beneficial and potentially deleterious processes that could affect the movement of water in the post-10,000-year period assures a more complete understanding of the barrier capability.

A few examples illustrate beneficial and potentially deleterious processes and their effects on the UNB. Flow diversion around repository drifts is a beneficial attribute of the unsaturated zone flow system that decreases the amount of water that can seep into emplacement drifts. Climate change is a potentially deleterious process that could increase precipitation and thus could reduce the effectiveness of the UNB by increasing the rate of water movement.

Topography and Surficial Soils—The following processes and characteristics of topography and surficial soils are important to the capability of the UNB:

- **Climate Change**—Long-term climate change processes can significantly affect the amount of precipitation that falls in any year as well as (1) the timing of when that precipitation is expected to occur; (2) the air temperature and other conditions that affect evapotranspiration; and (3) the amount and type of vegetation expected to be present in the surficial soils. As a result, the climate state affects the amount of water available and several of the key processes that are expected to affect the amount of water that can infiltrate into the surficial soils and percolate through the unsaturated zone. The effects of climate change have been included in the assessment of net infiltration and the variation of the net infiltration for 10,000 years after closure, as presented in *Simulation of Net Infiltration for Present-Day and Potential Future Climates* (SNL 2008 [DIRS 182145], Section 6). After 10,000 years, the rate of percolation at the repository horizon is specified by the proposed NRC rule (70 FR 53313 [DIRS 178394]). NRC proposes that DOE represent the effects of climate change after 10,000 years by assigning percolation rates at the repository horizon that vary between 13 to 64 mm/yr.

- **Climate Modification Increases Recharge**—Future climate change may significantly affect the amount and timing of precipitation and temperature, which in turn affect net infiltration into surficial soils. The net effect of climate change in the 10,000 years after closure is to increase the amount of water that precipitates and can infiltrate into and eventually percolate through the unsaturated zone. This increased recharge is calculated by the infiltration model (SNL 2008 [DIRS 182145], Section 6.5.7.4). The climate effect on net infiltration has been directly included in the TSPA by developing infiltration scenarios for each of three climates for the first 10,000 years after closure: present-day, monsoon, and glacial-transition. After the first 10,000 years and through the period of geological stability, the effect of climate modification on percolation and recharge is incorporated into the performance assessment using the distribution of deep percolation rate as specified in the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]).

- **Precipitation**—Precipitation processes are important in the evaluation of the net infiltration into the bedrock below the surficial soils. The temporal and spatial distribution of precipitation affects the amount of water available to potentially run off, evaporate, transpire, or infiltrate. Given the semiarid climate at Yucca Mountain, precipitation events are intermittent and result in long periods of time when there is a net evapotranspiration from the surficial soils, interrupted by short-duration precipitation events that can result in some infiltration. Net infiltration during current and future climate states is calculated in the infiltration model (SNL 2008 [DIRS 182145], Section 6.5.7). For the post-10,000-year period up to geologic stability, the precipitation effect is implicitly incorporated into the TSPA by using the distribution of deep percolation rate as specified in the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]).

- **Topography and Morphology**—The topography and morphology of the ground surface above the repository are such that a portion of the precipitation that falls at Yucca Mountain is unavailable for infiltration due to surface runoff. Generally, the steeper slopes have more runoff and less infiltration than the more gentle slopes. The effects of variability in topography on surface runoff have been included in the assessment of net infiltration and the uncertainty in net infiltration set forth in the infiltration model (SNL 2008 [DIRS 182145], Section 6.5.7).

- **Rock Properties of Host Rock and Other Units**—The hydrologic characteristics of the surficial soils and shallow bedrock above the repository significantly affect the amount of net infiltration following a precipitation event. The characteristics of the surficial soils and shallow bedrock also affect the soil retention and the time infiltrating water takes to pass below the root zone to become net infiltration (i.e., where it is not subject to further evapotranspiration processes). The hydrologic characteristics of the surface soils at Yucca Mountain, including associated uncertainty (most notably the permeability), are included in the assessment of net infiltration presented in the infiltration model (SNL 2008 [DIRS 182145], Sections 6.5.2.2 and 6.5.2.3).

- **Surface Runoff and Evapotranspiration**—Surface runoff redistributes precipitation to areas away from the repository footprint where it may infiltrate. Runoff is significant in moving precipitation water from where it intersects the surface to alluvial materials in washes, where flooding may allow storage and transpiration or infiltration below the root zone. Evapotranspiration removes a significant fraction of water from soil and rock by evaporation and transpiration via plant root water uptake, and results in a reduction in the amount of water available to infiltrate into the unsaturated zone beneath the surficial soils. Both of these processes are included in the infiltration model for the first 10,000 years following repository closure (SNL 2008 [DIRS 182145], Sections 6.4.3 and 6.4.4). For the post-10,000-year period, their effects are implicitly in the TSPA by using the distribution of deep percolation rate as specified in proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]).

- **Infiltration and Recharge**—Infiltration is the net result of all surficial processes related to the availability of water. These processes include the effects of seasonal and climate variations, climate change, runoff, evapotranspiration, and site topography (such as hillslopes and washes). The processes result in a significant reduction in the amount of water available to percolate into the unsaturated zone beneath the surficial soils. Uncertainty in infiltration is a result of uncertainty in soil and rock characteristics, precipitation, and surface topography. The rate of net infiltration and its associated uncertainty are assessed for the first 10,000 years following repository closure using the net infiltration model (SNL 2008 [DIRS 182145], Sections 6.5 and 6.6). Recharge is the percolation flux through the unsaturated zone that reaches the water table, and is included in the site-scale unsaturated zone flow model (SNL 2007 [DIRS 184614]). For the post 10,000 year period up to geologic stability, the effects of infiltration are implicitly included in the TSPA by using the distribution of deep percolation rate as specified in the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]).

- **Fractures**—Open fractures in the bedrock will tend to increase the bedrock effective hydraulic conductivity and result in an increased rate of net infiltration into the subsurface. However, a lower effective conductivity of the bedrock will tend to increase water storage in the surficial soil, increase the effectiveness of evapotranspiration, thereby reducing the rate of net infiltration into the subsurface. For example, fractures at or near the surface may be partially or completely filled, which could substantially reduce infiltration. The uncertainty in fracture properties and their effect on bedrock hydraulic conductivity are included in the net infiltration model (SNL 2008 [DIRS 182145], Section 6.5.2.6).

- **Fracture Flow in the Unsaturated Zone**—Fracture flow in the bedrock beneath the surficial soils affects the rate of water movement below the soil–bedrock contact, especially in areas of thin soils (SNL 2008 [DIRS 182145], Section 6.2.1). The rate of water flow in fractures at the soil-bedrock interface is influenced by fracture properties such as fracture frequency and permeability. As these properties increase in value, the effective conductivity of the bedrock will also increase and result in an increased rate of net infiltration into the subsurface.

Unsaturated Zone above the Repository—The following processes and characteristics of the unsaturated zone above the repository are important to the capability of the UNB:

- **Climate Change**—Future climate change causes several responses in the unsaturated zone, including changes in percolation flux through the unsaturated zone, seepage into the repository emplacement drifts, water table rise, and recharge to the saturated zone. Precipitation and net infiltration into the unsaturated zone tends to increase with climate change, causing an increase in these responses. The effects of climate change on groundwater flow in the unsaturated zone above the repository are incorporated into the TSPA using time-dependent infiltration rates as a boundary condition to the site-scale unsaturated zone flow model (SNL 2007 [DIRS 184614]) for the first 10,000 years and for the post-10,000-year period, using the deep percolation rate as specified in the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]). These responses to climate change are included in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6) and *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6).

- **Climate Modification Increases Recharge**—The percolation flux in the host rock above the emplacement drifts is significantly affected by the change in recharge and infiltration associated with the projected future climate changes in the 10,000 years after closure. The increased infiltration and percolation significantly increase the amount of water potentially available to seep into the drifts and the amount of water that is projected to seep. The effects of current and future climate states on the amount of water percolating through the unsaturated zone are included in the site-scale unsaturated zone flow model presented in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6). After 10,000 years and through the period of geological stability, the effect of climate modification on percolation and recharge is incorporated into the site-scale unsaturated zone flow model using the distribution of deep percolation rate as specified in the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]).

- **Stratigraphy—**The stratigraphic sequence of unsaturated strata defines the hydrologic characteristics through which percolating water flows between the surface and the repository horizon. This sequence of both welded and nonwelded tuffs affects the transient propagation of infiltration pulses and tends to spatially redistribute the percolation rates. Stratigraphy has been directly included in the site-scale unsaturated zone flow model (SNL 2007 [DIRS 184614], Section 6.1.1).

- **Rock Properties of Host Rock and Other Units—**Rock properties, such as fracture capillarity and permeability, significantly affect the distribution of percolation flux in the unsaturated zone and the amount of flow diversion for a given percolation flux around emplacement drifts. Layer-specific rock properties and fault properties represent large-scale heterogeneity and have a significant effect of site-scale flow processes. Small-scale heterogeneity within hydrogeologic units has much less of an effect on site-scale flow processes. Permeability contrasts between adjacent stratigraphic units, as well as the slope of these units, contribute to lateral diversion of percolation flux above the repository. In addition, the degree of flow focusing is related to the heterogeneous permeability distribution of the host rock. Properties of rock units and associated uncertainties are included in the models presented in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6 and Appendix B) and *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6).

- **Fractures**—Fractures are the main conduit for flow in most of the hydrogeologic units in the unsaturated zone above the repository. Fractures account for more than 90% of total water flux at the repository horizon within the repository footprint (SNL 2007 [DIRS 184614], Section 6.6.2.3). Fractures and their properties are included in the models presented in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6).

- **Fracture Flow in the Unsaturated Zone**—Above the repository, the percolation flux is principally controlled by gravity through a network of fractures in the TCw, PTn, and TSw units. Fracture flow is the dominant flow mechanism in the welded units with a high density of interconnected fractures. In the nonwelded PTn unit with relatively high matrix permeability and porosity, and relatively low fracture density, fracture flow is also significant even though the predominant fracture flow in the overlying TCw unit is converted to dominant matrix flow. As noted above, fractures account for 90% of total water flux at the repository horizon within the repository footprint (SNL 2007 [DIRS 184614], Section 6.6.2.3).

- **Unsaturated Groundwater Flow in the Geosphere**—Unsaturated groundwater flow defines the distribution of percolation flux in the unsaturated zone as a function of time, and is the primary mechanism for radionuclide transport below the repository. Although the flow rate in the unsaturated zone defines the amount of fracture flow, the fracture characteristics are also significant in determining the rate of radionuclide movement in the unsaturated zone (SNL 2007 [DIRS 177412], Section 6).

- **Flow Diversion around Repository Drifts**—Above the emplacement drifts, a portion of the percolating unsaturated flow is diverted around the repository drifts. This diversion prevents or substantially reduces the rate of movement of water to the emplacement drifts. The amount of water flow diversion is a function of: (1) the percolation in the unsaturated zone above the emplacement drifts, (2) hydrologic properties around the emplacement drifts, notably the permeability and capillarity of the fractured rock mass, and (3) the geometry of the emplacement drift and drift-wall properties. Assessment of the distribution of seepage into the emplacement drifts, including the associated uncertainties, is presented in *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6).

- **Water Influx at the Repository**—Water influx is the net result of flow diversion processes described above. Water that is not diverted around the emplacement drifts will flow into the emplacement drifts as seepage. Assessment of the distribution of seepage into the emplacement drifts, including the associated uncertainties, is presented in *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6).

The following discussion provides an integrated description of how stratigraphy, rock properties, fractures, fracture flow, and unsaturated groundwater flow influence water flow through the unsaturated zone above the repository.

The high density of interconnected fractures and low matrix permeability in the TCw unit (SNL 2007 [DIRS 179545], Tables 6-6 to 6-9 and Section 6.3.2) are conceptualized as giving rise to significant water flow in fractures and limited matrix imbibition (water flow from fractures to the matrix) within the TCw. Thus, episodic infiltration pulses are expected to percolate rapidly through fracture networks, with little attenuation by the matrix, in this unit. The relatively high matrix permeability and porosities and low fracture densities of the underlying PTn unit (SNL 2007 [DIRS 179545], Tables 6-6 through 6-9 and Section 6.3.2) convert the predominant fracture flow in the TCw to dominant matrix flow within the PTn. The dominance of matrix flow in the PTn and the relatively large storage capacity of the matrix, resulting from its high porosity and typically low saturation (under ambient conditions), give the PTn significant capacity to attenuate infiltration pulses. Faults (or geologic structures) may cut through the entire PTn unit at some locations, leading to fast flow paths if the local PTn tuff matrix is not able to convert all of the fault flow into matrix flow. In addition, some lateral diversion of water occurs in the PTn unit owing to the capillary barrier effects and the slope of the stratigraphic units (SNL 2007 [DIRS 184614], Sections 6.1.2 and 6.2.2). The PTn unit as a whole exhibits very different hydrogeologic properties from the TCw and TSw units that bound it above and below. Both the TCw and the TSw have low porosity and intense fracturing typical of the densely welded tuffs at Yucca Mountain. Therefore, unsaturated flow in the TSw and TCw hydrologic units occurs primarily through fractures.

The process models relevant to the UNB and their abstraction for use in the TSPA are founded on physical principles and extensive tests and observations from Yucca Mountain and appropriate analogue sites. The capability of the UNB is analyzed using models that simulate the flow of water (i.e., infiltration, percolation, and seepage) through the topography and surficial soils and the unsaturated zone above the repository. These models consider sixteen infiltration scenarios, resulting in 10th, 30th, 50th, and 90th percentile infiltration rates or maps for each of the three climate states (i.e., present-day, monsoon, and glacial-transition) estimated for the Yucca Mountain site and the fourth climate state (post-10,000-year climate state) specified in the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]). These infiltration maps, used as upper boundary conditions for the UZ Flow Model, represent uncertainty in infiltration. These flow fields incorporate a range of variability and uncertainty based on the calibrated unsaturated zone flow models for the site. For a given climate state, the relative importance of a selected infiltration map and corresponding flow field is represented by a weighting factor. The weighting factors are determined through comparison with measured subsurface data from the unsaturated zone (i.e., distributions of temperature and chloride) using a generalized likelihood uncertainty estimation method. Weighting factors of approximately 61.9%, 15.7%, 16.5%, and 6.0% were determined for the 10th, 30th, 50th, and 90th percentile infiltration maps, respectively (SNL 2007 [DIRS 184614], Section 6). These same weighting factors are also used for the monsoon, glacial-transition, and post-10,000-year climates.

As noted earlier, the fourth climate state, the post-10,000-year state, is also implemented in accordance with proposed 10 CFR 63.342(c)(2)(70 FR 53313 [DIRS 178394]). The fourth climate state extends the simulations from 10,000 years to 1,000,000 years. The fourth climate state contains four uncertainty cases based on the prescribed percolation flux distribution through the repository footprint in accordance with proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]).

6.2.2.1.1 Capability of the Topography and Surficial Soils to Prevent or Substantially Reduce Infiltration

Yucca Mountain is in a semiarid region where precipitation and humidity are low, thus promoting high potential evaporation rates. The topography and surficial soils features significantly reduce the movement of water into the unsaturated zone. Runoff, evaporation, and plant transpiration combine to divert water and permit only a small fraction of the expected low precipitation at the site to infiltrate into the unsaturated zone. These processes are included in the infiltration model (SNL 2008 [DIRS 182145], Section 6.5.7).

The capability of the UNB to prevent or substantially reduce infiltration into Yucca Mountain is due to the geographic and geologic setting of the site. Yucca Mountain is located in the Great Basin of the arid desert southwest. The Sierra Nevada Mountains serve as a physiographic barrier to the eastward migration of moisture from weather systems originating in the Pacific Ocean. As a result, average precipitation in the Yucca Mountain area is low throughout the year. The characteristics of topography and surficial soils and processes acting on them, including the effects of evapotranspiration and runoff, combine to result in infiltration into Yucca Mountain that is significantly less than the already low incident precipitation. During the warmer months, precipitation occurs intermittently, usually as isolated storms in the spring or late summer. Infiltration during these events is limited because of the high runoff associated with the topography and because of the high evaporation and transpiration rates associated with warm temperatures. Most of the small amount of infiltration that does occur is associated with low-intensity winter storms when lower evaporation and transpiration rates and the slow melting of snow create conditions favoring limited infiltration. The semiarid climate and the topography and surficial soils portion of the UNB also contribute to favorable site characteristics, such as the low rates of water flow in the unsaturated zone and the great depth of the water table (SNL 2008 [DIRS 182145], Section 6.5.7; SNL 2007 [DIRS 184614], Section 6; SNL 2007 [DIRS 177391], Section 6 and Table D-5).

Determination of net infiltration rates take into account the processes important to infiltration, including run-on and runoff, evaporation and transpirations, soil and bedrock hydraulic properties and spatial distribution, as well as topographic and climatic influences. The effect of climate variability (i.e., precipitation, temperature, and humidity) on infiltration rates is also incorporated into the model. The infiltration model is described in *Simulation of Net Infiltration for Present-Day and Potential Future Climates* (SNL 2008 [DIRS 182145], Section 6).

The precipitation and infiltration that influence potential seepage rates into the emplacement drifts are assessed for three climate states representing the climate conditions forecast to exist in the 10,000 years after closure (SNL 2008 [DIRS 183478], Section 6.3.1.2):

- Present-day climate state, representing conditions forecast to prevail for approximately the next 400 to 600 years
- Monsoon climate state, representing conditions forecast to prevail for approximately 900 to 1,400 years after the present-day climate conditions
- Glacial-transition climate state, representing conditions that are forecast to prevail over the following 8,000 to 8,700 years.

The climate durations used in the TSPA-LA Model for simulating the next 10,000 years at Yucca Mountain are the present-day climate for 600 years, followed by a warmer and wetter monsoon climate for 1,400 years, followed by a cooler and wetter glacial-transition climate for the remaining 8,000 years (SNL 2008 [DIRS 178871], Section 6.3.1.2).

In the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]), the NRC has specified that long-term climate after 10,000 years following disposal should be represented by a probabilistic distribution for a constant in time, but uncertain long-term average climate for Yucca Mountain.

For each climate state, four infiltration scenarios are evaluated: a 10th, a 30th, a 50th, and 90th-percentile scenarios. On average, the 10th percentile infiltration scenario for each climate state during the post-10,000-year period represents relatively dry conditions, whereas the 30th, 50th, and 90th percentile scenarios represent increasingly wetter conditions. The climate analysis and infiltration model for Yucca Mountain demonstrate that limited infiltration of water into Yucca Mountain is expected for present-day and future climates. Precipitation falling on Yucca Mountain is low, even for the glacial-transition climates that are forecast for most of the first 10,000 years after closure. For example, annual precipitation rates for the glacial-transition climate at the 50th percentile are expected to be 223 mm/yr to 287 mm/yr for the 90th percentile (SNL 2008 [DIRS 182145], Table 6.5.7.3-3). About 87% of the water falling on Yucca Mountain as precipitation during the glacial-transition climate state is expected to be diverted by runoff or returned to the atmosphere by evapotranspiration, whereas about 90% is diverted or returned to the atmosphere during present day and monsoon (SNL 2008 [DIRS 182145], Section 6.5.7.1).

Estimated average present-day net infiltration ranges from less than 3% of precipitation for the 10th percentile climate scenario to about 13% of precipitation for the 90th percentile climate scenario, with a mean 50th percentile infiltration of about 7% of the average present-day precipitation. The average infiltration rates over the four scenarios vary from about 4 to 27 mm/yr, with a 50th percentile of about 13 mm/yr for the present-day climate. For the monsoon climate scenarios, average net infiltration rate estimates for the 10th to 90th percentile climate scenarios range from less than 3% to 17% of precipitation, with a range from about 6 to 53 mm/yr. For the glacial-transition climate scenarios, the average net infiltration rate estimates for the 10th to 90th percentile climate scenarios range from about 5% to 16% of precipitation, with a range from about 13 to 47 mm/yr (SNL 2008 [DIRS 182145], Section 6.5.7).

6.2.2.1.2 Capability of the Unsaturated Zone above the Repository to Prevent or Substantially Reduce Seepage

The unsaturated zone above the repository horizon prevents or substantially reduces the movement of water through the unsaturated zone and into the emplacement drifts of the repository. The primary large-scale processes contributing to this capability are:

- Lateral diversion and evaporation of percolating water
- Damping of episodic pulses of precipitation and infiltration
- Capillary forces limiting seepage into the emplacement drift
- Limitation of seepage because of elevated temperatures in the rock associated with the thermal period.

Analyses of the effectiveness of the unsaturated zone above the repository horizon to prevent or substantially reduce water movement are described in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6) and *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6). The site-scale UZ flow model is based on field and laboratory testing, and is calibrated to match data and observations from pneumatic testing, water content (saturation) data, and water-potential data.

Figure 6-6 shows a cross section of the unsaturated zone down to the repository horizon. From the surface to the repository horizon, the unsaturated zone includes the Tiva Canyon welded (TCw) tuff, the Paintbrush nonwelded (PTn) unit (indicated as nonwelded bedded tuffs in the figure), and the upper part of the Topopah Spring (TSw) unit. The TCw and TSw units are composed of moderately to densely welded, highly fractured tuff deposits. The high density of interconnected fractures and the low matrix permeability of the welded tuffs result in a majority of the water flow in the fractures. Episodic infiltration pulses resulting from precipitation at the surface, less the effects of runoff, evaporation, and transpiration, are expected to move through the fractured TCw unit into the underlying PTn unit with little additional attenuation (SNL 2007 [DIRS 184614], Section 6.9).

Within the repository emplacement area, the interface between the TCw and PTn units is commonly characterized by a transition over a few tens of centimeters from densely welded to nonwelded tuff, accompanied by an increase in matrix porosity and a decrease in fracture frequency. Because of the relatively high matrix porosity and permeability and low fracture density, water flow within the PTn unit is predominantly in the matrix. Interconnected fracture networks in the nonwelded tuff are rare and are typically associated with faults, so only a small percentage of the water is expected to pass through fractures in the PTn unit. Because of strong capillarity and high matrix porosity and permeability, the PTn unit attenuates pulses in flux from the overlying TCw unit, resulting in approximately steady-state water flow below the PTn unit (SNL 2007 [DIRS 184614], Section 6.9).

The TSw unit has lower matrix porosity and higher fracture frequency than the overlying nonwelded tuff. The low matrix porosity in the TSw causes locally transient saturated conditions above the interface and results in fracture flow into the TSw unit. The matrix hydraulic conductivity of the welded tuff is less than the estimated average water flux. Therefore, unsaturated flow is primarily through the fractures within the TSw unit (SNL 2007 [DIRS 184614], Section 6.2.2).

In the unsaturated zone above the repository horizon, several processes prevent or substantially reduce the movement of water into the repository emplacement drifts. Most of the water percolating downward in fractures through the TCw unit continues to flow approximately vertically downward in the matrix of the PTn unit. The down-to-the-east dip of the PTn unit combined with the effects of the anisotropy in the fracture and bulk permeability across the TCw–PTn interface results in some lateral diversion of the unsaturated flow. In addition, at the interface between the PTn and the TSw units, the contrast in the hydraulic conductivity between the nonwelded and welded units causes some lateral diversion of the flow. The distribution of chloride in the PTn tuff also indicates that some downward-percolating water is diverted laterally (BSC 2004 [DIRS 170035], Section 6.1.2). Water retention by capillary processes in subunits of the PTn unit is considered the main mechanism for lateral diversion of flow in the PTn unit, particularly along sloping layers. Modeling studies, using both numerical and analytical solutions (Wu et al. 2000 [DIRS 154918]; Wu, et al. 2002 [DIRS 161058]; Pan et al. 2004 [DIRS 169760]), show lateral flow within the PTn unit.

A second effect of the unsaturated zone above the repository horizon is the damping of the pulses of flow down through the unsaturated zone within the PTn unit. Net infiltration at the surface of Yucca Mountain is variable in space and time. Significant pulses of infiltration occur only once every few years, and infiltration varies spatially depending on the degree of focusing by surficial processes. Pulses of moisture may also percolate rapidly through the highly fractured tuffs of the TCw unit, as indicated by the potential bomb-pulse ^{36}Cl signatures in the TSw unit. However, geologic and geochemical evidence indicates that percolation rates are comparatively homogeneous. The change from fracture-dominated to matrix-dominated flow at the contact of the TCw and the PTn units significantly attenuates the episodic infiltration flux, effectively smoothing the variability in percolation flux rates. Evenly distributed chloride mass-balance data and estimates of mineral accumulation rates in fractures and lithophysae indicate that percolation rates are relatively homogeneous, except for some focused flow in fault zones outside of the repository footprint (SNL 2007 [DIRS 184614], Section 6.6.2.1).

Sixteen unsaturated zone flow fields were generated for climate states (present-day, monsoon, glacial-transition, and post-10,000 year) and four infiltration scenarios (10th, 30th, 50th, and 90th-percentile scenarios). The analysis of these flow fields indicates that percolation fluxes at the repository horizon are very different from surface infiltration patterns, mainly, in the north of the model domain (SNL 2007 [DIRS 184614], Section 6.6.2.1). Under a steady-state flow condition, percolation flux and its distribution along any horizon of the model domain would be the same or very similar if there were no lateral flow. The major differences in percolation flux at the repository level from the surface infiltration maps are: (1) flow converted through faults in the very northern part of the model domain (with the north coordinate greater than 237,000 m) and (2) flow diverted into or near faults located in the rest of the model domain. Overall, percolation results for the repository horizon display different patterns from the surface infiltrations because of the lateral flow within the PTn unit as well as flow focusing into faults.

The flow field modeling analysis also indicates that fracture flow is dominant along the top of the PTn unit and the repository horizon (SNL 2007 [DIRS 184614], Section 6.6.2.3). At the repository level, fracture flow consists of about 60% to 80% of the total percolation flux over the entire model layer, and is generally greater than 90% within the repository footprint. On the other hand, the flow of water in larger fault zones increases with depth. Over the entire model layer, fault flow at the TCw–PTn interface is about 1% to 2% of the total flux over the entire model domain, and increases to 12% to 32% of the total flux over the entire model domain at the repository horizon.

The rate and distribution of seepage control the amount of water available to contact the EBS. In the unsaturated zone, seepage into the emplacement drifts is less than the percolation flux because capillary forces limit the movement of water into the drift openings. Water is retained in the small pores and tight fractures of the low-porosity welded tuff, and a substantial fraction of the flow moves around the drift opening and drains through the rock pillars between the drifts. The effectiveness of capillary forces in limiting water movement into drifts and moving flow around them depends on the characteristics of the rock matrix and fractures and on the connectivity and permeability of the fracture network. In addition, seepage rates are affected by the characteristics of the drift openings (e.g., asperities on the drift walls and flow in fractures that may have modified hydrologic properties in the disturbed zone created by drift excavation or heat from emplacement waste). For a period of time, the decay heat of the emplaced waste is great enough to heat the rock near the emplacement drifts to above the boiling point of water. As long as the temperature is above boiling at the drift wall, the water vapor will be driven away from the emplacement drift wall surfaces. This thermal effect, combined with the capillary effects, further prevents or substantially reduces seepage into the emplacement drifts. Seepage is also influenced by whether or not the emplacement drift is overlain by welded or nonwelded tuffs such as the PTn. The PTn has a higher storage capacity and permeability, and, thus, is able to imbibe water and dampen episodic infiltration events. In contrast, the nonlithophysal units present above emplacement drifts are welded and highly fractured, resulting in fast flow through the fracture network. The latter condition is an important reason why the occurrence of seepage was observed in the South Ramp section of the Exploratory Studies Facility (SNL 2007 [DIRS 181244], Section 7.1[a]).

The models that simulate seepage into the emplacement drifts under both ambient and thermally perturbed conditions are described in the *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6). These drift seepage models consider matrix and fracture hydrologic and thermal properties of the TSw unit and the design of the emplacement drifts. They incorporate the processes and conditions that evolve over time, including changes caused by the heat of the emplaced waste. The drift seepage model and analysis supporting the development of the abstraction of drift seepage uses a continuum fracture model and samples the uncertain stochastic distributions for the fracture permeability and capillary strength parameters to estimate the probability and amount of seepage. For the modeled future glacial-transition climate, on average, only about 30% of the drip shield locations are expected to experience any seepage in the 10,000 years after closure (SNL 2007 [DIRS 181244], Section 6.4[a]).

The following summary illustrates the barrier capability of the unsaturated flow processes in the fractured rock at and above the repository horizon. The results of the probabilistic seepage analysis for intact drifts are described in terms of the mean seepage rate, the mean seepage percentage (i.e., ratio of mean seepage rate to mean percolation flux), and the seepage fraction (i.e., fraction of waste packages in a percolation region experiencing seepage), during the present-day, the monsoon, and the glacial-transition climates (SNL 2007 [DIRS 181244], Section 6.4[a]). The four alternative unsaturated zone flow fields, which correspond to the 10th, 30th, 50th and 90th percentile infiltration scenarios, arrive at four different sets of seepage results. For the flow field based on the 10th percentile infiltration scenario—the most likely flow field with a relative probability of 61.91%, seepage is expected to occur at 7.6% of all waste packages during the present-day climate. This percentage rises to about 13.4% during the monsoon climate, and 17% during the glacial transition climate. On average over all waste packages, the amount of seeping water is 1.2, 4.6, and 14.4 kg/yr per waste package for the present-day, the monsoon, and the glacial-transition climates, respectively. This translates to mean seepage percentages of 1.1%, 2.2%, and 4.7%. In other words, during the present-day climate, on average about 99% of the percolation flux would be diverted around intact drifts in the Tptpll unit. For the wetter climate stages of the monsoon and the glacial transition period, the mean percentage of diverted flux would be smaller, but still at about 98 % and 95%, respectively.

The higher infiltration scenarios would result in more seepage. For the 30th percentile infiltration scenario, the seepage fraction varies from 16.7% for the present-day climate, to 22.8% during the monsoon climate, to 29.5% during the glacial-transition climate. The respective mean seepage percentages are 3.0%, 4.9%, and 8.0%. Most seepage is seen for the 90th percentile infiltration scenario, with the seepage fraction as high as 52.6% during the monsoon climate. The mean seepage percentage during this climate state is 19.5%. Thus, even for the least likely of the four unsaturated zone flow fields, with a relative probability of 6% and comparably strong downward percolation, the diversion capacity of the unsaturated rock is about 81% overall. However, more than half of all waste packages are expected to experience some amount of seepage in this case (SNL 2007 [DIRS 181244], Table 6-6[a]). Overall, the observed seepage percentages demonstrate the important barrier capability of the unsaturated flow processes in the fractured rock at and above the repository horizon.

6.2.2.1.3 Time Period over which the Upper Natural Barrier Functions

The topography and surficial soils and the unsaturated zone above the repository horizon are durable features of the geologic environment at Yucca Mountain. The characteristics and properties of these features are not expected to change in the 10,000 years after closure. Geomorphologic studies of the landforms at Yucca Mountain indicate that the basic configuration of topography, soil depth and characteristics, and stream channel locations has been consistent for at least hundreds of thousands of years (YMP 1993 [DIRS 100520], Section 3.4). Minor changes in the precise location of stream channels may occur, and erosion and sediment accumulation will continue at low rates, but the changes to the parameters describing these features (e.g., soil depth and slope aspect) are expected to be less than the variability that is explicitly accounted for in the infiltration model.

With the exception of the very minor effects caused by the construction of the repository, the basic geologic features of the site are not expected to change in any significant way in the 10,000 years after closure. However, climate is expected to vary in the future. This variability has been incorporated into performance models by forecasting climate states: the present-day, monsoon, and glacial-transition climates, and by using the regulatory specification for climate changes after 10,000 years.

Wetter, cooler conditions are expected to result in changes to the vegetation that could affect transpiration rates, thereby affecting net infiltration rates. The infiltration model includes parameter adjustments to address increases in root density, root zone depth, and vegetation cover and changes in vegetation type (SNL 2007 [DIRS 184614], Section 6; SNL 2007 [DIRS 181244], Section 6).

The effectiveness of the UNB is expected to change after closure because of changes in the infiltration flux. Climate changes that result in increased net infiltration are propagated through the unsaturated zone, which result in increased percolation at the repository horizon. This type of change in barrier effectiveness is taken into account in the unsaturated zone flow and seepage models.

The long-term effects of heat generated by the emplaced waste on the properties of the UNB, including changes to rock hydrologic properties due to mineral dissolution or precipitation and mechanical changes in the rock, have been investigated. The analyses indicate that the magnitudes of changes attributable to coupled thermal-hydrologic-chemical-mechanical processes do not affect the barrier capability. On the basis of these analyses, changes in drift-scale hydrologic properties induced by thermal effects are concluded to have no significant impact on seepage (SNL 2008 [DIRS 183041], Section 6.2, excluded FEPs 2.1.09.12.0A, 2.2.01.02.0A, and 2.2.10.04.0A). Although explicitly excluded from the TSPA, the permeability of rock in the mechanically disturbed zone around the emplacement drifts is expected to be higher than that of the undisturbed rock, and this is effectively accounted for in the test analyses used to support the development and validation of the seepage calibration model presented in *Seepage Calibration and Seepage Testing Data* (BSC 2004 [DIRS 171764]).

Drift collapse can lead to seepage behavior that is much different from that in intact drifts (SNL 2007 [DIRS 181244], Sections 6.4.2.4.2 and 6.2.2[a]). The larger size and possibly different shape of a collapsed drift can reduce the potential for flow diversion. In addition, the capillary barrier behavior at the drift wall can be affected by the rubble rock blocks filling the opening, as the capillary strength inside the opening is different from the zero-capillary-strength condition in the initially open drift. In the case of full drift collapse, when the original openings have filled with rubble rock material, capillary effects are still expected to cause some flow diversion at the interface between the solid rock and the rubble-filled drift. These effects are included in the drift seepage model (SNL 2007 [DIRS 181244], Section 6).

6.2.2.1.4 Uncertainties Associated with Upper Natural Barrier Capability

Uncertainties associated with the capability of the UNB are derived from both the models used to simulate important processes and from uncertainty and variability in the data and parameters used to represent the characteristics of the natural system.

Uncertainty in the climate analysis is considered in the development of the range of possible future climate states used in the barrier capability analysis (BSC 2004 [DIRS 170002]). These uncertainties are principally related to: (1) uncertainty in the Owens Lake paleoclimate record and its extrapolation to mean annual precipitation and mean annual temperature, (2) uncertainty in the average sediment accumulation rate used to project the duration of the present-day and monsoon climate states, (3) decade- to century-scale variability in the climate proxy records, and (4) the selection of analogue meteorological stations to represent future climate conditions.

Uncertainty is also accounted for in the numerical model for net infiltration (SNL 2008 [DIRS 182145], Section 6.5.5). The boundary conditions for the model include uncertainty in the annual precipitation estimates. In addition, the model evaluates uncertainty in runoff, evaporation, and transpiration processes. The model includes uncertainty distributions for porosity, root-zone thickness, soil depth, precipitation, potential evapotranspiration, bedrock saturated hydraulic conductivity, soil saturated hydraulic conductivity, bare-soil evaporation parameters, effective surface-water flow area, and parameters associated with sublimation and melting of snow cover.

The performance of the UNB is also subject to uncertainty that is a function of: (1) the applicability of the conceptual and numerical models used to describe unsaturated zone flow and (2) the degree of knowledge of the characteristics of the Yucca Mountain site. To accommodate both variability and uncertainty in the description of the site conditions, the UZ site-scale flow model captures the range of variation and resulting uncertainty in surface infiltration and calibrated properties through the use of four infiltration scenarios for the present-day, monsoon, glacial-transition, and post-10,000-year climates and four sets of calibrated parameters for the 10th, 30th, 50th and 90th percentile maps for each of the infiltration scenarios. These uncertainties are thus propagated through the TSPA by use of the sixteen unsaturated zone flow fields (SNL 2007 [DIRS 184614], Section 6). The model projections for flow have been calibrated and compared to hydrogeologic data to ensure that results are consistent with the characteristics of the unsaturated zone flow system in the vicinity of Yucca Mountain. Uncertainties in the percolation flux due to flow focusing are addressed in site-scale UZ flow model through the parameters of the active fracture model, and in drift seepage through both the parameters for the active fracture model and a flow focusing factor. These parameters are adjusted to provide consistency with measurements that implicitly take flow focusing into account.

The effectiveness of the capillary diversion around the emplacement drifts is dependent on the percolation flux, the spatial variability of the hydrologic properties of the lithophysal and nonlithophysal repository host rock units, the initial geometry of the emplacement drift opening and subsequent geometry resulting from drift collapse, and the properties of the emplacement drift wall. In addition, a vaporization effect develops when the emplacement drifts are ventilated or are heated to above the boiling temperature of water. The key hydrologic properties are the capillary strength parameter (BSC 2004 [DIRS 171764], Section 6.6.2.3) and the fracture permeability (BSC 2004 [DIRS 171764], Section 6.6.3). Distributions representing these input uncertainties are developed as part of the seepage abstraction and are implemented by a probabilistic treatment of seepage in the TSPA. The capillary strength parameter is uncertain due to uncertainty in the seepage-rate data and uncertainty in the seepage calibration model. The capillary strength parameter is also variable in space because different locations in the repository have different rock property characteristics and different capillary barrier behavior (BSC 2004 [DIRS 171764], Section 6.6.4). Uncertainties in permeability values stem from uncertainties in the measured airflow rate and pressure data from the air injection testing and the analytical method used to derive the permeability values from these data. There are several sources of uncertainty related to the percolation flux estimates provided by the site-scale UZ flow model, including uncertainty related to the future climates and infiltration.

6.2.2.1.5 Impact of Disruptive Events on the Upper Natural Barrier

The UNB may be affected by unlikely disruptive events. For seismic activity, it is expected that the general configuration of the geologic units will be unchanged. However, at the interface between the UNB and the EBS, there may be changes in the shape of the drift opening caused by drift collapse. Drift collapse can lead to seepage behavior that is much different from that in intact drifts (SNL 2007 [DIRS 181244], Sections 6.4.2.4.2 and 6.2.2[a]). The larger size and possibly different shape of a collapsed drift can reduce the potential for flow diversion. In addition, the capillary barrier behavior at the drift wall can be affected by the rubble rock blocks filling the opening, as the capillary strength inside the opening is different from the zero capillary strength condition in the initially open drift.

In the case of full drift collapse, when the original openings have been filled with rubble rock material, capillary effects are still expected to cause some flow diversion at the interface between the solid rock and the rubble-filled drift. Drift collapse is a function of the rock type at the repository horizon (i.e., whether the Topopah Spring Tuff contains lithophysal cavities or not).

Analyses indicate that in the lithophysal rock units (comprising more than 85% of the repository horizon), peak ground velocities (PGV) exceeding about 2 m/s are required to cause significant drift degradation and collapse (SNL 2007 [DIRS 176828], Section 6). Such velocities are only expected at annual exceedance probabilities of about one chance in a million.

Model results indicate that individual seismic events with PGV greater than 2 m/s often completely fill the drifts with rockfall in the lithophysal units, while individual seismic events with PGV between 1 m/s and 2 m/s fill a fraction of the free space in a drift (BSC 2004 [DIRS 166107], Figure 6-128). Such changes in barrier performance are considered in the model abstractions used in the TSPA (SNL 2007 [DIRS 176828], Section 6). Other potential effects of seismic events on the hydrology and hydrogeologic characteristics (e.g., porosity and permeability) of the features within the unsaturated zone above the repository have insignificant effects on the performance of the repository, and are excluded from assessments of the UNB capability (Appendix A, Table A-1).

For igneous activity, if a volcanic eruption should occur, the configuration of the UNB in the vicinity of the eruption would change. If an igneous intrusion into certain emplacement drifts occurs, the affected drifts are assumed to fill with magma; however, the general configuration of the UNB will not change. Seepage into the emplacement drifts is expected to change as a result of igneous activity and is conservatively treated in the TSPA as equivalent to the percolation flux in the vicinity of the igneous event. Other potential effects of igneous events on the hydrology and rock properties do not significantly affect the performance of the repository and are excluded from assessments of the UNB capability (Appendix A, Table A-1).

6.2.2.2 Engineered Barrier System

The EBS is composed of features/components designed to work together and to complement the natural barriers by preventing or substantially reducing the release rate of radionuclides from the waste and preventing or substantially reducing the rate of movement of radionuclides from the repository to the accessible environment. The EBS features/components that are important to waste isolation and that contribute to barrier capability are (1) emplacement drift, (2) drip shield, (3) waste package including inner vessel, (4) naval SNF structure, and (5) waste form (excluding DOE SNF waste form) and waste package internals including the transport, aging, and disposal (TAD) canister, naval canister, TAD and DOE SNF canister neutron absorber materials, and naval SNF canister system components. Commercial SNF waste packages are used to represent the naval SNF waste packages in the TSPA. EBS features/components that are not important to waste isolation are (1) commercial SNF cladding, (2) DOE SNF waste form, (3) the waste package pallet, and (4) invert.

The EBS performs these functions by preventing or substantially reducing the quantity of water capable of contacting the waste, reducing the rate of release due to the slow alteration of the waste and low solubility of many radionuclides, and thereby reducing the rate of radionuclide transport from the waste form to the LNB. Figure 6-6 depicts the configuration of the features of the EBS.

The features of the EBS have processes and characteristics that influence the capability of these features to prevent or substantially reduce the release of radionuclides from the waste. These processes include chemical and thermal-chemical processes, mechanical and thermal-mechanical processes, hydrologic and thermal-hydrologic processes, and transport processes, as identified in Appendix A, Table A-2.

In the evaluation of the important processes and events related to the capability of the EBS, consideration is given to both the beneficial as well as the potentially deleterious processes and events, which act on every feature of the barrier. The presence of a beneficial process generally results in either (1) preventing the release or substantially reducing the release rate of radionuclides from the waste or preventing the movement of radionuclides or (2) substantially reducing the rate of movement of radionuclides from the repository to the accessible environment. Similarly, the absence or the slow rate of degradation rate of a potentially deleterious process generally results in preventing or substantially reducing the release of radionuclides from the waste. The presence of a potentially deleterious process could result in an increase in the release rate or rate of movement of radionuclides. The evaluation of beneficial and potentially deleterious processes that could affect the release or movement of radionuclides, both for the 10,000-year compliance period and for the post-10,000-year period, ensures a more complete understanding of the barrier capability. Both beneficial and potentially deleterious processes have been identified as important contributors to the capability of the EBS.

A few examples illustrate beneficial and potentially deleterious processes and their effects on the EBS. General corrosion of the waste package is a potentially deleterious process. However, a beneficial attribute of the waste package is that general corrosion rates for Alloy 22 are so slow and spatially variable under repository-relevant conditions that degradation and breaching of waste packages will be distributed over hundreds of thousands of years. Sorption of dissolved radionuclides on corrosion products in the waste package and on the invert ballast material (crushed tuff) in the EBS is a beneficial process of the EBS when the waste packages are breached. Seismic ground motion is a potentially deleterious process that can diminish the performance of the EBS by inducing both dynamic and static loads on the waste package. In turn these loads could cause stress corrosion cracking of the outer corrosion barrier and allow moisture to enter the waste package and degrade the waste form.

The features of the EBS that are important to waste isolation and the processes and characteristics that contribute significantly to their barrier capability are summarized below.

Emplacement Drift—The following processes and characteristics are important to the capability of the emplacement drifts and the EBS:

- **Unsaturated Flow in the EBS—**The repository and emplacement drifts are located above the water table and saturated zone. Therefore, water saturation in the EBS tend to be low thus reducing the effective diffusivity and mobility of radionuclides in a breached waste package and invert.

- **Chemical Characteristics of Water in Drifts**— The chemical characteristics of water in the drift are affected by the incoming water chemistry (due to seepage, condensation, or capillary flow), evaporation, and other thermal-chemical processes in the drift that are a function of the thermal-hydrologic environment. These chemical characteristics affect the likelihood of potential localized corrosion of the waste package outer barrier (Section 2.3.6.4), as well as the transport characteristics of any radionuclides released from the waste package to the invert. As presented in *Engineered Barrier System: Physical and Chemical Environmen*t (SNL 2007 [DIRS 177412], Section 6), a range of in-drift chemical conditions that could potentially affect degradation of the EBS components and transport of radionuclides has been evaluated and included in the abstraction models for the TSPA. *Dissolved Concentration Limits of Elements with Radioactive Isotopes* (SNL 2007 [DIRS 177418], Section 6); *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (SNL 2007 [DIRS 177423], Section 6); and *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6) present the transport characteristics that are affected by the range of in-drift water chemical characteristics, notably the radionuclide solubility and colloid stability.

- **Heat Generation in EBS**—The heat generated by radioactive decay has multiple effects on repository-relevant processes, including degradation, deterioration, and alteration of the EBS. Heat generation in the emplacement drifts affects the timing of the onset of seepage processes, as well as the distribution of in-drift convection and condensation. The heat generation and resultant temperature also affects the chemical evolution of water in the rock and emplacement drifts (SNL 2007 [DIRS 177412], Section 6).

- **Seismically Induced Drift Collapse Damages EBS Components—**Vibratory ground motions associated with seismic activity could cause failure of the host rock around emplacement drifts. The resulting drift degradation could cause damage to the drip shields as a result of the static load from the rock rubble amplified by the dynamic load associated with vibratory ground motion. Such mechanisms may result in damaged areas on the drip shield plates and stress corrosion cracking. However, stress corrosion cracking would not compromise the barrier capability of the drip shield because crack openings would be very small and tight, so effective water flow rates would be too low to affect the performance of the drip shield in preventing or substantially reducing the amount of water that could directly contact the waste package, and is excluded from the TSPA, as discussed (SNL 2008 [DIRS 183041], FEP 2.1.03.02.0B and FEP 2.1.03.10.0B). Accumulated rubble on the drip shield can also cause failure (rather than just damaged areas) of the drip shield during a seismic event. Two failure modes of the drip shield could occur: (1) rupture or tearing of the drip shield plates, and (2) buckling or collapse of the sidewalls of the drip shield (SNL 2007 [DIRS 176828], Section 6.8). In addition, this drift collapse may have a very significant effect on waste package degradation. This effect manifests itself by a significantly reduced waste package (i.e., improved performance and enhanced barrier capability) damage if the rubble surrounds the waste package in the absence of a drip shield. The effects of drift collapse tend to degrade the performance of the drip shield while improving the performance of the waste package if the waste package is surrounded by rubble at late times (about 200,000 years).

- **Thermal Effects on Chemistry and Microbial Activity in the EBS**—As noted above, thermal effects strongly influence the evolution of the water chemistry in the rock and emplacement drifts. The chemistry of the water in the emplacement drift determines the potential for localized corrosion of the waste package outer barrier and, in the event of waste package failure, can affect the stability of radionuclide-bearing colloids and radionuclide solubility in the invert. Microbial effects will not significantly affect the in-drift chemical environment, including water chemistry.

- **Chemistry of Water Flowing into the Drift**—As seepage waters percolate into the drift, their chemical compositions change by dilution or by evaporation and mineral precipitation. Evaporation causes dissolved aqueous species concentrations to increase, minerals to precipitate, and the most soluble components to become concentrated in the resulting solution, ultimately leading to the formation of brine. Dilution generally has the opposite effect. The chemical composition of the seepage water on the waste package surface determines the potential for localized corrosion of the waste package outer barrier. The chemical composition of seepage in the invert affects radionuclide solubility and colloid stability in the invert, which in turn affect the mobile radionuclide source term for transport. The range of expected water chemistries, as well as their variation in time due to the heat generated in the EBS, is presented in *Engineered Barrier System: Physical and Chemical Environment* (SNL 2007 [DIRS 177412], Section 6).

- **Seismic Ground Motion Damages EBS Components**—Vibratory ground motion has the potential to cause seismically-induced rockfall that changes the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Sections 6.3.1.2 and 6.4.2.2) and changes the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). A change in the cross section of the emplacement drifts can alter the seepage into the drifts, flow pathways within the drift, condensation within the EBS, and the presence of rockfall and/or rubble about the drip shield can alter the mechanical response and temperature time history of the EBS components.

- **Seismic Induced Rockfall Damages EBS Components**—Seismically-induced rockfall in the emplacement drifts can change the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Section 6.3.1.2), and can change the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). A change in the cross section of the emplacement drifts can alter the seepage into the drifts, flow pathways within the drift, condensation within the drift, and the presence of rockfall and/or rubble around the drip shield can alter the mechanical response and temperature time history of the EBS components.

- **Seismic Induced Drift Collapse Alters In-Drift Thermal Hydrology**—Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse and/or rubble infill throughout part or all of the emplacement drifts. Drift collapse could impact flow pathways and condensation within the EBS, mechanisms for water contact with EBS components, and thermal properties within the EBS.

Drip Shield—The following processes associated with and characteristics are important to the capability of the drip shield and the EBS:

- **Physical Form of Drip Shield**—The physical characteristics of the drip shield, consistent with the design of this feature, have been included in the analyses and models of drip shield degradation, EBS flow and transport, and EBS environments. These characteristics are significant contributors to the capability of the drip shield to limit the flow of water and release of radionuclides. The assessment of barrier capability and performance accounts for design features, material characteristics, and the ways in which the design influences the evolution of the in-drift environment. Administrative controls for repository construction and operations activities will be developed to assure that drip shields are manufactured in accordance with design specifications and are emplaced properly.

- **General Corrosion of Drip Shield**—General corrosion rates of titanium alloys in a range of expected environmental conditions are sufficiently low that this process does not cause a through-wall penetration of the drip shield until about two to three hundred thousand years after repository closure. General corrosion is also an important process affecting drip shield structural integrity, because general corrosion thins and weakens the drip shields over long time periods by gradually thinning the drip shield plates and framework. Thinning makes these components more susceptible to being damaged by vibratory ground motion. The slow degradation rate of the titanium drip shield is an important beneficial characteristic of the drip shield feature.

- **Localized Corrosion of Drip Shields**—Titanium is extremely resistant to localized corrosion due to its very passive film. Localized corrosion will not occur in repository environments and is excluded from the TSPA (SNL 2008 [DIRS 183041], FEP 2.1.03.03.0B).

- **Stress Corrosion Cracking of Drip Shields**—In the presence of residual stresses or sustained loading, titanium is potentially susceptible to stress corrosion cracking. Residual stresses and sustained loading are possible as a result of rockfall or seismically induced damage. Uncertainty exists in the stress state and threshold stress required for a stress corrosion crack to be initiated, and other uncertainties exist regarding the degree of propagation of any stress-induced crack of titanium. Due to the long time frames, stress corrosion cracking is modeled to be independent of the environment, although the environments to support stress corrosion may not occur within the repository. Although stress corrosion cracking is modeled to occur in the drip shield, the presence of cracks is an insufficient condition to affect the performance of the drip shield in preventing or substantially reducing the amount of water that could directly contact the waste package, and is excluded from TSPA (SNL 2008 [DIRS 183041], FEP 2.1.03.02.0B).

- **Effects of Drip Shield on Flow**—The drip shield prevents seepage water from contacting the waste package. Thus the drip shield reduces the rate of movement of water that may contact the waste, as well as preventing potentially deleterious brines from contacting the waste package surface during the period when the waste package may be susceptible to localized corrosion.

- **Advection of Liquids and Solids through Cracks in the Drip Shield**— Any cracks that extend through the drip shield are expected to be of insufficient size and morphology to allow the advective flow of water through them. The process of formation and the physical characteristics of stress corrosion cracks resulting from denting of the drip shield by seismic-induced rockfall or drift collapse is summarized in (SNL 2008 [DIRS 183041], FEP 2.1.03.10.0B). The advection of liquids through seismic-induced stress corrosion cracks in the drip shield is excluded from the TSPA based on low consequence as a result of a number of factors, including: (1) the small aperture width (narrow opening and tight cracks) and the presence of capillary forces within the stress corrosion cracks; and (2) the potential for plugging of the cracks due to mineral deposits. In response to stresses induced by rockfall deformations, stress relief via creep mechanisms or stress corrosion cracking of the drip shield may occur. Such cracks in passive alloys, such as Titanium Grade 7, are tight (e.g., small crack-opening displacement) and are expected to be plugged by corrosion products and precipitates (SNL 2008 [DIRS 183041], FEP 2.1.03.10.0B). The lack of significant advection through cracks in the drip shield is an important beneficial characteristic of the drip shield.

- **Localized Corrosion on Drip Shield Surface Due to Deliquescence**— The potential for salts to deliquesce on the drip shield surface has been evaluated. Although the potential for salts to deliquesce exists, the effects of such deliquescence have been determined to be insignificant to performance because localized corrosion processes are not expected to be initiated. Even if localized corrosion were initiated, due to the limited volumes of brine caused by deliquescence, it is expected that the process would not propagate through the drip shield surface. As a result, this process is excluded from the performance assessment (SNL 2008 [DIRS 183041], FEP 2.1.09.28.0B). The lack of significant drip shield degradation by this process is a beneficial characteristic of the drip shield.

- **Early Failure of Drip Shields**—During fabrication and emplacement, a range of human factor errors could result in a drip shield being emplaced that has the potential for a drip shield failure. This possibility has been included in abstraction models used in the early failure scenario class of the TSPA as presented in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007 [DIRS 178765]).

- **Creep of Metallic Materials in the Drip Shield**—Titanium Grade 7, used for the drip shield plates, may undergo creep deformation at temperatures as low as room temperature when subjected to tensile stresses exceeding approximately 50% of the yield strength (SNL 2007 [DIRS 181953], Section 6.8.7). Titanium Grade 29, used for the drip shield structural supports, has significantly higher creep resistance than Titanium Grade 7 (SNL 2007 [DIRS 181953], Section 6.8.7). When the drip shield deforms through long-term creep, a confinement caused by the rubble is developed which tends to inhibit further creep deformation. Creep of titanium resulting in instability (collapse) of the drip shield has been excluded from the performance assessment (SNL 2008 [DIRS 183041], FEP 2.1.07.05.0B). If creep occurs, it has the beneficial effect of decreasing the stress profile which in turn will reduce the rate of crack propagation. This beneficial effect has not been included in the stress corrosion cracking model (SNL 2008 [DIRS 183041], FEP 2.1.07.05.0B).

- **Seismic Induced Drift Collapse Damages EBS Components**—Vibratory ground motions associated with seismic activity could cause failure of the host rock around emplacement drifts. The resulting rockfall could cause damage to the drip shields as a result of the static load from the rock rubble amplified by the dynamic load associated with vibratory ground motion. Such mechanisms may result in damaged areas on the drip shield plates and stress corrosion cracking. However, stress corrosion cracking would not compromise the barrier capability of the drip shield because crack openings be very small and tight, so effective water flow rates would be too low to affect the performance of the drip shield in preventing or substantially reducing the amount of water that could directly contact the waste package, and is excluded from the TSPA, as discussed (SNL 2008 [DIRS 183041], FEP 2.1.03.02.0B and FEP 2.1.03.10.0B). Accumulated rubble on the drip shield can also cause failure (rather than just damaged area) of the drip shield during a seismic event. Two failure modes of the drip shield could occur: (1) rupture or tearing of the drip shield plates, and (2) buckling or collapse of the sidewalls of the drip shield.

Waste Package—The following processes associated with and characteristics are important to the capability of the waste package and the EBS:

- **Physical Form of Waste Package**—The physical characteristics of the waste package, consistent with the design of this feature, have been included in the analyses and models of waste package degradation. These characteristics are significant contributors to the capability of the waste package to reduce the release rate of radionuclides from the waste. The assessment of barrier capability and performance account for design features, material characteristics, and the ways in which the design influences the evolution of the in-drift environment. Administrative controls for repository construction and operations will be developed to assure that waste packages are manufactured in accordance with design specifications and are emplaced properly.

- **General Corrosion of Waste Packages**—General corrosion rates of Alloy 22 in a range of expected environmental conditions are sufficiently low that this process is projected to cause a through-wall penetration in only a small fraction of the waste packages by 1 million years after repository closure. General corrosion is an important process affecting waste package structural integrity, because general corrosion thins and weakens the waste packages over long time periods by gradually thinning the Alloy 22 outer corrosion barrier, which makes the waste package more susceptible to being damaged by vibratory ground motion. Although the stainless steel inner vessel of the waste package and the TAD canister for the commercial SNF waste package will reduce the rate of movement of water that may contact the waste for tens of thousands of years after the Alloy 22 outer corrosion barrier is breached, this beneficial characteristic is not included in the performance assessment. The stainless steel inner vessel and TAD canister will provide additional structural resistance to vibratory ground-motion-induced damage to the waste packages; this beneficial characteristic is also incorporated into the performance assessment, but is not included in the performance assessment after the waste package Alloy 22 outer corrosion barrier has been breached.

- **Stress Corrosion Cracking of Waste Packages**— Stress corrosion cracking is the process by which cracks initiate in a material under stress in the presence of a corrosive environment. Stress corrosion cracking may affect the time to waste package breach. Stress corrosion cracks would allow diffusive transport of radionuclides from the waste package and therefore could compromise the barrier capability of the waste package. Alloy 22, the material used for the waste package outer corrosion barrier, is highly resistant to stress corrosion cracking, but may be susceptible to cracking in the Yucca Mountain environment and the stress conditions (SNL 2007 [DIRS 181953]). Stress corrosion cracking can occur via three possible mechanisms: (1) through-wall propagation of fabrication flaws (other than in the outer corrosion barrier weld region) in the waste packages that result in early waste package failure; (2) through-wall propagation of incipient cracks that can occur on the waste package outer corrosion barrier closure weld regions; (3) damage to the waste package induced by seismic events and drift collapse (SNL 2007 [DIRS 176828]).

- **Localized Corrosion of Waste Packages**— Localized corrosion is a phenomenon in which corrosion progresses at discrete sites or in a nonuniform manner. At least upon initiation, the propagation rate of localized corrosion is faster than that of general corrosion. Localized corrosion mechanisms on the waste package surface are dependent on the thermal-hydrologic and thermal-chemical environment on the waste package surface. The initiation of localized corrosion is possible in those cases where the drip shield has degraded sufficiently that incoming seepage is allowed to contact the waste package during the early part of the thermal period. In most cases, the drip shield will be intact during this period, protecting the waste package from seepage water contact. Should the drip shield fail to perform its function, such as in the unlikely event of drip shield failure due to large seismic motions or fault displacement in the first 12,000 years, seepage waters may form concentrated aggressive solutions on the waste package (SNL 2008 [DIRS 183478], Volume I, Section 6.3.5.2). In this case, waste packages that are susceptible to localized corrosion are expected to have already experienced substantial mechanical damage failure and any additional damage caused by localized corrosion would not significantly impact radionuclide release from already damaged waste packages. The possibility of localized corrosion also requires aggressive environmental exposure conditions that are generally not present (SNL 2008 [DIRS 183478], Volume III, Appendix O). The expected absence of the conditions necessary to initiate localized corrosion is an important beneficial characteristic of the waste package feature.

- **Advection of Liquids and Solids through Cracks in the Waste Package**—Similar to cracks in the drip shield, cracks in the waste package are expected to be of insufficient size and morphology to allow for the advection of water into the waste package. As a result, as discussed in *Features, Events, and Processes for the Total System Performance Assessment: Analyses* (SNL 2008 [DIRS 183041]), advective release from the waste package is only possible when the degradation mode causing breach is by general or localized corrosion, manufacturing defects resulting in early failure, or waste package rupture due to forces induced by seismic vibratory ground motion or fault displacement.

- **Localized Corrosion on Waste Package Outer Surface Due to Deliquescence—**Dust will be deposited on the surfaces of waste packages in emplacement drifts primarily during the operational and the preclosure ventilation periods. After emplacement, there is a period up to approximately 1,000 years in which no seepage is possible because the drift wall temperature is above boiling (SNL 2008 [DIRS 184433], Figure 6.3-76[a]). During this interval, and for as long as the drip shields perform their function, the only aqueous phase that could potentially contact the waste package is brine that originates by deliquescence of soluble salts in dust residing on the waste package (SNL 2007 [DIRS 181267], Sections 7.1 and 7.1[a]). The potential for brines formed by dust deliquescence to initiate and sustain localized corrosion resulting in breach of the waste package outer corrosion barrier has been evaluated and excluded from the TSPA.

- **Seismic Ground Motion Damages EBS Components—**Ground motion associated with seismic activity has the potential to disrupt the integrity of the waste package and other EBS components, which could lead to impaired waste package performance and/or breaching, with subsequent radionuclide release. Seismic-induced deformation of the waste package could result in plastic yielding or even breach of the waste package. If the residual stress on a plastically deformed waste package exceeds a threshold value, then accelerated stress corrosion cracking may result in the formation of diffusive transport pathways for radionuclides. Additional structural failures corresponding to the tearing or rupture of the waste package could also occur. A rupture or tear may occur if the local strain exceeds the ultimate tensile strain, and may partly or completely negate the effectiveness of the waste package in preventing the inflow of seepage water or the outward transport of radionuclides (SNL 2007 [DIRS 176828], Section 6.1.4).

- **Early Failure of Waste Packages**—During fabrication, waste loading, and emplacement, a range of human factor errors could result in a waste package being emplaced that has the potential for an early waste package failure. This possibility has been included in abstraction models used in the early failure scenario class of the TSPA as presented in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007 [DIRS 178765]).

Naval SNF Structure—The following process and characteristics are important contributors to the barrier capability of the naval SNF structure and EBS:

- **Naval SNF Structure**—In the modeled repository there are 8,213 waste packages of commercial SNF, 413 of which represent the naval SNF waste packages (SNL 2008 [DIRS 183478], Appendix L, Section L2.10). The TSPA model does not explicitly include the naval SNF waste packages, but represents its behavior with 413 commercial SNF waste packages that bound the naval SNF waste packages. That is, waste packages containing naval SNF are conservatively modeled in the TSPA as commercial SNF waste packages (SNL 2008 [DIRS 183041], FEP 2.1.02.25.0B).

Waste Form and Waste Package Internals (including the TAD canister, naval canister, TAD and DOE SNF canister internals, naval SNF structure, and naval SNF canister system components)—The following processes and characteristics are important to the capability of the waste form and waste package internals and the EBS:

- **Seismic Ground Motion Damages EBS Components—**Vibratory ground motion has the potential to damage the waste forms and waste package outer corrosion barrier as a result of waste package-to-waste package impacts and waste package-to-pallet impacts that may occur during a seismic event. This damage may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. Once the outer corrosion barrier is breached by a crack network, corrosion of the waste package internals (specifically TADs and Naval canisters represented by CNSF packages because of their original structural stability or weight) will compromise their capacity to support structural loads and to isolate the waste form during vibratory ground motion (SNL 2007 [DIRS 176828], Sections 5.4 and 6.1.4).

- **Commercial Spent Nuclear Fuel Degradation (Alteration, Dissolution, and Radionuclide Release)—**The availability of individual radionuclides for dissolution, once a commercial SNF waste package and fuel cladding are breached, is limited by the structure, microstructure, and physiochemical properties of the irradiated fuel, as well as by the distribution of radionuclides in the fuel rods. The part of the radionuclide inventory present, either as a solid solution in the fuel matrix or embedded as discrete phases in the fuel grains, is not available for dissolution until the fuel matrix is dissolved or degraded. The rate of dissolution or degradation will influence the rate at which soluble radionuclides can enter solution. The commercial SNF degradation rate is the product of the fuel surface area and the surface area-normalized dissolution rate. The latter depends on pH, carbonate levels, and the oxygen partial pressure (BSC 2004 [DIRS 169987]).

- **HLW Glass Degradation (Alteration, Dissolution, and Radionuclide Release)—**The availability of individual radionuclides for transport and release once a codisposal waste package is breached is determined by the rate at which radionuclides leave the waste form and enter solution. The rate at which radionuclides enter a solution is controlled either by the dissolution rate of the waste form or by the solubility limit of the constituent elements. A few soluble radionuclides, such as ^{99}Tc, will enter solution at the same rate glass dissolves, so the waste form dissolution rate determines their rate of release. ^{99}Tc from HLW is a key contributor to the annual dose to the RMEI in the 10,000-year period. HLW glass degradation depends upon the glass surface area and the surface area-normalized glass dissolution rate. The dissolution rate varies as a function of pH, being lowest at near neutral pH. Many radionuclides, however, quickly saturate the solution, so the solubility limits of these radionuclides determine their rate of release.

- **Chemical Characteristics of Water in Waste Package**—The chemical characteristics of the water in contact with the waste package internals, including void spaces, and the waste form affect the degradation characteristics of the waste form, the solubility of radionuclides in the dissolved phase, and the stability of colloidal particles. These chemical effects are significant in affecting the release of low solubility radionuclides (e.g., ^{90}Sr, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) and radionuclides that may be released attached to colloidal particles (e.g., ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am). Uncertainty in the in-package chemistry, in particular the ionic strength and pH that have the most significant effect on these coupled processes, has been considered in the abstraction models used in TSPA presented in *In-Package Chemistry Abstraction* (SNL 2007 [DIRS 180506]).

- **Chemical Interaction with Corrosion Products—**The corrosion products of the steel and aluminum alloys in the waste package, and their control on the concentration of aqueous species, are of primary importance in determining the pH and ionic strength of the solution, which impacts the alteration rates of the different waste forms, the solubility of radionuclides, and the colloid concentration and stability in the waste package. In addition, sorption onto corrosion products can significantly slow the release of radionuclides from the waste package. As discussed in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6.3.4.2), retardation of radionuclides will occur in the waste package corrosion products.

- **Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and EBS**—Solubility limits of low-solubility dissolved radionuclides (e.g., ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) significantly affect the amount of these radionuclides that may be released from the waste form through the other EBS features. The more soluble the radionuclide, generally the greater mass flux of that radionuclide that will be released by diffusive or advective release mechanisms from the waste form. The radionuclides most significant to dose that are released by diffusion are highly soluble ^{99}Tc and ^{129}I (SNL 2007 [DIRS 177418], Section 6).

- **Sorption of Dissolved Radionuclides in the EBS**—The degradation of the waste package inner vessel and internals (such as the TAD canister) results in a significant quantity of iron/chromium/nickel oxide materials. These materials have a significant amount of retardation potential, due to sorption, for a number of radionuclides that are potentially significant for the release from the waste form, including ^{90}Sr, ^{137}Cs, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am. This sorption significantly reduces the release of these radionuclides from the waste in the event that a breach in the waste package has occurred. The models used to evaluate radionuclide sorption are presented in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6).

- **Reaction Kinetics in Waste Package—**Chemical reactions, such as radionuclide dissolution/precipitation reactions and reactions controlling the reduction–oxidation state, may not be at equilibrium within the waste package and influence the in-package solution chemistry, the solubility of radionuclides, the degradation rate of HLW glass, and radionuclide sorption onto corrosion products. The effects of reaction kinetics on these processes and radionuclide releases from the waste package are included in TSPA.

- **Diffusion of Dissolved Radionuclides in the EBS**—Diffusion is an important mechanism that transports dissolved radionuclides from the waste form surface to the waste package internals and then through the degraded waste package to the invert. Diffusion is controlled by the degree of degradation of the waste package and the hydrologic characteristics within the waste package, which, in turn, are a function of the type of waste. The model presented in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6) assumes there is a continuous water film if relative humidity is greater than 95% and the temperature is less than 100°C through which radionuclides can diffuse.

- **Advection of Dissolved Radionuclides in the EBS**—Once the drip shields fail and patch breaches in the waste package form, water may enter the waste package, dissolve radionuclides, and flow out, thereby generating advective releases of radionuclides. Patch breaches may form due to manufacturing defects (early failure), general corrosion, or seismic-induced rupture or puncture. When advective transport occurs, advective release rates of radionuclides from the waste package are typically greater than diffusive release rates, particularly for solubility-limited radionuclides (e.g., ^{90}Sr, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) and radionuclides that may be released attached to colloidal particles (e.g., ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am). Models used for the advective transport processes are presented in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6).

- **Chemical Effects of Void Space in Waste Package—**Upon waste package breach, the inert gas initially present escapes and is replaced by humid air. The reaction of this air with waste package internals and the resulting changes in water chemistry influence the solubility characteristics of radionuclides, the degradation of waste package internals and the waste form, and the transport behavior of radionuclides released from the waste form. Chemistry effects of voids in the waste package internals are included in models of in-package water chemistry (SNL 2007 [DIRS 180506], Section 6.3.1.1).

- **In-Package Criticality (intact configurations, degraded configurations, resulting from a seismic event (intact and degraded configurations), and resulting from rockfall (intact and degraded configurations))**—For a criticality event to occur, the appropriate combination of materials (e.g., neutron moderators, neutron absorbers, fissile materials, or isotopes) and geometric configurations favorable to criticality must exist. As documented in *Screening Analysis of Criticality Features, Events, and Processes for License Application* (SNL 2008 [DIRS 173869], FEPs 2.1.14.15.0A, 2.1.14.16.0A, 2.1.14.18.0A, 2.1.14.19.0A, 2.1.14.21.0A, and 2.1.14.22.0A) the probability of criticality for the in-package location is less than 1 chance in 10,000 of occurrence within 10,000 years after disposal. Therefore, in-package criticality is excluded from the performance assessment.

- **Stress Corrosion Cracking of Waste Packages**—Stress corrosion cracking is the process by which cracks initiate in a material under stress in the presence of a corrosive environment. Stress corrosion cracking may affect the time to waste package breach. Stress corrosion cracks would allow diffusive transport of radionuclides from the waste package and therefore could compromise the barrier capability of the waste package.

Alloy 22, the material used for the waste package outer corrosion barrier, is highly resistant to stress corrosion cracking, but may be susceptible to cracking in the Yucca Mountain environment and the stress conditions (SNL 2007 [DIRS 181953]). Stress corrosion cracking can occur via three possible mechanisms: (1) through-wall propagation of fabrication flaws (other than in the outer corrosion barrier weld region) in the waste packages that result in early waste package failure; (2) through-wall propagation of incipient cracks that can occur on the waste package outer corrosion barrier closure weld regions; (3) damage to the waste package induced by seismic events and drift collapse (SNL 2007 [DIRS 176828]).

- **DOE SNF Degradation (Alteration, Dissolution, and Radionuclide Release)**—Little quality-level data exists on the DOE SNF fuel, so a bounding approach is used to account for uncertainty in the characteristics of the DOE SNF fuel (BSC 2004 [DIRS 172453]) and the degradation rate of all DOE SNF except naval waste packages is bounded in the TSPA as instantaneous. The degradation of DOE SNF waste packages strongly influences the pH of the water chemistry within the codisposal waste packages by buffering pH in the near-neutral range and therefore impacts radionuclide solubilities, colloid stability, and radionuclide mobility.

Waste Package Pallet—The following processes associated with and characteristics are important to the capability of the waste package pallet and the EBS:

- **Seismic Ground Motion Damages EBS Components—**Vibratory ground motion has the potential to damage the waste forms and waste package outer corrosion barrier as a result of waste package-to-pallet impacts that may occur during a seismic event. This damage may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. Once the outer corrosion barrier is breached by a crack network, corrosion of the waste package internals (specifically TADs and Naval canisters represented by CNSF packages because of their original structural stability or weight) will compromise their capacity to support structural loads and to isolate the waste form during vibratory ground motion (SNL 2007 [DIRS 176828], Section 6.1.4).

The waste package pallet and emplacement drift invert are two features of the EBS that are not important to waste isolation. While intact, the waste package pallet precludes contact between the waste package and the invert and stabilizes the waste package during seismic events. The invert maintains the pallet, waste package, and drip shield in a nominally horizontal configuration.

The presence of the pallet can delay diffusive releases of radionuclides from the waste package to the invert, as long as the cradles remain intact and can support the waste package above the invert. The EBS radionuclide transport abstraction model (SNL 2007 [DIRS 177407]**,** Section 6) implemented in the TSPA ignores this beneficial characteristic of the pallet and conservatively assumes that the waste package is in direct contact with the invert. The emplacement drift invert is composed of two parts: a steel invert structure and ballast (or crushed tuff). In the unsaturated repository environment, the crushed tuff in the invert sorbs radionuclides and slows the diffusive movement of radionuclides into the Lower Natural Barrier.

The significant processes described above determine the manner in which the features of the EBS work together to prevent or substantially reduce the release of radionuclides from the waste and prevent or substantially reduce the rate of movement of radionuclides from the repository to the accessible environment. These processes and their effects on the EBS can be summarized as: (1) chemical, thermal, and mechanical processes that affect the degradation of the drip shield and waste package, (2) thermal-hydrologic processes that affect the potential for liquid flow through cracks in degraded drip shields and waste packages, and (3) thermal and chemical processes that affect alteration of the waste form and waste package internals and transport from the waste form to the edge of the EBS. The most significant drip shield and waste package degradation processes are related to mechanical degradation processes associated with likely and unlikely seismic events that cause through-wall stress corrosion cracks. The most significant thermal-hydrologic processes are related to water entering the waste package. However, tight flow paths through potential cracks prevent liquid flow into the waste package and limit the radionuclide release process to follow a diffusive path through the waste package. The most significant thermal and chemical processes are related to waste form degradation, corrosion of internal materials, and diffusive transport processes limited by the low solubility of the radionuclides that are a significant fraction of the total inventory (notably ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am), as well as the sorption of these radionuclides onto iron oxide and other degradation products in the waste package.

The models developed to represent the physical and chemical environment in the emplacement drift are described in *General Corrosion and Localized Corrosion of the Drip Shield* (SNL 2007 [DIRS 180778]); *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519]); and *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007 [DIRS 181953]). The TSPA model integrates the models of degradation processes with models used to describe the environment within the emplacement drift. The waste form degradation models as well as the in-package chemistry and radionuclide solubility models described in *In-Package Chemistry Abstraction* (SNL 2007 [DIRS 180506], Section 6); and *Dissolved Concentration Limits of Elements with Radioactive Isotopes* (SNL 2007 [DIRS 177418], Section 6) are implemented in the TSPA model. Similarly, the model for EBS transport described in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6), which simulates the mobilization and movement of radionuclides from inside the waste package to and through the invert, is implemented in the TSPA model. The TSPA model integrates the degradation, mobilization, and transport models with other components, such as those used to describe the chemical and physical environment within the emplacement drift.

6.2.2.2.1 Capability of the Engineered Barrier System to Prevent or Substantially Reduce the Contact of Seepage with the Waste Form

The capability of the EBS to prevent or limit the movement of water and prevent contact between water and waste depends on the integrity of the drip shields and waste packages. Should the majority of waste packages remain intact for tens of thousands to hundreds of thousands of years as expected, only a limited number of the waste forms will be exposed to water during this period. The data and analyses used to assess waste form degradation are discussed in detail in *Defense HLW Glass Degradation Model* (BSC 2004 [DIRS 169988], Section 6.1), *CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004 [DIRS 169987], Section 6.2.2.2), *DSNF* *and Other Waste Form Degradation Abstraction* (BSC 2004 [DIRS 172453], Section 6). The possibility of early failure of some waste packages due to fabrication errors, as well as the effects of seismic-induced mechanical damage, have been considered in evaluating the overall barrier capability.

The drip shield is designed to divert seepage away from the waste package. It prevents water from contacting the waste package as long as it remains intact. The waste packages prevent water from contacting the waste forms. As long as the waste packages are intact, moisture cannot contact the waste forms. The Zircaloy cladding that encases much of the SNF also prevents the contact of seepage with the waste form as long as it remains intact although this capability is not considered in the TSPA. A detailed description of the testing data, geochemical constraints, and models of drip shield, waste package, and cladding integrity is presented in *General Corrosion and Localized Corrosion of the Drip Shield* (SNL 2007 [DIRS 180778]); *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519]); and *Cladding Degradation Summary for LA* (SNL 2007 [DIRS 180616], Section 6).

The degradation rates for general corrosion of Titanium Grade 7 (UNS R52400) are sufficiently low so that even the highest measured rates would not lead to failure of the drip shield for over 150,000 years. Seismic-induced stress corrosion cracking is not expected to have significant consequences to drip shield performance and is excluded from the TSPA (SNL 2008 [DIRS 183041], FEP 2.1.03.02.0B). Localized corrosion induced by seepage or by deliquescence will not occur in repository environments and is excluded from TSPA (SNL 2008 [DIRS 183041], FEPs 2.1.03.03.0B and 2.1.09.28.0B). Even with stress corrosion cracking of the drip shields or any subsequent creep deformation, the nature of any openings (e.g., the tightness of cracks or the small size at the initiation of breaching) prevents water movement onto the waste package. Early failure of a very small number of drip shields potentially may occur due to flaws that are undetected during fabrication and handling (SNL 2008 [DIRS 183041], Section 6.2, FEP 2.1.03.08.0B). These types of flaws would diminish the drip shield's ability to withstand dynamic and static loads caused by seismic activity; however, they are treated in the TSPA model as an immediate and complete failure, which means loss of protection of the waste package from seepage or drift degradation at time of repository closure.

The degradation rates for general corrosion of Alloy 22 are sufficiently low that breach of the waste packages due to general corrosion will be distributed over many hundreds of thousands of years, beginning at about 400,000 years. Although stress corrosion cracking may occur in the closure-lid weld regions of some of the waste packages, mitigation techniques are employed to reduce residual stresses below the stress corrosion cracking initiation threshold. However, stress corrosion cracking can eventually initiate beginning after about 100,000 years as general corrosion removes the stress-mitigated layer. Stress corrosion cracking of Alloy 22 may also occur as a result of residual stresses caused by mechanical impacts during seismic events. Such stress cracks are small and tight and limit the movement of water that could potentially contact the waste form and reduce the release rate of radionuclides from the waste packages. Localized corrosion is only possible in those cases where the drip shield fails to perform its function and certain aggressive incoming seepage is allowed to contact the waste package. This condition may occur in the unlikely case where seismic ground motion is accompanied by fault displacement or in the case of early drip shield failure. Early failure of a small number of waste packages potentially may occur due to flaws that are undetected during fabrication and handling.

No performance credit is taken for the ability of the stainless-steel inner vessel or TAD canister to preclude or limit water influx into the waste package once the Alloy 22 outer corrosion barrier is breached. However, performance credit is applied in the TSPA for the increase in waste package structural strength and accompanying resistance to seismic damage due to the inclusion of the inner vessel and the TAD canister (in commercial SNF waste packages).

Although no credit is taken for the performance of cladding as a barrier, it is expected that cladding will be largely intact in the repository environment, except for seismic-initiated events, and therefore will provide defense in depth against radionuclide releases from the waste form.

6.2.2.2.2 Capability of the Engineered Barrier System to Prevent the Release or Substantially Reduce the Release Rate of Radionuclides from the Waste and Transport to the Lower Natural Barrier

In the event that waste packages are breached, the release rate of radionuclides is limited by the characteristics and behavior of the EBS. The release of radionuclides is first impeded by the rate of degradation of the waste form. Waste form degradation cannot begin until the waste package is breached, allowing the ingress of air and water. Because of the unsaturated environment, the elevated temperatures within waste packages, and the presence of drip shields and waste packages, the amount of water in contact with the waste form is expected to be limited as long as decay heat exists. The data and analyses used to assess waste form degradation are discussed in detail in *Defense HLW Glass Degradation Model* (BSC 2004 [DIRS 169988], Section 6.1), *CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004 [DIRS 169987], Section 6.2.2.2), *DSNF and Other Waste Form Degradation Abstraction* (BSC 2004 [DIRS 172453], Section 6).

Release of radionuclides out of the waste package depends on the chemical environment within the waste package and on moisture conditions within the waste package. Release can only occur if radionuclides are dissolved in water and/or attached to colloids and if there are continuous liquid pathways in the waste package, including thin films of adsorbed water. Slow diffusive transport of radionuclides can occur in these thin films. Advective transport of radionuclides out of the waste package and EBS can occur only if breaches are sufficiently open to permit flow and there is a liquid flux of water through the waste package and invert. Continuous liquid pathways can only form if moisture enters the waste package. Waste heat and evaporation from hot surfaces within the waste package will prevent moisture from entering the waste package and subsequently forming continuous liquid pathways for diffusive transport. Continuous liquid pathways will form when the waste cools and relative humidity in the waste package increases sufficiently. Continuous pathways may not form in the hotter commercial SNF waste packages for several thousand years.

The transport of many dissolved radionuclides, including those that are the greatest contributors to the total inventory activity, such as ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu,^{241}Am, and ^{243}Am, is retarded by sorption on iron corrosion products within the waste package. The retardation depends on the volume of these corrosion products and on the distribution coefficients associated with them.

Sorption onto the corrosion products also reduces movement of those radionuclides that are reversibly attached to colloids in the water. The mobilization and transport of radionuclides out of breached waste packages and through the invert in the EBS are described in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6).The radionuclide inventory released from the EBS would be limited by diffusive transport if: (1) the drip shield remains intact, or (2) the waste package breach is a stress-induced crack. Although advective transport is not expected from the waste package for hundreds of thousands of years after closure, both diffusive and advective transport are considered in the potential for releasing radionuclides from the invert feature of the EBS starting at the time of repository closure.

6.2.2.2.3 Time Period over Which the Engineered Barrier System Functions

The EBS consists of features designed, fabricated, and constructed to perform their functions for well beyond 10,000 years. Through the appropriate use of thick, diverse, corrosion-resistant materials, the drip shields and the waste packages are expected to remain intact for tens of thousands of years. The EBS features will gradually degrade during and beyond the 1-million-year period of geologic stability. This process will result in the slow release of radionuclides over extended periods of time. Some components, such as the waste packages, are expected to contribute substantially to barrier performance up to and beyond 1,000,000 years.

The capability of the drip shield and the waste package to prevent or reduce the movement of water and radionuclides is not impacted until sufficient corrosion has occurred to cause through-wall breaches in the waste packages. General corrosion and stress corrosion cracking, along with seismic-initiated mechanical damage, will cause through-wall breaches in the waste package. A summary discussion of the thermal environment within the emplacement drift and how it evolves in time with respect to corrosion and condensation is presented below.

The environment within the emplacement drift evolves through three main stages. The initial stage includes the heat-up after closure with the drift wall and waste package surface temperatures increasing above the boiling point of water, then reaching their peak temperatures; this is followed by subsequent cool down period in which the surface temperatures continue to be above the boiling point of water. No seepage is expected during this period due to vaporization and capillary diversion effects. Any water vapor that flows from the host rock into the drift will be transported axially toward unheated regions at either end. The unheated regions are cooler so that condensation is possible (SNL 2007 [DIRS 181648], Section 6.3.3.1). Deliquescent brine films may form from salts or moisture in the air if the temperature is below the deliquescence point. Given the low volumes and high nitrate concentrations of such brines, even if they were to form and be stable, localized corrosion is not expected to occur under these films as presented in *Analysis of Dust Deliquescence for FEP Screening* (SNL 2007 [DIRS 181267]). This dryout period is expected to last for several hundred to more than 1,000 years, depending on the location in the repository. As presented in *Multiscale Thermohydrologic Model* (SNL 2008 [DIRS 184433], Section 6), elevated temperatures would persist longer near the center of the repository and would dissipate more quickly at the edges of the repository.

The second stage is the transition period during which drift wall temperatures drop below the boiling point of water and the waste package surface temperature is near the boiling point of water and localized corrosion on the waste package surface is possible under certain geochemical conditions. The emplacement drifts will enter this stage at the edges of the repository first where heat dissipates more quickly. It is during this transition period when drift wall temperatures are above and below the boiling point of water in different parts of the repository that water evaporated from the emplacement drift walls and invert is transported primarily by natural convection from warmer to cooler areas, where it condenses on cooler surfaces. In those regions where drift wall temperatures are below the boiling point of water and waste package surface temperatures are near 100°C, waters from the rock (seepage) and condensation can fall onto hot metal surfaces. Evaporative concentration of seepage may produce aggressive chemistry that is more conducive to localized corrosion for Alloy 22 (SNL 2008 [DIRS 183478], Section 6.3.3 and Appendix O). Condensation that forms on the drip shield or waste package surface or that occurs in the absence of seepage is assumed to have a benign composition with respect to the corrosion environment because it is dilute (SNL 2008 [DIRS 183041], FEP 2.1.08.14.0A). Should the drip shield fail to perform its function, these seepage and condensation waters may fall on the waste package. However, given the absence of drip shield failure during this transition period, except in the rare case of early drip shield failure and the unlikely occurrence of a damaging fault displacement event, localized corrosion is not expected to be initiated in environmental conditions relevant to the repository. In the rare case of early drip shield failure, it was assumed in the TSPA that a waste package under an early failed drip shield would fail completely due to localized corrosion; this assumption is conservative with respect to barrier capability because a smaller failure would reduce the release rate of radionuclides from the waste and waste package. In addition, analyses show that any additional damage caused by localized corrosion would not significantly impact radionuclide release from already damaged waste packages (SNL 2008 [DIRS 183478], Section 7.3.2.7).

The third stage is the period in which drift wall and waste package surface temperatures have further decreased and the likelihood of localized corrosion on the waste package surface is reduced and will not occur after 12,000 years (SNL 2008 [DIRS 183478], Volume III, Appendix O). During this stage the relative humidity within the drift increases. At the locations of cooler waste packages, especially in the outer portions of the drift, relative humidity may achieve 100% so that condensation occurs. At the hotter locations (central portion of the drift and hotter waste packages in the outer portions of the drift), the relative humidity remains below 100%, evaporation in the host rock continues, and condensation does not occur. TSPA projections indicate that condensation will cease throughout the repository by approximately 2,000 years. This period lasts for the remainder of the period of geologic stability. General corrosion and stress corrosion cracking, along with seismic-initiated mechanical damage, may still occur. Waste packages, on average, are not expected to begin to fail until after 100,000 years, with breaches caused by through-wall stress corrosion cracks in the weld of the outer closure lid and about 60% of the waste packages are estimated to fail by stress corrosion cracking by 1 million years. General corrosion failures would start, on average, at approximately 400,000 years and about 10% of the waste packages would experience a general corrosion breach in 1 million years. Diffusion would be the only transport mechanism acting to release radionuclides from a waste package when cracks were the only penetration through the waste package.

Degradation of the materials used in the pallet supporting the waste package may occur by mechanical or chemical degradation processes. These processes have been determined not to result in a significant adverse change in the magnitude or timing of radionuclide releases to the accessible environment (SNL 2008 [DIRS 183041], FEP 2.1.06.05.0A, FEP 2.1.06.05.0C). However, thinning of the waste package pallet due to chemical degradation is included in seismic analyses, however, the effect of the emplacement pallet on radionuclide release is not considered (SNL 2008 [DIRS 183041], FEP 2.1.06.05.0C). The invert is anticipated to provide a stable mechanical foundation for the waste package pallet and drip shield for at least 10,000 years after closure. Although chemical and mechanical changes may occur in the invert, these changes do not significantly affect the transport characteristics of the invert (Table A-2) or the response of the EBS to seismic vibratory ground motion. The transport characteristics of the invert that affect radionuclide release from the EBS and waste package response are presented in *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6).

6.2.2.2.4 Uncertainties Associated with Engineered Barrier System Capability

Uncertainty in the representation of the capability of the drip shields and waste packages arises primarily from uncertainties in environmental conditions and from uncertainties in the models for the various degradation processes. These uncertainties are described in detail in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519], Section 6.4); *General Corrosion and Localized Corrosion of the Drip Shield* (SNL 2007 [DIRS 180778], Section 6.1); and *Engineered Barrier System: Physical and Chemical Environment* (SNL 2007 [DIRS 177412], Section 6). These include uncertainties in the data from tests measuring the various degradation processes and uncertainties in the conceptual and numerical models used to analyze both environmental conditions and degradation processes. These uncertainties are incorporated probabilistically in the models for thermal-hydrologic conditions, waste form degradation, radionuclide transport, radionuclide solubility, and radionuclide sorption by sampling across uncertainty ranges in the inputs to these models. Similarly, uncertainty in corrosion or degradation processes is also represented by sampling degradation parameters across their uncertainty ranges. These uncertainties are analyzed directly in the TSPA model with multiple realizations. For each realization, input and parameter values are sampled and a complete simulation of the EBS thermal and chemical environment is performed that includes the resulting drip shield and waste package degradation, waste form degradation, and radionuclide mobilization. Accordingly, multiple realizations represent the range of uncertainty in EBS capability as modeled. Uncertainties in the environmental conditions affecting the degradation of the waste package (Alloy 22) and the drip shield (Titanium Grade 7), including general corrosion, microbially influenced corrosion, stress corrosion cracking, and localized corrosion, are summarized below. The use of a temperature dependence term is appropriate because the general corrosion (passive dissolution) of highly corrosion-resistant alloys such as Alloy 22 is governed by the transport properties of reacting species in the passive film and the rate of activation-controlled ion transfer at the film-solution interface, both of which are thermally activated processes. Data from short-term polarization-resistance data for Alloy 22 samples tested for a range of sample configurations, metallurgical conditions, and exposure conditions (temperature and water chemistry) indicate a temperature dependence. Accordingly, the general corrosion model addresses temperature dependence and uncertainty in the temperature dependence data consistent with the short-term polarization-resistance tests. Uncertainty associated with projection of Alloy 22 general corrosion rates, based on the 5-year test data, to the repository performance period is bound in the TSPA by applying time-independent, constant general corrosion rates. The general corrosion rates of metals and alloys decrease with time.

Nickel-based alloys, such as Alloy 22, are resistant to microbially influenced corrosion. The microbially influenced corrosion rate multiplier for Alloy 22 is a uniform distribution between 1 and 2. Titanium Grade 7 is shown not to be susceptible to microbially influenced corrosion, and, therefore, no multiplier is applied. A detailed discussion of the effects of microbially influenced corrosion on these materials is provided in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519]).

Stress corrosion cracking may occur and contribute to the degradation of Alloy 22 and Titanium Grade 7. The extent of this process affects analyses of performance. The sources of uncertainty in the stress corrosion cracking model have been considered in analyses of waste package degradation. These analyses consider an expanded range of parameter values for the residual stress profile of the drip shields and waste packages, including closure-lid weld regions of waste packages, the threshold stress for stress corrosion crack initiation, and the orientation of the weld flaws. The modeling of stress corrosion cracking for Alloy 22 and Titanium Grade 7 is discussed in *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007 [DIRS 181953]). The effects of seismic-induced motion and rockfall on stress corrosion cracking are discussed in *Mechanical Assessment of Degraded Waste Packages and Drip Shields Subject to Vibratory Ground Motion* (SNL 2007 [DIRS 178851]).

Uncertainty in the possible initiation and propagation of localized corrosion is a function of the chemical environment on the waste package surface, as well as the uncertainty in the functional dependency of the corrosion potential and critical potential to the thermal-chemical environment. Uncertainty in the chemical environment for both aqueous and salt-deliquescence conditions has been included in the models presented in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519]); and *Analysis of Dust Deliquescence for FEP Screening* (SNL 2007 [DIRS 181267]), respectively. Uncertainty in the data used to develop the functional dependence, in particular the effect of variable chloride, nitrate, and chloride-to-nitrate ratios, has been included in the localized corrosion model described in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519], Section 4.1.1.2).

Uncertainty in the characterization of degradation of the waste form and cladding and in the mobilization and transport of radionuclides through the EBS arises from uncertainties in the inputs for the models for the various degradation and transport processes. These uncertainties are described in *CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004 [DIRS 169987], Section 6); *DSNF and Other Waste Form Degradation Abstraction* (BSC 2004 [DIRS 172453], Section 6); *Defense HLW Glass Degradation Model* (BSC 2004 [DIRS 169988], Section 6); *Cladding Degradation Summary for LA* (SNL 2007 [DIRS 180616], Section 6); and *EBS Radionuclide Transport Abstraction* (SNL 2007 [DIRS 177407], Section 6). These uncertainties include, for example, initial mass of each radionuclide per waste package, in-package pH and ionic strength, porosity of the commercial SNF, gap and grain boundary inventories, fuel specific surface area, HLW glass degradation rate and surface area exposure coefficients, equilibrium constants used to predict radionuclide solubilities, sorption coefficients and sorption rate constants for radionuclide sorption in the waste package and invert, and corrosion rates for waste package internals, such as the inner vessel and the TAD canister. These uncertainties are incorporated probabilistically in the TSPA by using ranges of parameter values in the models for the chemical and physical environments (e.g., temperature and chemical characteristics of fluids that can contact the waste form) and for the rates of the various degradation and transport processes, as well as dissolved concentration limits. The ranges of parameters and process rates used in the TSPA are based on the results of testing and analysis, as well as on the fundamental physical principles that apply.

6.2.2.2.5 Impact of Disruptive Events on the Engineered Barrier System

Disruptive events may significantly impact the features of the EBS; however, the natural barrier features remain generally intact and continue to prevent or substantially reduce the rate of movement of water or radionuclides from the repository to the accessible environment following the occurrence of a disruptive event.

Seismic activity may cause sufficiently high levels of ground motion to result in mechanical interactions between waste packages or between a waste package and the waste package pallet, which may, in turn, cause waste packages to develop small stress corrosion cracks. However, seismic events are not expected to significantly affect the performance of the drip shield with respect to its function of protecting the waste package from the potential effects of seeping water or rockfall for about the first 250,000 years after repository closure. Should the degraded EBS lose its ability to prevent or substantially reduce the release rate of radionuclides from the waste, the LNB remains intact to prevent or substantially reduce the rate of movement of radionuclides to the accessible environment. A complete discussion of the effects of seismic activity on the EBS is provided in *Mechanical Assessment of Degraded Waste Packages and Drip Shields Subject to Vibratory Ground Motion* (SNL 2007 [DIRS 178851]).

Should an unlikely igneous event occur, it is estimated that the EBS would be subjected to significant localized damage. There are two components of an unlikely igneous event, an eruptive component and an intrusive component. In the eruptive component of an igneous event, the rising magma conduit interacts with an uncertain small number of waste packages (e.g., a maximum of seven waste packages with a median of about zero waste packages), destroying the waste packages and releasing the contained radionuclides in the erupting material.

In the intrusive component of an unexpected igneous event, the rising magma interacts with the entire inventory in the repository. Although complete destruction of the affected waste packages is not expected, the ability of the EBS to prevent water from contacting the waste is assumed to be compromised. The general performance of the natural barriers continues to complement the remaining capability of the EBS.

6.2.2.3 Lower Natural Barrier

The Lower Natural Barrier includes the unsaturated zone below the repository horizon and the saturated zone below the repository and down gradient from the repository to the accessible environment. Both the unsaturated and saturated features of the Lower Natural Barrier are important to waste isolation and prevent or substantially reduce the rate of movement of radionuclides from the repository to the accessible environment due to slow advective transport combined with matrix diffusion and radionuclide sorption processes. Figure 6-7 is a schematic illustration of the LNB.

As discussed in Section 6.2.1.3, the features of the LNB have different processes and characteristics that influence the capability of these features to prevent or substantially reduce the rate of movement of radionuclides from the repository to the accessible environment. The significant processes include hydrologic, thermal-hydrologic, and transport processes, as identified in Table A-3. Additional chemical, thermal-chemical, mechanical, and thermal-mechanical processes are generally of lesser significance in affecting the features of the LNB. The processes identified in Table A-3 have varying degrees of influence on the capability of the LNB to perform its barrier function.

Some processes identified in Table 6-3 are more important contributors than others to the overall capability of the Lower Natural Barrier in preventing or substantially reducing the rate of movement of radionuclides from the repository to the accessible environment. Table 6-3 identifies those processes that significantly influence the ability of a particular feature to contribute to barrier capability. In the evaluation of the important processes related to the capability of the LNB, consideration is given to both the beneficial as well as the potentially deleterious processes that act on each of the features of the barrier. The presence of a beneficial process generally results in preventing the movement of radionuclides or substantially reducing the rate of movement of radionuclides from the repository to the accessible environment. The evaluation of both beneficial and potentially deleterious processes that could affect the movement of radionuclides, ensures a more complete understanding of the barrier capability. The presence of a potentially deleterious process could result in an increase in the rate of movement of radionuclides from the repository to the accessible environment. Both beneficial and potentially deleterious processes have been identified as important contributors to the capability of the LNB (SNL 2008 [DIRS 183041]).

A few examples illustrate both beneficial and potentially deleterious processes and their effect on the LNB. Sorption (in both the unsaturated and saturated zones) has the beneficial effect of preventing the movement or substantially reducing the rate of movement of certain radionuclides that are major contributors to the activity of the radioactive waste. Climate modification, that can affect the amount of recharge in the unsaturated zone and the water table rise in the saturated zone, can significantly increase the rate of movement of radionuclides by increasing the flux. While the presence of fracture flow has a generally deleterious effect on unsaturated and saturated zone transport (depending on the degree of matrix diffusion), the absence of fracture flow has a beneficial effect of decreasing the rate of movement of radionuclides.

Unsaturated Zone below the Repository—The following processes and characteristics of the unsaturated zone below the repository are important to the capability of the LNB:

- **Climate Change**—Future climate change causes several responses in the unsaturated zone beneath the repository, including changes in percolation flux and attendant radionuclide transport, water table rise, and recharge to the saturated zone. Precipitation and net infiltration into the unsaturated zone tends to increase with future climate change causing an increase in fracture flux and, hence, a reduction in the effectiveness of matrix diffusion, and an increase in recharge during the first 10,000 years after repository closure. After 10,000 years, the rate of percolation at the repository horizon is specified by proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394). In addition, based on forecast climate changes in the future, a higher water table is expected in the Yucca

Mountain region for future, wetter climatic conditions. A higher water table impacts radionuclide transport in the unsaturated zone by shortening the transport distance between the repository and the water table as presented in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6); and *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6).

- **Climate Modification Increases Recharge**—The ability of the unsaturated zone to prevent or substantially reduce the rate of movement of radionuclides is dependent on the flux of water through the unsaturated zone and the distribution of that flux within the fractured rock mass. This flux is directly dependent on the surficial recharge that, in turn, is affected by climatic change. The increase in recharge associated with the monsoon and glacial-transition climate states reduces the capability of the unsaturated zone feature below the repository to reduce the rate of radionuclide movement. This reduction is a function of: (1) the increase in fracture flux and corresponding reduction in the effectiveness of matrix diffusion and (2) the rise in the water table and the associated reduction in the unsaturated zone radionuclide travel length. These effects associated with a future climate change are included in the TSPA models presented in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6); and *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6).

- **Stratigraphy**—Stratigraphy and associated hydrologic properties have significant effects on unsaturated zone flow and transport processes due to the contribution of faults in conducting flow below the repository and due to the different flow characteristics of the TSw and zeolitic and vitric CHn and CFu units. In particular, the low matrix permeability of the zeolitic CHn unit beneath the northern half of the repository block promotes fracture flow and/or lateral diversion towards faults. In contrast, the unaltered, vitric CHn unit beneath the southern region of the repository block has a relatively high matrix porosity and permeability, and matrix flow dominates. As a consequence, radionuclides released from the northern region of the repository tend to have much shorter travel times to the saturated zone than those released in the southern region because transport is primarily downward through fast flowing fractures and faults as opposed to much slower matrix flow (SNL 2007 [DIRS 184614]; SNL 2008 [DIRS 184748]).

- **Rock Properties of Host Rock and Other Units**—Percolation of water in the unsaturated zone below the repository is significantly affected by the hydrogeologic properties of the rock units above and below the repository. Where fracture-matrix properties change abruptly, such as at the contact between welded tuffs and low permeability units with sparse fractures, perched water zones may form, leading to lateral diversion of flow (SNL 2008 [DIRS 182145], Sections 6.5.2.2 and 6.5.2.3).

- **Fractures**—Fractures below the repository conduct the majority of the percolation flux through the unsaturated zone, although: (1) the low-matrix-permeability zeolitic rocks of the CHn cause increased lateral diversion toward the faults; and (2) the vitric CHn is dominated by matrix flow. The rate of flow and the extent of transport in fractures are influenced by characteristics, such as orientation, aperture, asperity, spacing, fracture length, connectivity, and the nature of any linings or infills (SNL 2008 [DIRS 182145], Section 6.5.2.6).

- **Faults**—Faults of various sizes have been noted in the Yucca Mountain region, and specifically in the repository area. A significant fraction of percolation flux below the repository occurs through faults (SNL 2007 [DIRS 184614], Section 6.2.2). Faults provide fast flow and radionuclide transport pathways through the unsaturated zone, particularly below the northern region of the repository where the low matrix permeability of the underlying zeolitic CHn unit promotes lateral flow and transport towards and down faults. (SNL 2008 [DIRS 184748], Section 6.6).

- **Fracture Flow in the Unsaturated Zone—**The rate of movement of radionuclides in the unsaturated zone is dependent on the flux of water through the fractured rock mass. This flux is distributed between faults, fractures, and the matrix of the host rock and other units in the unsaturated zone. The rate of movement of radionuclides is dependent on the degree of fracture flow, which is variable across the unsaturated zone below the repository. This rate of movement is not significantly reduced in the fractured portion of the unsaturated zone, unless matrix-diffusion processes occur. The absence of fracture flow in the vitric portions of the Calico Hills substantially reduces the advective transport velocity thus increasing the delay of movement of radionuclides in the unsaturated zone. The effects of fracture flow are included in the TSPA models presented in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Section 6); and *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6).

- **Unsaturated Groundwater Flow in the Geosphere—**Unsaturated groundwater flow below the repository defines the redistribution of percolation flux in the unsaturated zone as a function of time, and is the primary mechanism for radionuclide transport below the repository. Although the flow rate in the unsaturated zone influence the amount of fracture flow, the fracture characteristics are also significant in determining the rate of radionuclide movement in the unsaturated zone. (BSC 2004 [DIRS 170035], Section 6.1).

- **Perched Water Develops—**The strongly altered northern part of the CHn unit is composed of zeolites and clays with low permeability and poorly developed, sparsely connected fractures. Because of low permeability, perched water may form at the contacts with CHn zeolitic (CHnz) tuffs below the northern half of the repository block, and a large portion of the percolating flux may be diverted laterally to the east towards the faults, which act as main pathways for fast flow and transport in the unsaturated zone. The effects of existing perched-water zones below the repository and potential changes in these perched-water zones caused by climate changes are included in the mountain-scale unsaturated zone flow model presented in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614]). These zones lead to lateral diversion of flow in the CHn towards the faults, which act as main pathways for fast flow and transport in the unsaturated zone.

- **Advection and Dispersion in the Unsaturated Zone**—Flow in the fractured rock system below the repository is dominated by fracture flow. Therefore, radionuclide transport is primarily advection dominated, and the influence of dispersion may be important. However, when compared to the spreading of radionuclides due to matrix diffusion effects, the impact on transport times of longitudinal dispersion is expected to be small (SNL 2008 [DIRS 184748], Section 6.5.2).

- **Matrix Diffusion in the Unsaturated Zone**–Matrix diffusion results in the diffusion of dissolved radionuclides from the fractures into the matrix of the rock. Because the advective transport is significantly slower in the matrix, matrix diffusion is an effective retardation mechanism, especially for moderately to strongly sorbing radionuclides, due to the increase in rock surface accessible to sorption. Matrix diffusion of colloidally transported radionuclides has been excluded from the unsaturated zone transport model presented in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6).

- **Matrix Imbibition in the UZ**—Water and (dissolved and colloidal) radionuclides may be imbibed into the matrix between the flowing fractures. Matrix imbibition affects the distribution of flow between fractures and the matrix in the fractured unsaturated zone. Matrix imbibition is dominant in the Calico Hills nonwelded vitric rock, which substantially slows radionuclide transport (SNL 2007 [DIRS 184748]).

- **Sorption in the Unsaturated Zone**–Radionuclides released from the repository have varying retardation characteristics. Several radionuclides that are the dominant contributors to the total inventory (^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) are significantly retarded in the unsaturated zone when there has been significant matrix diffusion or matrix-dominated flow in the vitric Calico Hills. The sorption of these radionuclides that diffuse into the matrix or are transported in the matrix of Calico Hills prevents the movement or significantly reduces the rate of movement of these radionuclides from the repository to the accessible environment. Sorption is included in the unsaturated zone transport models presented in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6).

Saturated Zone—The following processes and characteristics of the saturated zone are important to the capability of the LNB:

- **Climate Change**—Climate change causes two primary responses in the saturated zone: (1) water table rise; and (2) recharge to the saturated zone. A higher water table is expected in the Yucca Mountain region for future, wetter climatic conditions. Also, groundwater flow would tend to increase for future, wetter climates. Both these effects are included in the TSPA models presented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6.3.1).

- **Climate Modification Increases Recharge**—The increase in recharge to the saturated zone associated with the monsoon and glacial-transition climate states is expected to increase groundwater flow in the saturated zone. This effect is included in the TSPA models presented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6.3.1).

- **Stratigraphy**—The geometric relationships and characteristics of stratigraphic variations and faults have a pronounced effect on saturated zone flow at the site scale. The location at which groundwater flow moves from fractured volcanic rocks to alluvium is of particular significance from the perspective of barrier capability. This volcanic/alluvium contact is important because of contrasts between the fractured volcanic units and the alluvium in terms of groundwater flow (fracture-dominated flow versus porous medium flow) and in terms of improved sorptive properties of the alluvium for some radionuclides relative to the volcanic rocks. Stratigraphic variations and geometry are also major factors leading to three-dimensional flow patterns in the saturated zone. These flow patterns have a significant impact on flow in the saturated zone with respect to radionuclide transport. The stratigraphic relationships are incorporated into *Hydrogeologic Framework Model for the Saturated Zone Site-Scale Flow and Transport Model* (SNL 2007 [DIRS 174109]).

- **Rock Properties of Host Rock and Other Units**—Flow of water in the saturated zone is significantly affected by the hydrogeologic properties of the rock units, particularly where fracture-matrix properties change abruptly, such as at the contact between the volcanic and alluvium units. Rock properties also have a significant effect on the rate of radionuclide movement through their influence on the transport properties (notably the flowing interval spacing, matrix diffusion, fracture porosity, and matrix porosity of the alluvium), retardation properties, matrix porosity of the volcanic units, and effective porosity of the alluvium. Rock properties for 23 hydrostratigraphic units and 10 discrete hydrogeologic features related to faults and factures are explicitly included in the *Saturated Zone Flow and Transport Abstraction* (SNL 2008 [DIRS 183750], Section 6.5).

- **Fractures**—Fracture characteristics are important to the barrier capability of the saturated zone, because groundwater flow occurs primarily within the fracture network of the volcanic tuff units. The fracture networks in the saturated zone appear to be well connected over large distances at the scales of interest (hundreds of meters to kilometers). Fracture networks, in turn, control the movement of dissolved and colloidal radionuclides below the water table. Fracture characteristics (e.g., fracture porosity, flowing interval porosity, and flowing interval spacing) are included in the saturated flow and transport abstraction model using a dual-porosity effective continuum approach (SNL 2008 [DIRS 183750], Section 6).

- **Faults—**Numerous faults of various sizes have been noted in the Yucca Mountain region and, specifically, in the repository area. Numerous faults of various sizes have been noted in the Yucca Mountain region, and specifically in the repository area. Faults affect the groundwater flow paths, influence the horizontal anisotropy in permeability, and can enhance dispersion by increasing permeability heterogeneities along the saturated zone flow paths. Geologic features and hydrostratigraphic units are explicitly included in the models for saturated zone flow and transport in a configuration that accounts for the effects of existing faults based on the hydrogeologic framework model (SNL 2007 [DIRS 174109], Section 6). Geologic features and hydrostratigraphic units are explicitly included in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6.3.1) in a configuration that accounts for the effects of existing faults based on the hydrogeologic framework model (SNL 2007 [DIRS 174109], Section 6).

- **Water-Conducting Features in the Saturated Zone**—Water flow in the saturated zone occurs within either the fractured tuff units or the alluvium. The groundwater flow rates, radionuclide transport velocities, and radionuclide retardation characteristics of these different water-conducting features are significantly different. In particular, the alluvium provides a significant reduction in the movement of radionuclides to the accessible environment due to the lack of fracture flow. In addition to the differences in flow and transport characteristics of the different lithologic units in the saturated zone, the presence of discrete flowing features in the fractured tuff units affects the rate of movement of radionuclides to the accessible environment. These characteristics of the saturated zone have been included in the TSPA models presented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6).

- **Saturated Groundwater Flow in the Geosphere—**Groundwater flow in the saturated zone below the water table may affect long-term performance of the repository. The location, magnitude, and direction of flow under present and future conditions will influence transport to the accessible environment. These effects are included in the TSPA model presented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6.3.1).

- **Advection and Dispersion in the Saturated Zone**—Advection is the principal transport mechanism for both dissolved and colloidal radionuclides in the saturated zone. The advective flux is dependent on the hydrogeologic characteristics of the water-conducting features in the saturated zone, as well as the groundwater flux through these features. Dispersive processes tend to spread transient radionuclide pulses that may be released to the saturated zone (e.g., following the water table rise associated with climate changes). These processes have been included in the TSPA models presented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6).

- **Matrix Diffusion in the Saturated Zone—**Matrix diffusion is the process by which radionuclides and other species transported in the saturated zone by advective flow in fractures or other pathways move into the matrix of the porous volcanic rock formations by diffusion. Matrix diffusion can be a very efficient retarding mechanism, especially for strongly sorbed radionuclides, due to the increase in rock surface accessible to sorption. Field scale in situ tracer tests at the C-Wells demonstrated matrix diffusion as an important transport mechanism in fractured volcanic formations in the saturated zone. Matrix diffusion is included in the saturated zone transport model abstraction (SNL 2008 [DIRS 183750], Section 6.3.1 and Table 6-8).

- **Sorption in the Saturated Zone**—Radionuclides released from the repository have varying retardation characteristics. Several radionuclides that are the dominant contributors to the total inventory are significantly retarded in the saturated zone. These include ^{90}Sr, ^{230}Th, ^{226}Ra, ^{137}Cs, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{241}Am, and ^{243}Am. The sorption behavior of these radionuclides significantly reduces the rate of movement of these radionuclides from the repository to the accessible environment. Sorption effects are included in the TSPA models presented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6).

The bases for the models used in the analysis of unsaturated zone flow are described in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614], Sections 6). The flow fields are generated using the three-dimensional site-scale unsaturated zone flow model with input parameters based on unsaturated zone calibrated properties (SNL 2007 [DIRS 179545], Section 6.3). These flow fields are developed for spatially varying net-infiltration maps for the present-day, monsoon, and glacial-transition climate states and the post-10,000-year climate. The bases for the model used in the analysis of radionuclide transport in the unsaturated zone are described in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6). The processes incorporated into the unsaturated zone transport model include sorption, fracture-matrix interaction, colloid-facilitated radionuclide transport, radioactive decay and ingrowth, and dispersion. The bases for the process models used to assess the capability of the unsaturated zone component of the LNB are the same as the bases contained in the TSPA abstraction.

The flow and radionuclide transport model for the saturated zone is discussed in detail in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6). The analysis of the capability of the saturated zone component of the LNB is derived from the same models used as the basis for the TSPA calculations. Key uncertainty parameters (i.e., groundwater flux, sorption coefficients, and matrix-imbibition and matrix diffusion transport parameters) are varied, subject to uncertainty distributions based on the available data and observations, and these uncertainties are reflected in the model results.

6.2.2.3.1 Capability of the Unsaturated Zone below the Repository to Prevent or Substantially Reduce the Rate of Movement of Radionuclides to the Water Table

The unsaturated zone below the repository prevents or substantially reduces the rate of movement of radionuclides from the repository horizon to the water table. The radionuclides take time to move through the unsaturated zone. As water percolates down, sorption, colloid filtration, matrix imbibition, and matrix diffusion cause the movement of radionuclides to be slower relative to the general movement of the percolating water. The existence of perched-water bodies introduces three-dimensional lateral flow within the unsaturated zone below the repository level. Below the northern half of the repository block, low-permeability layers and perched water bodies in the CHn unit channel a large fraction of flow laterally to faults that act as conduits for water flow to the water table (SNL 2007 [DIRS 184614], Section 6.6.2.2). Radionuclides are also dispersed during movement in the unsaturated zone because of variability in radionuclide transport times and in the retardation characteristics of the various volcanic units.

The data and analyses supporting models of radionuclide transport in the unsaturated zone that are summarized below are described in detail in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6). Figure 6-8 shows the sequence of tuffs comprising the unsaturated zone below the repository. This figure shows that these features include the lower part of the TSw and Calico Hills nonwelded (CHn) units and tuffs of the Crater Flat Group, including the Prow Pass welded tuff. These units together provide a feature ranging from about 200-m to 400-m-thick, under present-day climate conditions. The TSw unit is characterized by very low matrix permeability and well-connected, steeply dipping fracture networks. The CHn unit underlies the TSw unit. Below the southern part of the repository, the CHn unit is vitric, composed of unaltered glassy shards of volcanic ash and characterized by relatively high matrix permeability. Fractures are rare to nonexistent in the vitric CHn unit and flow through this unit is predominantly through the matrix. Below the vitric CHn unit are the devitrified and zeolitized tuffs of the Prow Pass welded tuff unit. These tuffs have lower matrix permeability than the vitric CHn unit, and flow down through such tuffs is primarily in fractures. The fracture networks in these nonwelded tuffs are generally bed-confined and not well connected.

The movement of radionuclides carried by water in the matrix of the TSw unit is slow because of sorption and colloid filtration processes in the rock matrix. The rate of movement of radionuclides carried by water in the fractures is more rapid than in the matrix, and sorption and colloid filtration are weaker. Consequently, the matrix of the TSw unit more effectively retards the migration of the radionuclides than the fracture system. Matrix diffusion and imbibition transfers radionuclide mass from fractures into the matrix.

As shown in Figure 6-8, downward-moving radionuclides encounter the CHn unit at the base of the TSw unit. Because of the low permeability and infrequency of connected fractures of the zeolitic CHn unit beneath the northern part of the repository block and because the flow down from the overlying TSw unit is primarily in the fractures, perched-water zones form at the TSw-CHn contact. A significant fraction of the downward-percolating flux is diverted laterally to the east in this region. The present age of the perched water ranges from several thousand years old to as much as 11,000 years old.

Beneath the northern part of the repository, the radionuclides either enter the zeolitic CHn unit or are diverted to the east in the perched water. The zeolitic CHn unit is strongly altered to a mixture of minerals, including zeolites and clays. The minerals have precipitated in the pores of the rock so that the matrix permeability of the zeolitic CHn unit is low. Most of the downward flow that reaches the zeolitic CHn is diverted laterally through perched water zones at the TSw-CHn contact, bypassing this unit and flowing through faults or connected fractures, which leads to short radionuclide transport times to the saturated zone.

Beneath the southern part of the repository, the radionuclides are transferred into the vitric CHn unit matrix where groundwater velocity is low relative to the velocity in the fractures and where sorption and colloid filtration are strong. Below the vitric CHn unit, the radionuclides move predominantly in the fractures of the underlying devitrified and zeolitized tuffs of the Prow Pass Tuff. Because the fracture flow pathways are not continuous, the alternating layers of welded, nonwelded, and zeolitized tuffs delay the movement of radionuclides, which leads to long transport times to the saturated zone compared to release locations in the northern repository region.

The combination of slow water movement from the repository to the water table and processes that retard the rate of movement of radionuclides in the unsaturated zone results in a reduction in the activity of the radionuclides and their release to the saturated zone.

6.2.2.3.2 Capability of the Saturated Zone to Prevent or Substantially Reduce the Rate of Movement of Radionuclides to the Accessible Environment

Radionuclides that migrate through the unsaturated zone to the water table are transported through the saturated zone before they can reach the accessible environment. The data and analyses supporting models of radionuclide transport in the saturated zone that are summarized below are described in detail in *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391], Section 6); and *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6). Groundwater below Yucca Mountain is part of the Alkali Flat–Furnace Creek groundwater subbasin within the Death Valley regional groundwater system. Groundwater flow is generally to the south and east near Yucca Mountain. The southeasterly flow from the site is incorporated into the stronger southward flow in western Jackass Flats. The expected pathway for movement of radionuclides through the saturated zone is southeast from the repository site, transitioning to southerly flow to the accessible environment in the Amargosa Desert.

The pathways for radionuclide movement, in the saturated zone, for the first 12 to 14 km downgradient from Yucca Mountain, occur in fractured volcanic rocks. This portion of the saturated zone is affected by the faulting and tilting of the volcanic rocks and is represented in an equivalent continuum model in terms of two aquifers: an upper volcanic aquifer associated with the Topopah Spring Tuff units, and a lower volcanic aquifer associated with the Prow Pass, Bullfrog, and Tram Tuff units.

The schematic shown in Figure 6-8 is located along the approximate pathways for radionuclide movement as the radionuclides encounter alluvial sediments approximately 12 to 14 km from Yucca Mountain. These alluvial sediments are generally represented as a single porous medium with equivalent continuum properties to represent heterogeneity in the flow and transport characteristics of these sediments.

The saturated zone feature of the LNB includes the fractured volcanic rocks from below the repository to approximately 12 to 14 km southeast and south of Yucca Mountain and the saturated alluvium at the water table from the volcanic aquifer to the accessible environment. The movement of radionuclides in the saturated zone is slow because the velocity of water that can carry such radionuclides is low. In addition, processes discussed below cause the rate of movement of radionuclides to be slower compared to the rate of movement of the water. The data and models for saturated zone flow and transport that support this analysis are discussed in

Saturated Zone Site-Scale Flow Model (SNL 2007 [DIRS 177391], Section 6); and *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6).

The flow in the upper and lower volcanic aquifers is predominantly in the fractures. The matrix materials of the volcanic tuffs generally have a 2 to 6 order-of-magnitude lower hydraulic conductivity than observed in flowing fractures under natural groundwater-flow conditions. The matrix materials also have significantly greater effective porosity than do fractures, so there is a correspondingly greater volume of fluid stored in the matrix pore space of these saturated aquifers. The additional stored fluid and pore space is important to radionuclide transport because radionuclides can exchange between the fractures and matrix via matrix diffusion. This diffusive exchange results in a slower effective travel velocity for the bulk of the released radionuclides relative to water flow velocities in the fractures for two reasons. First, the velocity of water in the pores of the matrix is slower than that in the fracture pores. Second, sorption onto mineral surface areas in the matrix pores will result in an even slower rate of movement of the radionuclides that diffuse into the matrix materials.

Because the alluvial materials are a porous medium, water flow and radionuclide transport occur in the intergranular pores in the alluvium. The conceptual model for transport in the alluvial sediments is that of a porous continuum. The effective porosity of the alluvium is greater than the fracture porosity of the tuffs. Consequently, pore velocities in the alluvium, are smaller than those in the fractures of the volcanic aquifers. Although matrix diffusion is not considered to be important in the alluvium, radionuclide rate of movement can be slow if the water velocity is slow. In addition, sorption onto minerals in the alluvium results in retardation of radionuclides relative to the water movement in these sediments.

The volcanic rocks and alluvial material in the saturated zone also reduce the rate of movement of radionuclides associated with colloids. Filtration (nonphysical) of colloids results in retardation of the movement of radionuclides embedded in the colloids or irreversibly sorbed to these colloids. Radionuclides that are sorbed reversibly to colloids are affected by matrix diffusion in the volcanic aquifers and by sorption in the alluvial hydrogeologic units; consequently, movement of these colloid-associated radionuclides is also retarded relative to the movement of water in the saturated zone.

This analysis demonstrates that the combination of low groundwater velocity and retardation and sorption processes prevent or substantially reduce the rate of movement of radionuclides to the accessible environment.

6.2.2.3.3 Time Period over which the Lower Natural Barrier Functions

The LNB is a durable feature of the geologic setting at Yucca Mountain and is not expected to change over the regulatory period of geologic stability. With the exception of the very minor effects caused by the construction of the repository, the emplacement of waste, and the rise in the water table and increase in percolation and saturated zone flux as a result of future climate states, the hydrogeology and physical characteristics of the LNB are not expected to change in any significant way in the 10,000 year period after closure. It is also assumed that for the purposes of projecting postclosure performance after 10,000 years, but within the period of geologic stability, that the intrinsic hydrologic, geologic and geochemical characteristics of the Lower Natural

Barrier will not change significantly. This assumption is consistent with the requirements of proposed 10 CFR 63.342(c) (70 FR 53313 [DIRS 178394]) by projecting the continued effects of the 10,000-year screened-in features, events, and processes out to the limit of geologic stability at 1 million years, with the exception of those features, events, and processes outlined in proposed 10 CFR 63.342(c) (70 FR 53313 [DIRS 178394]) related to the effect of seismic events, igneous events, climate change, and general corrosion beyond 10,000 years.

The unsaturated zone is largely unaffected by the local changes associated with repository construction and waste emplacement. The magnitude of changes to rock hydrologic properties attributable to coupled thermal-hydrologic-geochemical-mechanical processes do not have a significant effect on the overall behavior of unsaturated zone flow and transport. Geochemical studies have shown that minerals, such as calcite, silica, clays, and zeolites, could be dissolved and/or diagenetically altered in some areas or precipitated and altered in other areas, depending on local geochemical conditions. However, these local changes are not expected to change the overall hydraulic properties of the repository host rock that are included in the variability in performance models (Table A-3) because changes in fracture properties due to mineral precipitation or dissolution or thermal-mechanical stresses are on the order of natural variation (SNL 2008 [DIRS 183041], Section 6.2, FEPs 2.2.08.03.0B and 2.2.10.04.0A) and are therefore excluded from TSPA.

Projected climate change will raise the water table and increase the flux of percolating water through the unsaturated zone. The impact of these two effects on transport through the unsaturated zone is included in the TSPA. However, these factors are not expected to alter appreciably the processes that influence radionuclide transport. The potential for increased percolation flux through the unsaturated zone results in increased advective transport velocities through the fractured rock mass in the unsaturated zone, which tend to decrease the advective transport time of radionuclides to the water table. However, the properties controlling matrix diffusion and radionuclide retardation on radionuclide transport through the unsaturated zone are not expected to change with time (Table A-3).

The volcanic tuffs and alluvium in the saturated zone are durable features of the geologic environment, and the characteristics of this feature of the LNB system are not expected to change during the 10,000-year period. Processes acting during the first 10,000-year assessment are propagated to continue throughout the period of geologic stability. Although the effects may change with time (for example, as degradation of the drifts and engineered feature change with time), the processes and events acting on the system are the same throughout time. The hydrologic conditions within the saturated zone may change, however, as the climate changes. At a regional scale, future climate conditions that are wetter than present-day conditions are expected to yield greater groundwater recharge, resulting in a rise in the water table and greater groundwater flux along the saturated zone flow path. This change in the water table and flux is explicitly taken into account in the model abstraction for saturated zone flow and transport.

6.2.2.3.4 Uncertainties Associated with Lower Natural Barrier Capability

The performance of the LNB is subject to uncertainty that is a function of the applicability of the conceptual and numerical models used to describe flow and transport in the LNB, and of the degree of knowledge of the characteristics of the Yucca Mountain site. To accommodate both variability and uncertainty in the description of the site, many of the input parameters to the unsaturated and saturated zone flow and transport models have been defined as probabilistic distributions. This approach allows a large range of uncertainty to be directly incorporated into process and performance assessment models. The variability and uncertainty in barrier capability is reflected in the broad range of transport times and radionuclide breakthrough curves resulting from the unsaturated zone and saturated zone transport models. The data uncertainties associated with analyses of the LNB are described in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 184614]; *Radionuclide Transport Models Under Ambient Conditions* (SNL 2007 [DIRS 177396]); *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6); and *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391], Section 6).

Uncertainties in the flow and transport characteristics affecting radionuclide transport in the unsaturated zone have been included in the model abstractions or have been conservatively represented, as presented in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6). Uncertain parameters related to unsaturated zone flow include the percolation flux and fracture–matrix interaction (which is correlated to the percolation flux), both of which affect the flux distribution in fractures. Uncertain parameters related to matrix diffusion include tortuosity. Uncertain parameters related to sorption include the sorption coefficients for various radionuclides in the vitric, devitrified, and zeolitic tuff rock units. Uncertain parameters used to model colloid-facilitated transport include the colloid retardation factor.

Uncertainties in the unsaturated zone flow characteristics have been addressed by evaluating four percolation flux distributions related to the 10th, 30th, 50th and 90th percentiles of the infiltration rates. Uncertainties in the conceptual model of matrix diffusion are larger than the impact of parameter uncertainties, and have been conservatively treated in the unsaturated zone transport model using a dual-permeability formulation. Other transport-related uncertainties have been addressed by sampling from the range of parameter values determined to reasonably represent the uncertainty, including sorption parameters and colloid retardation parameters.

Uncertainties in flow and transport characteristics affecting radionuclide transport in the saturated zone have been included in the model abstractions presented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6). Uncertain parameters related to saturated zone flow include uncertainty in the groundwater-specific discharge, flowing interval porosity, alluvium effective porosity, and horizontal anisotropy. Uncertain parameters related to matrix diffusion include flowing interval spacing, effective diffusion coefficient, and matrix porosity. Uncertain parameters related to sorption include the sorption coefficients for various radionuclides for tuff and alluvium. Uncertain parameters used to model colloid-facilitated transport include the colloid retardation factor, fast fraction of colloids, groundwater concentration of colloids, and sorption coefficients onto colloids.

Uncertainties in saturated zone groundwater flow and transport have been addressed by using probabilistic representations of parameter values that are important to transport, such as hydrologic and geologic properties. Uncertainty in groundwater flow or advection has been considered by evaluating ranges of groundwater-specific discharge, flowing interval porosity, alluvium effective porosity, and horizontal anisotropy.

There is uncertainty concerning the nature of the geology in the saturated zone, along the inferred flow path from the repository at distances of approximately 10 to 18 km downgradient from the repository. The portions of the flow path devoted to fractured volcanic rock and alluvium are important to saturated zone capability because the movement of radionuclides through the saturated zone is affected by the contrast in the flow between these two media and because the retardation characteristics of the two media are different. Uncertainty in the location of the alluvium is represented in terms of a probability distribution for its northern and western boundaries. This distribution is sampled in the TSPA and in barrier capability analyses.

6.2.2.3.5 Impact of Disruptive Events on the Lower Natural Barrier

The LNB is generally unaffected by disruptive events. For seismic activity, it is expected that the general configuration of the geologic units below the repository and downgradient to the accessible environment will remain unchanged. Fault displacements do not have any significant effects on unsaturated zone flow and transport, as demonstrated in an analysis of effects of fault displacements on unsaturated zone flow and transport (SNL 2008 [DIRS 183041], Appendix I, Section I3). The velocity of percolating water in the unsaturated zone and of groundwater in the saturated zone will not increase due to seismic activity. The characteristics of matrix and fracture flow, colloidal transport, and sorption are not expected to change due to seismic activity. For igneous activity, both the intrusive and eruptive cases involve isolated dikes of magma that rise through the LNB. However, the processes and characteristics of the LNB are not significantly affected (SNL 2008 [DIRS 183041], Section 6.2, FEP 1.2.04.02.0A); therefore, the general effectiveness of the LNB to prevent or substantially reduce the rate of movement of radionuclides from the repository to the accessible environment would not significantly change following disruptive events.

6.2.3 Technical Bases for Barrier Capability

[NUREG-1804, Section 2.2.1.1.3: AC 3]

Section 6.2.1 identifies the three barriers that comprise the repository system: the UNB, the EBS, and the LNB. Section 6.2.2 presents a summary description of the capability of these barriers. Table 6-4 provides the relationship between the barriers and the TSPA models, where the performance of the features of each barrier are represented. The following sections provide an overview of the technical bases for the models used to represent the performance of the barriers in the TSPA.

6.2.3.1 Upper Natural Barrier

As shown in Table 6-4, the UNB is represented in the TSPA by the infiltration, site-scale unsaturated zone flow, ambient seepage, and thermal seepage models. The following paragraphs provide brief summaries of the technical bases for these models.

Infiltration Model—This model was developed on the basis of geologic and hydrologic studies of soil and bedrock properties, as well as data from precipitation and temperature monitoring. Using this information, spatial and temporal infiltration estimates were developed for use as input to the site-scale unsaturated zone flow model. Ranges of annual precipitation and air temperatures for future climate states were forecast on the basis of analogue sites, paleoclimate data, and earth-orbital parameters. Infiltration estimates include the range of infiltration expected under future climatic conditions (SNL 2008 [DIRS 182145], Section 6). The infiltration model produces net infiltration values for use as inputs to the site-scale unsaturated zone flow model under present-day and future climatic conditions expected during the first 10,000 years after closure. For the period from 10,000 years after permanent closure up to 1 million years after closure, infiltration rates are not provided from the analysis; rather, a range of deep percolation fluxes specified by the proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]) is used in the unsaturated zone flow simulations (SNL 2007 [DIRS 184614], Section 6).

Site-Scale Unsaturated Zone Flow Model—This model was developed on the basis of a combination of surface- and subsurface-based field investigations and laboratory studies that have produced a conceptual understanding of flow paths in the unsaturated zone. These studies show that subsurface heterogeneities have important effects on flow paths, and, together with net infiltration, control the quantity and distribution of water that comes into contact with waste emplacement drifts. Several mathematical models have been developed to simulate unsaturated zone flow under ambient conditions and in response to future climate changes. A method that represents fracture and matrix flow under ambient and thermally perturbed conditions was selected. A dual-permeability continuum method was selected as being most consistent with available data and suitable for modeling unsaturated flow at Yucca Mountain. Mathematical models were calibrated against multiple sources of information (e.g., water potential, pneumatic, and perched water). The UZ flow model is used to generate flow fields that are used directly by the TSPA to predict seepage into drifts and radionuclide transport through the unsaturated zone (SNL 2007 [DIRS 184614], Section 6).

Ambient Seepage Model—The physics that control water percolating through the unsaturated zone, combined with hydrologic properties of the rock surrounding the emplacement drifts, including the geometry of the drift opening (intact versus collapsed), provide the technical basis for this model. When percolating water encounters an opening in unsaturated rock, it tends to be diverted around the opening due to capillarity. Seepage testing in the Exploratory Studies Facility and the enhanced characterization of the repository block cross-drift provided the data needed to develop a seepage process model. Seepage tests were conducted for both natural percolation flux conditions and localized, high-flux conditions that could induce seepage. Results show that there is threshold water flux, such that seepage into the drift will not occur if the local percolation flux is below the threshold. The seepage process model relies directly on seepage-rate data and is calibrated against other seepage data not used to develop the model. This model is abstracted for use in the TSPA. The seepage abstraction provides seepage rates and uncertainties for both intact and collapsed drifts over a range of percolation fluxes, capillary strengths, and permeabilities (SNL 2007 [DIRS 181244], Section 6).

Thermal Seepage Model—Field testing of the thermal-hydrologic response of the host rock, particularly the drift scale test in the Exploratory Studies Facility, provides the technical basis for this model. The drift scale test was designed to monitor evolution of temperature and liquid saturation and to observe evidence of thermally induced liquid refluxing. Results show that heat from emplaced waste will cause pore water in the rock matrix to vaporize and move away from emplacement drift openings. In cooler rock, the vapor will condense in fractures and drain either away or back toward the emplacement drift. While temperatures are above the boiling point of water, vaporization of percolating water in the fractured rock above emplacement drifts will prevent seepage. The thermal seepage model, developed on the basis of these results, includes the effects of capillary diversion and vaporization due to heat. In the TSPA, seepage rates and the fraction of waste packages locations that experience seepage are predicted using the drift seepage model. The technical basis provided by this model is used in the TSPA to justify the assumption that seepage cannot enter the drift if the drift wall temperature is equal to or greater than 100°C (SNL 2007 [DIRS 181244], Section 6).

6.2.3.2 Engineered Barrier System

As shown in Table 6-4, the EBS is represented in the TSPA by the following models: drift degradation and rockfall, near-field chemistry, thermal-hydrologic, in-drift chemical environment, drip shield degradation, waste package degradation, in-package water chemistry, commercial spent nuclear fuel cladding degradation, commercial SNF degradation, DOE SNF degradation, HLW degradation, dissolved concentration limits, colloid transport, and EBS flow and transport. The following paragraphs provide brief summaries of the technical bases for these models.

Drift Degradation and Rockfall—This model was developed on the basis of detailed geologic characterization of the repository host rock. Data were developed on rock mass structure and variability of rock properties. Laboratory and in situ testing provided ranges of values for mechanical and thermal properties for intact rock matrix, fractures, and large-scale properties of the lithophysal rock mass. Two- and three-dimensional numerical models, developed on the basis of these data, were used to represent the processes of degradation of drift walls and rockfall. These models provide the tools needed to assess rockfall and time-related drift degradation as a function of in situ, thermal, and seismic loading states. Results from these models are used to estimate impacts of vibratory ground motion, fault displacement, and rockfall induced by vibratory ground motion on drip shields, and waste packages. Further discussion of drift degradation and rockfall model are provided in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Section 6).

Near-Field Chemistry Model—The primary role of the near-field chemistry model is to provide the near-field gas and water chemistries for use in simulating the in-drift chemical environment. Field and laboratory studies have provided the hydrologic, thermal, and mineralogical data necessary to develop this model. Measurements of pore-water and gas chemistry data as reported in *Engineered Barrier System: Physical and Chemical Environment* (SNL 2007 [DIRS 177412]), supplemented with kinetic and thermodynamic data from externally published sources, provide the basis for modeling the evolution of water and gas compositions in near-field host rock. Heat, gas, and liquid in the rock affects the chemical composition of host-rock pore and fracture waters and the location and type of mineral dissolution and precipitation reactions.

Evaporation serves to concentrate aqueous species in solution. The TSPA uses results from this model to calculate in-drift water chemistry due to seepage evaporation.

Multiscale Thermal-Hydrologic Model—Field thermal testing, modeling studies, natural analogues, and externally published data provide the technical basis for this model. The model was developed by combining the results of submodels at various scales and dimensionalities to produce a three-dimensional representation of the natural and engineered systems. This multiscale model relies on the UZ flow model for hydrologic properties and percolation flux boundary conditions and uncertainties. The multiscale model is combined with an in-drift condensation model to represent temperature and relative humidity in the emplacement drifts for the TSPA, as well as the onset conditions, location, and magnitude of in-drift condensation as discussed in *Multiscale Thermohydrologic Model* (SNL 2008 [DIRS 184433], Section 6); and *In-Drift Natural Convection and Condensation* (SNL 2007 [DIRS 181648], Section 6).

In-Drift Condensation Model—The in-drift condensation model complements the multiscale thermal-hydrologic model in terms of evaluating the in-drift thermal-hydrologic environment. Field thermal testing and modeling studies provide the technical basis for this model. The multiscale thermal-hydrologic model provides the TSPA model with the temperature and relative humidity at all waste package locations; however, the model simulations do not include axial transport of water vapor along the drifts. The in-drift condensation model was used to calculate the hydrologic effects of axial transport of water vapor, namely drift wall condensation, to be used as input to the TSPA model. The in-drift condensation model provides the TSPA model with the potential for drift wall condensation at waste package locations, and, when condensation occurs, with the magnitude of condensation, which is correlated with percolation rate. Condensation is another source of liquid water that can potentially contact the drip shield or waste package in EBS flow calculations (SNL 2007 [DIRS 181648], Section 6.3.1).

In-Drift Physical and Chemical Environment—This model relies on the technical basis developed for the near-field chemistry model to establish the compositional range of waters that could contact the drip shield, the outer barrier of the waste package, and the invert. While waste package surface temperatures are high, seepage water will tend to evaporate and may form concentrated brines. The in-drift chemical environment changes with time as heat from decay decreases and geochemical processes modify in-drift conditions. Characteristics of the environment through the stages of dryout, transition, and return to a low-temperature condition are included in the range of parameters covered in this model as discussed in *Engineered Barrier System: Physical and Chemical Environment* (SNL 2007 [DIRS 177412], Section 6) and *In-Drift Precipitates/Salts Model* (SNL 2007 [DIRS 177411], Section 6).

Drip Shield Degradation and Early Failure Model—Long-term corrosion tests on titanium for both weight-loss and creviced specimens provide the technical basis for models for drip shield degradation. Results from testing in repository-relevant environments show that creviced specimens exhibit slightly higher corrosion rates than weight-loss samples. The inner surface of the drip shield was modeled using data from weight-loss specimens, while the outer surface was modeled using a combination of corrosion rate data from weight-loss and creviced specimens. The rationale for this choice is that the outer surface would be exposed to seepage environments, whereas the inner surface would only be expected to experience water films due to condensation. Under repository conditions, the general corrosion penetration depth in the 10,000 years after closure will be extremely limited failures resulting from through-wall penetration will not occur until after 200,000 years, and localized corrosion and stress corrosion cracking are not expected to significantly degrade the capability of the drip shield feature. For the case of impacts on drip shields due to seismic-induced rockfall, stress corrosion cracking is considered possible. However, this degradation mode is not included in the TSPA because cracks in the titanium will be sufficiently tight that they do not allow advective flux of water, and, even if water is present, the cracks are predicted to plug from mineral precipitation and corrosion products within a few hundred years after a seismic event. Literature surveys were also used to obtain data on manufacturing defects and human error probabilities to develop a drip shield early failure model. The number of potential drip shield failures is very small such that, for example, the probability of having one early failure is about 2%.

Waste Package Degradation: General and Localized Corrosion, Stress Corrosion Cracking, and Early Failure—The technical basis for waste package degradation modeling was derived from YMP and externally published data. The technical basis includes data regarding general and localized corrosion, microbial processes, stress corrosion cracking, and early failures due to manufacturing defects. Data for general corrosion rates of the waste package outer barrier have been obtained from weight-loss and dimensional-change measurements of descaled Alloy 22 samples after 5 years. General corrosion rates were also measured electrochemically to estimate the temperature dependence of general corrosion for Alloy 22. Localized corrosion data are available for Alloy 22 from a wide range of exposure environments. Long-term corrosion potential and short-term cyclic polarization data are available to evaluate susceptibility of Alloy 22 to localized corrosion. Laboratory tests also provided estimates of the effects of microbial processes on general corrosion. Because penetration rate data for localized corrosion under repository conditions are limited, published crevice corrosion rates under highly aggressive conditions were also used to establish the technical basis for waste package models. YMP and externally published data are available to estimate stress corrosion cracking of Alloy 22. Threshold stresses for initiation of stress corrosion cracking, crack growth rates, and stress and stress intensity factor profiles for welded regions, as well as data on weld flaws, were compiled. Literature surveys were also used to obtain data on manufacturing defects and human error probabilities to develop a waste package early failure model.

In-Package Water Chemistry Model—This model is a reaction-path model that predicts the chemical features, such as pH and ionic strength, of in-package fluids. The technical bases for this model include degradation rates for waste package and basket materials as a function of surface area. Degradation rates for the various waste forms as a function of pH, temperature, and surface area are also inputs to the model. A thermodynamic database has been compiled from YMP and externally published data containing solubilities of radionuclides and corrosion products as a function of solution composition and temperature. Surface thermodynamic parameters for corrosion products were also obtained from the literature.

Commercial SNF Degradation Model—YMP and externally published data provide the technical basis for the commercial SNF degradation model. The rate at which the radionuclides enter solution is controlled either by the degradation rate of the waste form, or by the solubility limit of the radionuclides. The commercial SNF degradation rates determine the rate at which soluble radionuclides can enter solution. The release rate of other radionuclides is determined by their solubility limits. YMP and externally published data were used to develop thermodynamic databases for use with a geochemical modeling tool.

DOE SNF Degradation Model—The rate at which radionuclides enter a solution is controlled either by the degradation rate of the waste form or by the solubility limit of the radionuclides. All DOE SNF types except naval SNF are modeled as degrading instantaneously upon waste package breach. Commercial SNF degradation model results are used to represent the impacts of naval SNF in the TSPA.

HLW Glass Degradation Model—Similar to other waste forms, the rate at which radionuclides enter a solution is controlled either by the dissolution rate of the waste form, or by the solubility limit of the constituent elements. Glass dissolution kinetics are known on the basis of many experiments to be controlled by a single dissolved species, orthosilicic acid. YMP and externally published data show that release of soluble components from glass decreases when the concentration of orthosilicic acid increases. Dissolution studies have been conducted under conditions that cover the following range of water contact modes postulated for the repository: contact with humid air, contact with dripping water, and immersion. The data were collected over a wide range of borosilicate glass compositions that meet the DOE-specified acceptance requirements for chemical durability and other specifications.

Dissolved Concentrations Limits Model—This model determines the maximum dissolved concentration of radionuclides as a function of water chemistry over the range of physical and chemical conditions established in the In-package chemistry model described earlier. The model relies on a thermodynamic database compiled from YMP and externally published data. A geochemical modeling tool utilizes the database to establish solubility limits for radionuclides within the specified in-package water chemistries. Solubility limits are determined considering the controlling solid phases, water chemistry, and temperature.

Colloidal Radionuclide Availability—The technical basis for the colloidal radionuclide availability model rests on YMP and externally published data. Both waste form colloids resulting from waste degradation and pseudocolloids, which are colloidal particles of waste forms and other materials with attached radionuclides, are evaluated. Measurements of colloid concentrations, studies of colloid stability, and experiments to determine radionuclide sorption properties were used to develop the colloid source term abstraction used in the TSPA. Characteristics of water in the waste package from the In-package chemistry model are used to describe the stability and concentration of colloids and the concentrations of radionuclides in the waste package.

EBS Flow and Transport Model—The technical basis for this model was developed using the results of the seepage models, in-drift chemical environment model, waste package and drip shield degradation models, in-package chemistry model, and waste form degradation and radionuclide mobilization models. The EBS Flow and Transport Model consists of two parts: flow pathways within the EBS and radionuclide transport along specific flow pathways. Transport out of the waste package can occur by advection when there is a liquid flux through the waste package and by diffusion through continuous liquid pathways. These two transport processes depend on the types of penetrations through the waste package and on local seepage and condensation conditions. Diffusive transport depends on differences in concentrations, which are determined from the In-package chemistry model, and the solubility limit for each radionuclide. Concentrations in the waste package depend on radionuclide solubility limits, sorption of radionuclides onto corrosion products, sorption and desorption onto colloids, and colloid stability. Concentrations in the invert depend on radionuclide solubility limits and colloid stability in the invert, partitioning of radionuclides between colloids and the invert, and the boundary concentrations at the invert–unsaturated zone interface. Transport at the invert–unsaturated zone interface may be advective or diffusive, and an important aspect of this model is to represent partitioning of radionuclide mass flux to the fractures and matrix consistent with hydrologic characteristics of the rock. Partitioning is time dependent, and reflects variations in rates of radionuclide release from the EBS and changes in seepage or condensation flux in the emplacement drifts.

6.2.3.3 Lower Natural Barrier

As shown in Table 6-4, the LNB is represented in the TSPA by the site-scale unsaturated zone flow, site-scale unsaturated zone radionuclide transport, saturated zone flow, and site-scale saturated zone radionuclide transport models. The two saturated zone process models are not implemented directly in the TSPA, but are used to develop radionuclide breakthrough curves which are implemented in the TSPA using a convolution algorithm. The following paragraphs provide brief summaries of the technical bases for these models.

Site-Scale Unsaturated Zone Flow Model—The site-scale unsaturated zone flow model is used to generate flow fields that are used directly by the TSPA to predict radionuclide transport through the unsaturated zone. This model was developed on the basis of a combination of surface- and subsurface-based field investigations and laboratory studies that have produced a conceptual understanding of flow paths in the unsaturated zone. These studies show that subsurface heterogeneities have important effects on flow paths, and, together with net infiltration, control the quantity and distribution of water that comes into contact with waste emplacement drifts. Several mathematical models have been developed to simulate unsaturated zone flow under ambient conditions and in response to future climate changes. A method that represents fracture and matrix flow under ambient and thermally perturbed conditions was selected. A dual-permeability continuum method was selected as being most consistent with available data and suitable for modeling unsaturated flow at Yucca Mountain. Mathematical models were calibrated against multiple sources of information (e.g., water potential, pneumatic, and perched-water) (SNL 2007 [DIRS 184614], Section 6).

Site-Scale Unsaturated Zone Radionuclide Transport Model—The technical basis for this model (SNL 2007 [DIRS 177396]) rests on the conceptual and numerical models developed to represent unsaturated zone flow (SNL 2007 [DIRS 184614], Section 6). Advection, fracture-matrix interaction, sorption, and colloid-facilitated transport are important processes for radionuclide transport in the unsaturated zone. Mass and energy transfer are included in the models to address thermal effects on transport. Data sources supporting the site-scale unsaturated zone radionuclide transport model include laboratory sorption and matrix diffusion measurements, testing to support extension to larger scales at a test facility at Busted Butte, Alcove 8–Niche 3 testing to investigate fracture–matrix interactions, colloid retardation testing at the Busted Butte facility, pore-water chemistry testing, and isotope studies to address the prevalence and frequency of fracture flow in the unsaturated zone. The approach used to represent unsaturated zone radionuclide transport is a dual-permeability model with distinct hydraulic and transport behavior for fractures and matrix. This approach best accounts for data from geochemical studies, field tracer tests, and modeling sensitivity studies.

Site-Scale Saturated Zone Flow Model—The site-scale saturated zone flow model provides a three-dimensional calibrated simulation of groundwater flow paths and rates near Yucca Mountain. The technical basis for the saturated zone flow models rests on geologic and field studies in the region surrounding Yucca Mountain. These studies provide the overall framework in terms of the lateral and vertical extent of aquifers and confining units, as well as locations of recharge and discharge areas. This model is calibrated using water-level data and is supported by a variety of field data including hydrochemical and isotopic data, hydraulic field testing, and temperature data. The site-scale saturated zone flow model was constructed using a continuum approach. A continuum model was considered appropriate because field evidence indicates groundwater flow occurs through well-connected fractures on the order of tens to hundreds of meters apart. Use of a continuum model allows for the use of widely accepted equations describing groundwater flow through porous media (SNL 2007 [DIRS 177391], Section 6).

Site-Scale Saturated Zone Radionuclide Transport Model—The technical basis for this model rests on the geologic and hydrologic studies used to develop the *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6); and *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391], Section 6) supplemented by additional data on chemical characteristics of dissolved or colloidal radionuclides and the characteristics of the geochemical environment along transport pathways. Transport of radionuclides as dissolved species will be affected by advection, diffusion, dispersion, and, for reactive radionuclides, sorption. Transport of radionuclides sorbed onto colloids is affected by the rate of colloid filtration, radionuclide desorption rates from colloids, and steady-state colloid concentrations. The rate of radionuclide transport is a function of specific discharge, the porosity of the materials through which water flows, effective diffusion coefficient, dispersivity, decay constants, and radionuclide sorption coefficients. Data from hydraulic and tracer tests at a multiple-well complex provide the basis for modeling advective transport over scales relevant to radionuclide transport. These test results were used to develop values for flow and transport modeling parameters and to confirm that the dual-porosity continuum conceptualization is appropriate for representing transport. Other field tests provide evidence supporting the predominance of fracture flow in the volcanic tuff units. Tracer test results were used to define flowing interval porosity and uncertainty in this parameter, which is the volume of pore space that is highly conductive. Field and laboratory tests have established matrix diffusion coefficients for fractured volcanic tuffs, dispersivity values for the saturated zone were estimated from the literature. Sorption coefficients for the volcanic tuff and alluvium were obtained from laboratory measurements and scaled-up for site-scale application.

6.2.3.4 Technical Basis for Unlikely Events Potentially Affecting Barrier Capability

The capability of the barriers is potentially affected by the occurrence of unlikely events that may degrade, alter, or otherwise disrupt the features and components of the natural setting or EBS. These events include seismic and igneous events. Both of these event types are included in the scenario classes that have been retained for assessing performance of the repository system.

The technical basis of the probability of seismic-induced degradation has been formally elicited from an expert elicitation based upon site-specific observations of previous seismic activity and faulting as described in *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (CRWMS M&O 1998 [DIRS 103731]).

However, when the models developed in the PSHA were applied, low-probability ground motion values were allowed to increase without bound, eventually reaching levels that are inconsistent with the geologic setting for Yucca Mountain. Therefore, using data, analyses, and modeling results developed after the PSHA, a separate analysis was performed, using data that became available after the PSHA, to determine a reasonable bound to peak horizontal ground velocity at the waste emplacement level. A general discussion of the basis for the site specific ground motions and of the bounded hazard curve is presented in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Section 6.4.3).

The effects of seismic activity on a range of possible seismic response spectra at the repository have been modeled using site-specific rock property data. The effects of seismic activity on EBS degradation have been modeled using site-specific information on rock mass response, design information on structural characteristics of the engineered SSCs, and laboratory testing information on material properties. This information was used to evaluate the degradation of the EBS as a function of seismic PGV (SNL 2007 [DIRS 178851]). The results of seismic-induced consequences are presented in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Section 6) and are represented in the TSPA.

The technical basis of the probability of igneous-induced degradation has been formally elicited from an expert elicitation based upon observations of previous igneous activity as described in *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* (CRWMS M&O 1996 [DIRS 100116]). The effects of igneous activity on EBS degradation have been evaluated using analogues to similar igneous activity that have been supplemented by an independent peer review and a range of conservative assumptions.

6.2.3.5 Summary of Technical Bases for Barrier Capability

The technical bases for the assessment of the capability of the three barriers to: (1) prevent or substantially reduce the rate of movement of water or radionuclides from the repository to the accessible environment or (2) prevent or substantially reduce the rate of release of radionuclides from the waste are the same as the bases used for the compliance of the repository system with the postclosure performance assessment objectives and requirements. The barrier capability is based on the abstraction models of processes included in the performance assessment and considered processes and events that have been excluded from the performance assessment.

6.2.4 Summary

The Yucca Mountain repository system comprises three barriers that have the functions of: (1) preventing or substantially reducing the rate of movement of water or radionuclides from the repository to the accessible environment or (2) preventing or substantially reducing the release rate of radionuclides from the waste. These three barriers include two natural barriers and one engineered barrier system: namely, the UNB, the EBS, and the LNB. These barriers include multiple features that have processes and events that may act on or within the barriers to affect the capability of the performance of the barrier.

The relevant FEPs that most significantly contribute to the capability of the barriers are presented in Appendix A, Tables A-1, A-2, and A-3. A complete evaluation of all potential FEPs, including the technical basis for their inclusion or exclusion in the performance assessment, is presented in the FEPs (SNL 2008 [DIRS 183041], Section 6).

Detailed descriptions of the models used to evaluate the barrier capability, as well as the technical basis for the treatment of uncertainties associated with the models and parameters used in the evaluation are provided in the references listed in Table 6-4.

The UNB, by preventing or substantially reducing the amount and the rate of water seeping into the drifts, prevents or substantially reduces the rate of movement of water from the repository to the accessible environment and prevents or reduces the release rate of radionuclides from the waste. For the present-day climate on average nearly all of the percolation flux would be diverted around drifts in TSw unit. For the wetter climate states of the monsoonal and the glacial-transition climate states, over 80% of the flux would still be diverted around the drifts (SNL 2007 [DIRS 181244], Table 6-6[a]). Drift collapse due to seismic events can reduce the potential for flow diversion. After several hundred thousand years, when drifts may fill with accumulated rubble from several seismic events, the diverted flux potentially is about half compared to the uncollapsed drifts (SNL 2007 [DIRS 181244], Table 6-7[a]). In addition, during the glacial transition climate state, the Upper Natural Barrier is projected to prevent water from contacting more than half of the waste package locations. For collapsed drifts caused by seismic events this potential flow diversion is much less. Overall, the reduction in seepage into drifts relative to percolation flux demonstrate the important barrier capability of the unsaturated flow processes in the fractured rock at and above the repository horizon.

The EBS prevents or substantially reduces the release rate of radionuclides from the waste and prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment. It performs these functions by virtue of the materials and design of the emplacement drifts, drip shields, waste packages, and waste form and waste package internals. In addition, the EBS provides for chemical and thermal-hydrologic environments that lead to low solubilities for the radionuclides that make up the greatest fraction of the inventory activity. Finally, the EBS environments are such that radionuclide transport from the waste to the unsaturated zone is limited to a small fraction of the available inventory, even in the case of seismic-induced mechanical degradation.

The LNB prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment. The key processes associated with the performance of the LNB are related to matrix diffusion and sorption of radionuclides.

The parameters and models used in the quantification of barrier capability are the same as those developed for use in the TSPA for evaluation of performance of the natural and engineered barriers in the assessment of the individual and groundwater protection. Although uncertainty exists in the parameters and models of the relevant processes that affect the assessment of barrier capability and the TSPA, this uncertainty has been included in the assessments. As a result, the description of the repository system and the demonstration of multiple barriers increase the likelihood that the postclosure performance objectives specified in 10 CFR 63.113(b) and (c) [DIRS 180319] will be achieved.

6.3 NON-BARRIER-SPECIFIC FEATURES EVENTS AND PROCESSES

374 FEPs and feature-components were considered for potential effects on barrier capability. Most of these FEPs were addressed as part of the barrier capability analysis. However, some FEPs were considered to be not relevant to any of the three ITWI barriers. For completeness, these FEPs are listed in Table 6-8.

The non-barrier-specific FEPs fall into two categories. The first category of non-barrier-specific FEPs relate to events that do not affect any of the ITWI barriers. Human intrusion is a special case, which while potentially important to performance assessment, does not prevent or substantially reduce water or radionuclide movement through any of the ITWI barriers.

The second category of non-barrier-specific FEPs relate to features of the biosphere and system that are not part of any of the ITWI barriers. The biosphere is not considered part of the LNB because it exists at the boundary of the accessible environment. While the biosphere is important to performance assessment in that it defines the characteristics of the receptor, it does not have any effect on movement of water or radionuclides from the repository to the accessible environment. FEPs classified as “System” capture processes and events that act upon the repository system as a whole, but do not generally relate to the capability of a single feature or barrier. Some system FEPs were relevant to the ITWI barriers and were addressed in Sections 6.1 and 6.2.

Table 6-8. Non-Barrier-Specific Features and Events

FEP Number	FEP Name	FEP Status
Event: Human Intrusion		
1.4.02.01.0A	Deliberate Human Intrusion	Excluded
1.4.02.02.0A	Inadvertent Human Intrusion	Excluded
1.4.03.00.0A	Unintrusive Site Investigation	Excluded
1.4.04.00.0A	Drilling Activities (Human Intrusion)	Excluded
1.4.04.01.0A	Effects of Drilling Intrusion	Excluded
1.4.05.00.0A	Mining and Other Underground Activities (Human Intrusion)	Excluded
1.4.11.00.0A	Explosions and Crashes (Human Activities)	Excluded
3.3.06.01.0A	Repository Excavation	Excluded
Feature: Backfill and Seals		
1.1.03.01.0B	Error in Backfill Emplacement	Excluded
2.1.05.01.0A	Flow through Seals (Access Ramps and Ventilation Shafts)	Excluded
2.1.05.03.0A	Degradation of Seals	Excluded
2.1.04.09.0A	Radionuclide Transport in Backfill	Excluded
Feature: Biosphere		
1.2.04.07.0A	Ashfall	Included
1.2.04.07.0C	Ash Redistribution via Soil and Sediment Transport	Included
1.4.01.00.0A	Human Influences on Climate	Excluded

Table 6-8. Non-Barrier-Specific Features and Events (Continued)

FEP Number	FEP Name	FEP Status
Feature: Biosphere (Continued)		
1.4.01.02.0A	Greenhouse Gas Effects	Excluded
1.4.01.03.0A	Acid rain	Excluded
1.4.01.04.0A	Ozone Layer Failure	Excluded
1.4.07.01.0A	Water Management Activities	Included
1.4.07.03.0A	Recycling of Accumulated Radionuclides from soils to Groundwater	Excluded
1.4.08.00.0A	Social and Institutional Developments	Excluded
1.4.09.00.0A	Technological Developments	Excluded
1.5.02.00.0A	Species Evolution	Exclude
2.2.08.07.0C	Radionuclide Solubility Limits in the Biosphere	Excluded
2.2.08.11.0A	Groundwater Discharge to Surface within the Reference Biosphere	Excluded
2.3.02.01.0A	Soil Type	Included
2.3.02.02.0A	Radionuclide Accumulation in Soils	Included
2.3.02.03.0A	Soil and Sediment Transport in the Biosphere	Included
2.3.04.01.0A	Surface Water Transport and Mixing	Included
2.3.09.01.0A	Animal Burrowing/Intrusion	Excluded
2.3.11.04.0A	Groundwater Discharge to Surface Outside the Reference Biosphere	Excluded
2.3.13.01.0A	Biosphere Characteristics	Included
2.3.13.02.0A	Radionuclide Alteration during Biosphere Transport	Included
2.3.13.03.0A	Effects of Repository Heat on the Biosphere	Excluded
2.3.13.04.0A	Radionuclide Release Outside the Reference Biosphere	Excluded
2.4.01.00.0A	Human Characteristics (Physiology, Metabolism)	Included
2.4.04.01.0A	Human Lifestyle	Included
2.4.07.00.0A	Dwellings	Included
2.4.08.00.0A	Wild and Natural Land and Water Use	Included
2.4.09.01.0A	Implementation of New Agricultural Practices or Land Use	Excluded
2.4.09.01.0B	Agricultural Land Use and Irrigation	Included
2.4.09.02.0A	Animal Farms and Fisheries	Included
2.4.10.00.0A	Urban and Industrial Land and Water Use	Included
3.2.10.00.0A	Atmospheric Transport of Contaminants	Included
3.3.01.00.0A	Contaminated Drinking Water, Foodstuffs and Drugs	Included
3.3.02.01.0A	Plant Uptake	Included
3.3.02.02.0A	Animal Uptake	Included
3.3.02.03.0A	Fish Uptake	Included
3.3.03.01.0A	Contaminated Non-food Products and Exposure	Included
3.3.04.01.0A	Ingestion	Included
3.3.04.02.0A	Inhalation	Included
3.3.06.02.0A	Sensitization to Radiation	Excluded
3.3.07.00.0A	Non-radiological Toxicity and Effects	Excluded
3.3.08.00.0A	Radon and Radon Decay Product Exposure	Included
3.3.04.03.0A	External Exposure	Included
3.3.05.01.0A	Radiation Doses	Included
3.3.06.00.0A	Radiological Toxicity and Effects	Excluded

Table 6-8. Non-Barrier-Specific Features and Events (Continued)

FEP Number	FEP Name	FEP Status
Feature: System		
0.1.02.00.0A	Timescales of Concern	Included
0.1.03.00.0A	Spatial Domain of Concern	Included
0.1.09.00.0A	Regulatory Requirements and Exclusions	Included
0.1.10.00.0A	Model and Data Issues	Included
1.1.05.00.0A	Records and Markers for the Repository	Excluded
1.1.09.00.0A	Schedule and Planning	Excluded
1.1.10.00.0A	Administrative Control of the Repository Site	Excluded
1.1.11.00.0A	Monitoring of the Repository	Excluded
1.1.12.01.0A	Accidents and Unplanned Events During Construction and Operation	Excluded
1.1.13.00.0A	Retrievability	Included
1.2.01.01.0A	Tectonic Activity - Large Scale	Excluded
1.2.05.00.0A	Metamorphism	Excluded
1.2.08.00.0A	Diagenesis	Excluded
1.2.09.00.0A	Salt diapirism and dissolution	Excluded
1.2.09.01.0A	Diapirism	Excluded
1.3.04.00.0A	Periglacial Effects	Excluded
1.3.05.00.0A	Glacial and Ice Sheet Effect	Excluded
1.4.02.03.0A	Igneous Event Precedes Human Intrusion	Excluded
1.4.02.04.0A	Seismic Event Precedes Human Intrusion	Excluded
1.5.01.01.0A	Meteorite Impact	Excluded
1.5.01.02.0A	Extraterrestrial Events	Excluded
1.5.03.01.0A	Changes in the Earth's Magnetic Field	Excluded
1.5.03.02.0A	Earth Tides	Excluded
2.2.06.05.0A	Salt Creep	Excluded
2.3.06.00.0A	Marine Features	Excluded

7. CONCLUSIONS

Three barriers important to waste isolation (ITWI) have been identified (Section 6.1.2). These barriers are the Upper Natural Barrier, the Engineered Barrier System, and the Lower Natural Barrier. The specification of these barriers as ITWI is a result of an analysis conducted and documented in this report (Section 6.1.2 and 6.1.5). This analysis considers these barriers to be ITWI because they contain at least one feature that is classified as ITWI. Table 7-1 provides a list of ITWI features / components supporting each of the three barriers as well as the barrier function for each and the relevant control parameter characteristics that apply to those ITWI Features / components (Output DTN: MO0801TABLITWI.000) A feature is classified as ITWI if it meets two conditions. The first condition is that the feature is associated with one or more parameter characteristic classified as important to barrier capability (ITBC). The second condition is that the feature is a significant contributor to the barrier capability relative to the other features of the barrier. In addition, a feature is classified ITWI even if does not have ITBC control parameters if it one of the engineered features/components of the geologic repository whose function is to prevent or mitigate the consequences of potential disruptive events (e.g., criticality), or other additional constraints are placed on them (e.g. emplacement of naval waste packages, the TAD specification (DOE 2007 [DIRS 181403], Sections 3.1.1(1) and (2) and 3.1.8(1)), or the Waste Acceptance System Requirements Document (DOE 2007 [DIRS 169992]). Consistent with 10 CFR 63.2 and 10 CFR 63.142(a) [DIRS 180319], a parameter characteristic is classified as ITBC if it: 1) prevents or substantially reduces the rate of movement of water from the repository to the accessible environment; 2) prevents the release or substantially reduces the release rate of radionuclides from the waste; 3) prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment, or 4) prevents or substantially reduces the consequences of disruptive events (e.g. criticality).

Consumable materials to be incorporated into any engineered item important to waste isolation during fabrication of that item are also included as items important to waste isolation. The control parameters that are related to this specific criteria include 02-03: Committed Materials and 04-09: Waste Package & TAD Canister Excluded Materials.

Additional constraints beyond the control parameters listed are placed on some features or SSCs. Table 7-1 lists these additional controlling mechanisms as control parameter characteristics for the features or SSCs where they apply. These include: the Transportation, Aging, and Disposal Canister System Performance Specification (DOE 2007 [DIRS 181403], and the Waste Acceptance System Requirements Document (DOE 2007 [DIRS 169992]) and information contained in Naval Nuclear Propulsion Program classified documents. In addition, for postclosure purposes, NUREG-1536 and NUREG-1567 are equivalent in their requirements for moisture removal and are therefore acceptable.

The methodology for the determination of ITWI barriers is primarily based on the information contained in the screening justifications and screening dispositions of the Features, Events, and Processes (FEPs). As the FEPs form the bases of technical support for the TSPA, this approach is both efficient and comprehensive for ITWI barrier determination. The FEP screening justifications and dispositions can also be associated with specific parameter characteristics. The parameter characteristics associated with each FEP relevant to specific features/components of each barrier are identified (Appendix A and Tables 7-2, 7-3, and 7-4) (Output DTN: MO0802ITWITABS.000).

Parameter characteristics fall into two categories: ‘core’ and ‘control.’ Core parameter characteristics are a logical grouping of core parameters that combine to produce a contribution to the capability of a barrier’s feature/component. A core parameter is a quantity or variable that supports the postclosure technical bases and is not controlled or manipulated during design, construction, or operations. Core parameter characteristics were identified from knowledge of defining processes and features relevant to FEP screening justifications and dispositions. Core parameter characteristics are candidates for monitoring during Performance Confirmation. Control parameter characteristics are similarly defined except that control parameters are controlled or manipulated during design, construction, or operations in such a fashion as to provide a reasonable expectation that the feature/component’s capability will be as described in the postclosure technical baseline, TSPA, and Safety Analysis Report. A control parameter characteristic may include, but not be limited to, fit, form, and functionality of the materials of a barriers feature/component. It also identifies the specific functions to be performed by a feature/component (or SSC). These control parameter characteristics (Table 6-6) are obtained from *Postclosure Modeling and Analyses Design Parameters* (BSC 2008 [DIRS 183627]).

Once the FEPs have been associated with specific barrier features and core and control parameter characteristics identified, the core and control parameter characteristics were evaluated as being ITBC or non-ITBC. This determination is based on evaluation of their role in FEP screening justifications and dispositions specific to a barrier features relevant to the three criteria identified in the first paragraph of this section and which follow from the regulations, 10 CFR 63.2 [DIRS 180319]. The association of FEPs with features/components of barriers, the identification of core and control parameters, and the identification of ITBC parameter characteristics are presented in the tables of Appendix A and summarized in Tables 7-2, 7-3, and 7-4. Core parameter characteristics that are ITBC are candidates for monitoring during Performance Confirmation.

A qualitative discussion of the barrier capability and the contribution of each barrier’s feature/component to barrier capability are presented in Section 6.2. These features and the capability of each barrier are described in terms of the physical processes that contribute to repository system performance. This discussion supplements the analysis of ITBC by FEPs presented in Appendix A. The qualitative discussion is drawn from the information of the FEP analysis as well as information presented in the AMR reports supporting the postclosure technical bases, the TSPA, and the Safety Analysis Report. The information presented in Section 6.2 helps demonstrate that the three repository system barriers function in a manner to provide a reasonable expectation that HLW can be disposed of without exceeding the requirements of 10 CFR 63.113(b) and (c) [DIRS 180319]. The understanding of the barriers gained through site characterization and/or repository design permits a demonstration that the barriers work together to perform their postclosure functions. These features and the capability of each barrier are described in terms of the physical processes that contribute to repository system performance. Key barrier capabilities of the three ITWI barriers are summarized below.

As described in Section 6.2.1.1, the UNB is composed of two features: topography and surficial soils, and unsaturated zone above the repository. The amount of water that falls on the topography and surficial soils as precipitation is significantly reduced by runoff and evapotranspiration from infiltrating and percolating through the unsaturated zone above the repository. In addition, the capillarity and permeability of the unsaturated zone prevent a significant fraction of the percolation flux from entering the emplacement drifts over a large fraction of the repository. These processes prevent or substantially reduce the rate of water movement through the unsaturated zone above the repository, which in turn prevents or substantially reduces the rate of movement of water from the repository to the accessible environment.

As described in Section 6.2.1.2, the EBS is composed of several features designed to work together and to complement the natural barriers. The EBS prevents or substantially reduces the contact of water with the waste, reducing the release rate of radionuclides due to the slow alteration of the waste and low solubility of many radionuclides, which in turn prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment. The EBS features/components that are important to waste isolation and that contribute to barrier capability are (1) emplacement drift, (2) drip shield, (3) waste package including inner vessel, (4) naval SNF structure, and (5) waste form (excluding DOE SNF waste form) and waste package internals including the transport, aging, and disposal (TAD) canister, naval canister, TAD and DOE SNF canister neutron absorber materials, and naval SNF canister system components. Commercial SNF waste packages are used to represent the naval SNF waste packages in the TSPA. EBS features/components that are not important to waste isolation are (1) commercial SNF cladding, (2) DOE SNF waste form (3) the waste package pallet, and (3) invert.

As described in Section 6.2.1.3, the LNB prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment. The key processes associated with the capability of the LNB are slow advective transport, matrix diffusion, and sorption of radionuclides.

As presented in Section 6.1.4 all barriers and features/components that are identified as ITWI are included in the postclosure technical baseline and the TSPA model. The parameters and models used in the quantification of barrier capability are the same as those developed for use in the TSPA for evaluation of performance of the natural and engineered barriers in the assessment of the individual and groundwater protection. Although uncertainty exists in the parameters and models of the relevant processes that affect the assessment of barrier capability and TSPA, this uncertainty has been appropriately included in the assessments. As a result, the description of the repository system and the demonstration of multiple barriers increase the confidence that the postclosure performance objectives specified in 10 CFR 63.113(b) and (c) [DIRS 180319] will be achieved.

The postclosure performance assessment, analyzes the natural environment and the engineered component performance after closure of the repository. To perform those analyses, modeling was developed to estimate the conditions and processes spatially and temporally in the closed repository. To ensure that those analyses and results are representative of the repository postclosure performance, it is necessary that those SSCs together with the geologic conditions relied upon in the analyses, are within the modeled conditions at the time the repository is closed. Table 7-1 provides a summary of the ITWI classification of major features/ SSCs that support the characterization of three barriers as ITWI.

Table 7-5 contains a summary of the parameters that require controls including the summarized important to barrier capability classification to ensure the postclosure performance assessment analytical bases are established during preclosure operations (Output DTN: MO0802ITWIBARR.000). This table also details the derived internal constraints applied to each control parameter characteristic (BSC 2008 [DIRS 183627]). It also indicates which control parameter characteristics that were determined to be ITBC are not significant enough to support a feature being determined to be ITWI. For the purposes of this table, the controls are grouped into nine engineered subsystem categories: Subsurface Facilities, Engineered Barrier System In-Drift Configuration, Waste Package, Waste Form and Waste Package Internals, Emplacement and Retrieval, Subsurface Ventilation, Drip Shield, Emplacement Pallet, and Sealing and Closure.

Within each barrier feature, those features / SSCs that provide substantial performance are selected in order to determine the parameters to be controlled. Those features and SSCs identified in Table 7-5 are candidates for quality assurance controls applied in accordance with 10 CFR 63.142 [DIRS 180319]. Through the application of the postclosure performance assessment and quality assurance controls, the analytical basis of the postclosure performance assessment will be established during the preclosure period, with additional controls on those parameters necessary to ensure the initial conditions for the ITWI barrier functions are established.

In summary, the analysis present in the Appendix and the qualitative discussion of barrier capability demonstrate that the three repository system barriers function in a manner to provide a reasonable expectation that HLW can be disposed of without exceeding the requirements of 10 CFR 63.113(b) and (c) [DIRS 180319].

Table 7-1. ITWI Features / Components Supporting Each of the Three Barriers

Barrier	Feature[1]	SSC	Safety Classification[2]	Barrier Function	Relevant Control Parameter Characteristics[3]
UNB	Topography and Surficial Soils	N/A	ITWI	Prevents or substantially reduces the rate of movement of water	09-04 Reclamation of Lands Disturbed by Repository
UNB	Unsaturated Zone above the Repository	N/A	ITWI	Prevents or substantially reduces the rate of movement of water	01-20 Repository Standoff from Paintbrush Nonwelded Hydrogeologic Unit 01-21 Minimum Thickness of the Paintbrush Nonwelded Hydrogeologic Unit above the Repository
EBS	Emplacement Drift - Non-emplacement Openings	Subsurface Facilities - Non-emplacement Openings	Non-ITWI	None	N/A
		Subsurface Facilities - Ground Support for Non-emplacement Openings			
EBS	Emplacement Drift - Closure	Borehole Closure	Non-ITWI	None	N/A
		Ramp and Shaft Closure			
EBS	Emplacement Drift	Emplacement Drift	ITWI	Prevents or substantially reduces the rate of movement of water Prevents or substantially reduces the rate of movement of radionuclides	01-06 Repository Elevation - Overburden Thickness 01-10 Emplacement Drift Configuration 02-03 Committed Materials
EBS	Emplacement Drift	Ground Support for Emplacement Drift	Non-ITWI	None	N/A
		Subsurface Ventilation System			

Table 7-1. ITWI Features / Components Supporting Each of the Three Barriers (Continued)

Barrier	Feature[1]	SSC	Safety Classification[2]	Barrier Function	Relevant Control Parameter Characteristics[3]
EBS	Drip Shield	Drip Shield	ITWI	Prevents or substantially reduces the rate of movement of water Prevents or substantially reduces the rate of movement of radionuclides	07-02 Drip Shield Design and Installation 07-04 Drip Shield Materials and Thicknesses 07-07 EBS Drip Shield / Emplacement Drift Invert Materials Interactions 07-09 Drip Shield Fabrication 07-10 Drip Shield Fabrication Weld Inspections 07-11 Drip Shield Fabrication Welding Flaws 07-12 Drip Shield Fabrication Weld Materials 07-13 Drip Shield Heat Treatment 07-14 Drip Shield Handling
EBS	Waste Package	Waste Package Outer Corrosion Barrier	ITWI	Prevents or substantially reduces the rate of movement of water Prevents or substantially reduces the release rate of radionuclides from the waste Prevents or substantially reduces the rate of movement of radionuclides	03-03 Waste Package Outer Barrier 03-12 Waste Package Fabrication 03-13 Waste Package Fabrication Weld Inspections 03-14 Waste Package Welding Materials 03-15 Waste Package Fabrication Welding Flaws 03-16 Waste Package Annealing 03-17 Waste Package Closure 03-18 Waste Package Surface Damage Prior to Emplacement 03-19 Waste Package Outer Barrier Material Specifications 03-21 Waste Package Handling 03-23 Waste Package Surface Finish 03-24 Waste Package Surface Damage Prior to Closure 03-26 Waste Package Moisture Removal & Inerting 05-03 Waste Package Thermal Limits 06-03 Waste Package Temperature Limit

Table 7-1. ITWI Features / Components Supporting Each of the Three Barriers (Continued)

Barrier	Feature[1]	SSC	Safety Classification[2]	Barrier Function	Relevant Control Parameter Characteristics[3]
EBS	Waste Package	Waste Package Inner Vessel	ITWI	Prevents or substantially reduces the release rate of radionuclides from the waste Prevents or substantially reduces the rate of movement of radionuclides	03-14 Waste Package Welding Materials 03-15 Waste Package Fabrication Welding Flaws
EBS	Waste Form and Waste Package Internals - TAD Canister	TAD Canister	ITWI	Prevents or substantially reduces the release rate of radionuclides from the waste Prevents or substantially reduces the rate of movement of radionuclides	See the Transportation, Aging, and Disposal Canister System Performance Specification (DOE 2007 [DIRS 181403], Sections 3.1.1(1) and (2) and 3.1.8(1)).
	Waste Form and Waste Package Internals – Naval Canister	Naval Canister	ITWI	Prevents or substantially reduces the release rate of radionuclides from the waste Prevents or substantially reduces the rate of movement of radionuclides Reduces the probability of criticality	See the Waste Acceptance System Requirements Document (DOE 2007 [DIRS 169992], Section 4.4) and Naval Nuclear Propulsion Program classified documents.
EBS	Waste Form and Waste Package Internals –DOE SNF Canister and HLW Canister	DOE SNF Canister	Non-ITWI	None	N/A
		HLW Canister			
EBS	Waste Form and Waste Package Internals - Naval SNF Canister System Components	Naval SNF Baskets	ITWI	Reduces the probability of criticality	See the Waste Acceptance System Requirements Document (DOE 2007 [DIRS 169992], Section 4.4) and Naval Nuclear Propulsion Program classified documents.
		Naval SNF Basket Spacers			
		Naval Neutron Absorber Assemblies (includes retention hardware)			
		Naval Control Rods (includes retention hardware)			
		Corrosion-resistant cans			

Table 7-1. ITWI Features / Components Supporting Each of the Three Barriers (Continued)

Barrier	Feature[1]	SSC	Safety Classification[2]	Barrier Function	Relevant Control Parameter Characteristics[3]
EBS	Waste Form and Waste Package Internals - Codisposal Waste Package Internals	Codisposal Packages Internals	Non-ITWI	None	N/A
		Baskets, Spacers			
EBS	Waste Form and Waste Package Internals – TAD Canister Internals	Neutron Absorbers	ITWI	Reduces the probability of criticality	See the Transportation, Aging, and Disposal Canister System Performance Specification (DOE 2007 [DIRS 181403], Section 3.1.5(2))
EBS	Waste Form and Waste Package Internals - DOE SNF Canister Internals	Neutron Absorbers	ITWI	Reduces the probability of criticality	See the Waste Acceptance System Requirements Document (DOE 2007 [DIRS 169992], Section 4.3.8 (b))
EBS	Waste Form and Waste Package Internals – Commercial Spent Nuclear Fuel and High Level Glass	CSNF	ITWI	Prevents or substantially reduces the release rate of radionuclides from the waste Prevents or substantially reduces the rate of movement of radionuclides	04-04 Waste Form Moisture Removal & Inerting (applies to CSNF only) 04-07 Waste Package Capacities 04-09 Waste Package & TAD Canister Excluded Materials
		HLW			
EBS	Waste Form and Waste Package Internals – Naval Spent Nuclear Fuel	Naval SNF Structure (includes cladding)	ITWI	Prevents or substantially reduces the release rate of radionuclides from the waste Prevents or substantially reduces the rate of movement of radionuclides	See the Waste Acceptance System Requirements Document (DOE 2007 [DIRS 169992], Section 4.4) and Naval Nuclear Propulsion Program classified documents
EBS	Waste Form and Waste Package Internals – DOE Spent Nuclear Fuel	DOE SNF	Non-ITWI	None	N/A
EBS	Cladding – CSNF / DOE SNF	Cladding (CSNF / DOE SNF)	Non-ITWI	None	N/A
EBS	Waste Package Pallet	Pallet	Non-ITWI	None	N/A
EBS	Invert	Emplacement Drift Ballast	Non-ITWI	None	N/A
		Invert Structure			

Table 7-1. ITWI Features / Components Supporting Each of the Three Barriers (Continued)

Barrier	Feature[1]	SSC	Safety Classification[2]	Barrier Function	Relevant Control Parameter Characteristics[3]
LNB	Unsaturated Zone below the Repository	N/A	ITWI	Prevents or substantially reduces the rate of movement of radionuclides	01-04 Repository Elevation – Standoff from Water Table
LNB	Saturated Zone	N/A	ITWI	Prevents or substantially reduces the rate of movement of radionuclides	01-04 Repository Elevation – Standoff from Water Table

Source: DTN: MO0801TABLITWI.000.

NOTES:

[1] Some features in this column are further divided into additional groupings signified by text after a dash so that those subparts of that feature as analyzed in Section 6.2 and Appendix Tables A-1, A-2, and A-3 could be properly classified as ITWI or Non-ITWI.

[2] ITWI classification applies to barriers. The barriers are comprised of features and SSCs that support the function of the barrier. A feature is classified as ITWI if it meets two conditions: (a) the feature is associated with one or more parameter characteristic classified as important to barrier capability (ITBC); and (b) the feature is a significant contributor to the barrier capability relative to the other features of the barrier. In addition, a feature may be classified ITWI even if does not have ITBC control parameters if it one of the engineered features/components of the geologic repository whose function is to prevent or mitigate the consequences of potential disruptive events (e.g., criticality), or other additional constraints are placed on them by other cited documents.

[3] Only those relevant control parameters related to the ITWI features and SSCs were selected if they meet two requirements: (a) They are directly associated with the barrier feature, and (b) They are a relevant control necessary for that feature to perform its function and contribute significantly to its ITWI status.

Additional details associated with the evaluation of the basis for the capability of the barriers are presented in Section 6.2 and Appendix Tables A-1, A-2, and A-3.

Acronyms: EBS = Engineered Barrier System; LNB = lower natural barrier; UNB = upper natural barrier; ITWI = Important to Waste Isolation (classification applies to barriers; SSCs support barrier function).

Table 7-2. ITBC Features / Components and ITBC Parameter Characteristics of Upper Natural Barrier

Feature / Component	Characteristic	Type	Analysis Basis
Topography & Surficial Soils	Infiltration & Seepage	Core	1.2.02.01.0A - Fractures (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.3.11.01.0A - Precipitation (Included)
			2.3.11.02.0A - Surface Runoff and Evapotranspiration (Included)
			2.3.11.03.0A - Infiltration and Recharge (Included)
			2.3.01.00.0A - Topography and Morphology (Included)
	Reclamation of Lands Disturbed by Repository	Control	2.3.01.00.0A - Topography and Morphology (Included)
	Repository Elevation below the Surface	Control	1.4.01.01.0A - Climate Modification Increases Recharge (Included)
	Repository Geographic & Geologic Location	Control	1.2.02.01.0A - Fractures (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.3.11.01.0A - Precipitation (Included)
			2.3.11.02.0A - Surface Runoff and Evapotranspiration (Included)
			2.3.11.03.0A - Infiltration and Recharge (Included)
			2.3.01.00.0A - Topography and Morphology (Included)
	Surface Soil Properties (Including Vegetation)	Core	1.2.02.01.0A - Fractures (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.3.11.02.0A - Surface Runoff and Evapotranspiration (Included)
			2.3.11.03.0A - Infiltration and Recharge (Included)
			2.3.01.00.0A - Topography and Morphology (Included)
	Unsaturated Zone Properties	Core	1.3.01.00.0A - Climate Change (Included)

Table 7-2. ITBC Features / Components and ITBC Parameter Characteristics of Upper Natural Barrier (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
UZ above the Repository	Infiltration and Seepage	Core	1.2.02.01.0A - Fractures (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.1.08.01.0A - Water Influx at the Repository (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.02.0A - Unsaturated Groundwater Flow in the Geosphere (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.2.07.20.0A - Flow Diversion around Repository Drifts (Included)
	Minimum Thickness of the PTn Unit Above the Repository		2.2.03.01.0A - Stratigraphy (Included)
	Properties of the Host Rock Unit	Core	2.1.08.01.0A - Water Influx at the Repository (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.2.07.20.0A - Flow Diversion Around Repository Drifts (Included)
	Repository Elevation below the Surface	Control	1.2.02.01.0A - Fractures (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
	Repository Geographic & Geologic Location	Control	1.2.02.01.0A - Fractures (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.02.0A - Unsaturated Groundwater Flow in the Geosphere (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
	Unsaturated Zone Properties	Core	1.2.02.01.0A - Fractures (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.1.08.01.0A - Water Influx at the Repository (Included)
			2.2.03.01.0A - Stratigraphy (Included)

Table 7-2. ITBC Features / Components and ITBC Parameter Characteristics of Upper Natural Barrier (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
UZ above the Repository (Continued)	Unsaturated Zone Properties (Continued)		2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.02.0A - Unsaturated Groundwater Flow in the Geosphere (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.2.07.20.0A - Flow Diversion Around Repository Drifts (Included)
	Verification of Design Rock Properties	Control	2.2.03.01.0a - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)

Source: Output DTN: MO0802ITWITABS.000.

Table 7-3. ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System

Feature / Component	Characteristic	Type	Analysis Basis
Emplacement Drift	As-Emplaced Waste Package-Drip Shield Configuration	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Characterization of Seismic Events	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Committed Materials	Control	2.1.09.01.0A - Chemical Characteristics of Water in Drifts (Included)
	Corrosion Products Properties	Core	2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
			2.2.08.12.0A - Chemistry of Water Flowing into the Drift (Included)
	Drip Shield Materials and Thicknesses	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.11.01.0A - Heat Generation in EBS (Included)
	Drip Shield Materials, Properties, and Configuration	Core	1.2.03.02.0C - Seismic-induced Drift Collapse Damages EBS Components (Included)
			2.1.11.01.0A - Heat Generation in EBS (Included)
	Drip Shield Seismic Performance	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			1.2.03.02.0C - Seismic-induced Drift Collapse Damages EBS Components (Included)
	EBS Material Interactions - Copper	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Emplacement Drift (Continued)	In-Drift Chemical Environment	Core	2.1.09.01.0A - Chemical Characteristics of Water in Drifts (Included)
			2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
			2.2.08.12.0A - Chemistry of Water Flowing into the Drift (Included)
	In-Drift Thermal Environment, Convection, Condensation, and Evaporation	Core	1.2.03.02.0D - Seismic-induced Drift Collapse Alters In-drift Thermal-Hydrology (Included)
			2.1.09.01.0A - Chemical Characteristics of Water in Drifts (Included)
			2.1.11.01.0A - Heat Generation in EBS (Included)
			2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
			2.2.08.12.0A - Chemistry of Water Flowing into the Drift (Included)
	Infiltration and Seepage	Core	1.2.03.02.0D - Seismic-induced Drift Collapse Alters In-drift Thermal-hydrology (Included)
	Infiltration and Seepage Properties	Core	2.1.08.07.0A - Unsaturated Flow in the EBS (Included)
	Properties of the Host Rock Unit	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			1.2.03.02.0B - Seismic-induced Rockfall Damages EBS Components (Excluded)
			1.2.03.02.0C - Seismic-induced Drift Collapse Damages EBS Components (Included)
			1.2.03.02.0D - Seismic-induced Drift Collapse Alters In-drift Thermal-hydrology (Included)
	Radionuclide and Source-Term Properties	Core	2.1.09.01.0A - Chemical Characteristics of Water in Drifts (Included)
			2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
			2.2.08.12.0A - Chemistry of Water Flowing into the Drift (Included)
	Repository Elevation - Overburden Thickness	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			1.2.03.02.0C - Seismic-induced Drift Collapse Damages EBS Components (Included)
			2.1.08.07.0A - Unsaturated Flow in the EBS (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Emplacement Drift (Continued)	Repository Geographic and Geologic Location	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			1.2.03.02.0B - Seismic-induced Rockfall Damages EBS Components (Excluded)
			2.1.08.07.0A - Unsaturated Flow in the EBS (Included)
	Seepage Water Properties	Core	2.1.09.01.0A - Chemical Characteristics of Water in Drifts (Included)
			2.1.11.01.0A - Heat Generation in EBS (Included)
			2.2.08.12.0A - Chemistry of Water Flowing into the Drift (Included)
	Seismic Design of Waste Package	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Verification of Design Rock Properties	Control	1.2.03.02.0C - Seismic-induced Drift Collapse Damages EBS Components (Included)
			1.2.03.02.0B - Seismic-induced Rockfall damages EBS Components (Excluded)
	Waste Form Degradation	Core	2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
	Waste Package Corrosion Allowance	Control	2.1.11.01.0A - Heat Generation in EBS (Included)
			2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
	Waste Package Decay Heat	Core	2.1.11.01.0A - Heat Generation in EBS (Included)
			2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
	Waste Package Materials, Properties, and Configuration	Core	2.1.11.01.0A - Heat Generation in EBS (Included)
	Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	Core	2.1.11.01.0A - Heat Generation in EBS (Included)
			2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)
			2.2.08.12.0A - Chemistry of Water Flowing into the Drift (Included)
	Waste Package Spacing	Control	2.1.11.01.0A - Heat Generation in EBS (Included)
	Waste Package Thermal Limits	Control	2.1.11.01.0A - Heat Generation in EBS (Included)
			2.1.11.08.0A - Thermal Effects on Chemistry and Microbial Activity in the EBS (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Drip Shield	As-Emplaced Waste Package-Drip Shield Configuration	Control	1.2.03.02.0B - Seismic-Induced Rockfall Damages Drip Shield (Excluded)
			1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
	Characterization of Seismic Events	Core	1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
	Drip Shield Corrosion Allowance	Control	2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.03.0B - Localized Corrosion of Drip Shields (Excluded)
			2.1.03.10.0B - Advection of Liquids and Solids through Cracks in the Drip Shield (Excluded)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)
	Drip Shield Design	Control	1.2.03.02.0B - Seismic-Induced Rockfall Damages Drip Shield (Excluded)
			1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
			2.1.03.01.0B - General Corrosion of Drip Shields (Included)
			2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.03.0B - Localized Corrosion of Drip Shields (Excluded)
			2.1.03.10.0B - Advection of Liquids and Solids through Cracks in the Drip Shield (Excluded)
			2.1.03.11.0A - Physical Form of Waste Package and Drip Shield (Included)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)
	Drip Shield Design and Installation	Control	2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
			1.2.03.02.0B - Seismic-Induced Rockfall Damages Drip Shield (Excluded)
	Drip Shield Fabrication	Control	2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.08.0B - Early Failure of Drip Shields (Included)
	Drip Shield Fabrication Weld Inspections	Control	2.1.03.08.0B - Early Failure of Drip Shields (Included)
	Drip Shield Fabrication Weld Materials	Control	2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.08.0B - Early Failure of Drip Shields (Included)
			2.1.03.11.0A - Physical Form of Waste Package and Drip Shield (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Drip Shield (Continued)	Drip Shield Fabrication Welding Flaws	Control	2.1.03.08.0B -Early Failure of Drip Shields (Included)
	Drip Shield Handing	Control	2.1.03.08.0B -Early Failure of Drip Shields (Included)
	Drip Shield Heat Treatment	Control	2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.08.0B - Early Failure of Drip Shields (Included)
			2.1.03.10.0B - Advection of Liquids and Solids through Cracks in the Drip Shield (Excluded)
	Drip Shield Materials and Thicknesses	Control	1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
			2.1.03.01.0B - General Corrosion of Drip Shields (Included)
			2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.03.0B - Localized Corrosion of Drip Shields (Excluded)
			2.1.03.10.0B - Advection of Liquids and Solids through Cracks in the Drip Shield (Excluded)
			2.1.03.11.0A - Physical Form of Waste Package and Drip Shield (Included)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			2.1.07.05.0B - Creep of Metallic Materials in the Drip Shield (Excluded)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)
	Drip Shield Materials, Properties, and Configuration	Core	1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
			2.1.03.01.0B - General Corrosion of Drip Shields (Included)
			2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.03.0B - Localized Corrosion of Drip Shields (Excluded)
			2.1.03.10.0B - Advection of Liquids and Solids through Cracks in the Drip Shield (Excluded)
			2.1.03.11.0A - Physical Form of Waste Package and Drip Shield (Included)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			2.1.07.05.0B -Creep of Metallic Materials in the Drip Shield (Excluded)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)
	Drip Shield Seismic Performance	Control	1.2.03.02.0B - Seismic-Induced Rockfall Damages Drip Shield (Excluded)
			1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Drip Shield (Continued)	EBS Drip Shield / Emplacement Drift Invert Materials Interactions	Control	2.1.03.10.0B -Advection of Liquids and Solids through Cracks in the Drip Shield (Excluded)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)
	In-Drift Chemical Environment	Core	2.1.03.01.0B - General Corrosion of Drip Shields (Included)
			2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.03.0B - Localized Corrosion of Drip Shields (Excluded)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)
	In-Drift Thermal Environment, Convection, Condensation, and Evaporation	Core	2.1.03.01.0B - General Corrosion of Drip Shields (Included)
			2.1.03.02.0B - Stress Corrosion Cracking of Drip Shields (Excluded)
			2.1.03.03.0B - Localized Corrosion of Drip Shields (Excluded)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)
	Infiltration and Seepage Properties	Core	2.1.03.01.0B - General Corrosion of Drip Shields (Included)
			2.1.03.10.0B - Advection of Liquids and Solids through Cracks in the Drip Shield (Excluded)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
	Properties of the Host Rock Unit	Core	1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
	Repository Elevation - Overburden Thickness	Control	1.2.03.02.0B - Seismic-Induced Rockfall Damages Drip Shield (Excluded)
			1.2.03.02.0C - Seismic-Induced Drift Collapse Damages EBS Components (Included)
	Repository Geographic and Geologic Location	Control	1.2.03.02.0B - Seismic-Induced Rockfall Damages Drip Shield (Excluded)
	Seepage Water Properties	Core	2.1.03.01.0B - General Corrosion of Drip Shields (Included)
			2.1.06.06.0A - Effects of Drip Shield on Flow (Included)
			2.1.09.28.0B - Localized Corrosion on Drip Shield Surfaces due to Deliquescence (Excluded)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Waste Package	As-Emplaced Waste Package-Drip Shield Configuration	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.11.0A - Physical Form of Waste Package and Drip Shield (Included)
	Characterization of Seismic Events	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Committed Materials	Control	2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	Drip Shield Corrosion Allowance	Control	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Drip Shield Design	Control	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Drip Shield Design and Installation	Control	2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Drip Shield Early Failure	Control	2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Drip Shield Materials and Thicknesses	Control	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Drip Shield Materials, Properties, and Configuration	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Waste Package (Continued)	Drip Shield Seismic Performance	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	EBS Materials Interactions - Copper	Control	2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	EBS Drip Shield / Emplacement Drift Invert Materials Interactions	Control	2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	Emplacement Pallet Function	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	In-Drift Chemical Environment	Core	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	In-Drift Thermal Environment, Convection, Condensation, and Evaporation	Core	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
	Infiltration and Seepage Properties	Core	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Materials Contacting the Waste Package	Control	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	Repository Elevation - Overburden Thickness	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Repository Geographic and Geologic Location	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Waste Package (Continued)	Seepage Water Properties	Core	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	Seismic Design of Waste Package	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Waste Form Degradation	Core	2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Waste Form/Package Internals Materials, Properties, and Configuration	Core	2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
	Waste Package and Emplacement Pallet Static Stresses	Control	2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
	Waste Package Annealing	Control	2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.08.0A - Early Failure of Waste Packages (Included)
	Waste Package Closure	Control	2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.08.0A - Early Failure of Waste Packages (Included)
	Waste Package Corrosion Allowance	Control	2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
	Waste Package Design Basis Bounding Dose Rate	Control	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
	Waste Package Dimensions and Component Masses	Control	2.1.03.11.0A - Physical Form of Waste Package and Drip Shield (Included)
	Waste Package Fabrication	Control	2.1.03.08.0A - Early Failure of Waste Packages (Included)
	Waste Package Fabrication Welding Flaws	Control	2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.08.0A - Early Failure of Waste Packages (Included)
	Waste Package Handing	Control	2.1.03.08.0A - Early Failure of Waste Packages (Included)
	Waste Package Fabrication Weld Inspections	Control	2.1.03.08.0A - Early Failure of Waste Packages (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Waste Package (Continued)	Waste Package Materials, Properties, and Configuration	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.10.0A - Advection of Liquids and Solids through Cracks in the Waste Package (Excluded)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	Waste Package Outer Barrier Material Specifications	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	Waste Package Quantities	Control	2.1.03.01.0A - General Corrosion of Waste Packages (Included)
			2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.03.0A - Localized Corrosion of Waste Packages (Included)
			2.1.03.11.0A - Physical Form of Waste Package and Drip Shield (Included)
			2.1.09.28.0A - Localized Corrosion on Waste Package Outer Surface due to Deliquescence (Excluded)
	Waste Package Surface Damage Prior to Closure	Control	2.1.03.08.0A - Early Failure of Waste Packages (Included)
	Waste Package Surface Finish	Control	2.1.03.02.0A - Stress Corrosion Cracking of Waste Packages (Included)
			2.1.03.08.0A - Early Failure of Waste Packages (Included)
	Waste Package Welding Materials	Control	2.1.03.08.0A - Early Failure of Waste Packages (Included)
Cladding	Characterization of Seismic Events	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Waste Package Thermal Limits	Control	2.1.02.25.0B - Naval SNF Cladding (Included)
	Drip Shield Seismic Performance	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	EBS Material Interactions	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Cladding (Continued)	Seismic Design of Waste Package	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Waste Form/Package Internals Materials, Properties, and Configuration	Core	2.1.02.25.0B - Naval SNF Cladding (Included)
	Waste Package Materials, Properties, and Configuration	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Waste Package Outer Barrier Material Specifications	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
Waste Form and Waste Package Internals	As-Emplaced Waste Package-Drip Shield Configuration	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Characterization of Seismic Events	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Corrosion Products Properties	Core	2.1.02.09.0A - Chemical Effects of Void Space in Waste Package (Included)
			2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)
	Corrosion Products Properties	Core	2.1.09.02.0A - Chemical Interaction with Corrosion Products (Included)
	Drip Shield Materials, Properties, and Configuration	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Drip Shield Seismic Performance	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	EBS Material Interactions - Copper	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
		Core	2.1.02.01.0A - DSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.02.0A - CSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.09.0A - Chemical Effects of Void Space in Waste Package (Included)
			2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)
			2.1.09.02.0A - Chemical Interaction with Corrosion Products (Included)
			2.1.09.04.0A - Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and EBS (Included)
			2.1.09.05.0A - Sorption of Dissolved Radionuclides in EBS (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Waste Form and Waste Package Internals (Continued)	In-Package Chemical Environment (Continued)		2.1.09.08.0A - Diffusion of Dissolved Radionuclides in EBS (Included)
			2.1.02.03.0A - HLW Glass Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.09.07.0A - Reaction Kinetics in Waste Package (Included)
			2.1.09.08.0B - Advection of Dissolved Radionuclides in EBS (Included)
	In-Package Thermal Environment	Core	2.1.02.01.0A - DSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.02.0A - CSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.03.0A - HLW Glass Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.09.08.0A - Diffusion of Dissolved Radionuclides in EBS (Included)
			2.1.09.04.0A - Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and EBS (Included)
			2.1.09.05.0A - Sorption of Dissolved Radionuclides in EBS (Included)
			2.1.09.07.0A - Reaction Kinetics in Waste Package (Included)
			2.1.09.08.0B - Advection of Dissolved Radionuclides in EBS (Included)
	Loading of Waste Forms	Control	2.1.02.03.0A - HLW Glass Degradation (alteration, dissolution, and radionuclide release) (Included)
	Properties of the Host Rock Unit	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Radionuclide Inventory and Source-Term Properties	Core	2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)
			2.1.09.04.0A - Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and EBS (Included)
			2.1.09.05.0A - Sorption of Dissolved Radionuclides in EBS (Included)
			2.1.09.07.0A - Reaction Kinetics in Waste Package (Included)
			2.1.09.08.0A - Diffusion of Dissolved Radionuclides in EBS (Included)
			2.1.09.08.0B -Advection of Dissolved Radionuclides in EBS (Included)
	Repository Elevation - Standoff from Water Table	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Repository Geographic and Geologic Location	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Seismic Design of Waste Package	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Waste Form CSNF Fuel Rod Maximum Burnup Limit	Control	2.1.02.02.0A - CSNF Degradation (alteration, dissolution, and radionuclide release) (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Waste Form and Waste Package Internals (Continued)	Waste Form/Package Internals Materials, Properties, and Configuration	Core	2.1.02.01.0A - DSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.02.0A - CSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.03.0A -HLW Glass Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.09.0A - Chemical Effects of Void Space in Waste Package (Included)
			2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)
			2.1.09.02.0A - Chemical Interaction with Corrosion Products (Included)
			2.1.09.08.0B - Advection of Dissolved Radionuclides in EBS (Included)
			2.1.09.08.0A - Diffusion of Dissolved Radionuclides in EBS (Included)
	Waste Form Degradation	Core	2.1.02.01.0A - DSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.02.0A - CSNF Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.02.03.0A - HLW Glass Degradation (alteration, dissolution, and radionuclide release) (Included)
			2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)
	Waste Package Moisture Removal and Inerting	Control	2.1.02.03.0A - HLW Glass Degradation (alteration, dissolution, and radionuclide release) (Included)
	Waste Package and TAD Canister Excluded Materials	Control	2.1.09.07.0A - Reaction Kinetics in Waste Package (Included)
	Waste Package Corrosion Allowance	Control	2.1.09.02.0A - Chemical Interaction with Corrosion Products (Included)
	Waste Package Decay heat	Control	2.1.09.07.0A - Reaction Kinetics in Waste Package (Included)
	Waste Package Dimensions and Component Masses	Control	2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)
	Waste Package Materials, Properties, and Configuration	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
			2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)
			2.1.09.08.0A - Diffusion of Dissolved Radionuclides in EBS (Included)
			2.1.09.08.0B - Advection of Dissolved Radionuclides in EBS (Included)
	Waste Package Quantities	Control	2.1.09.01.0B - Chemical Characteristics of Water in Waste Package (Included)

Table 7-3 ITBC Features / Components and ITBC Parameter Characteristics of Engineered Barrier System (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
Waste Form and Waste Package Internals (Continued)	Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	Core	2.1.09.04.0A - Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and EBS (Included)
			2.1.09.05.0A - Sorption of Dissolved Radionuclides in EBS (Included)
			2.1.09.07.0A - Reaction Kinetics in Waste Package (Included)
			2.1.09.08.0A - Diffusion of Dissolved Radionuclides in EBS (Included)
			2.1.09.08.0B - Advection of Dissolved Radionuclides in EBS (Included)
	Waste Package Thermal Limits	Control	2.1.09.07.0A - Reaction Kinetics in Waste Package (Included)
Waste Package Pallet	As-Emplaced Waste Package-Drip Shield Configuration	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Characterization of Seismic Events	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	EBS Drip Shield / Emplacement Drift Invert Materials Interactions	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	EBS Materials Interactions - Pallet	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Emplacement Pallet Design	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Emplacement Pallet Fabrication and Corrosion Allowance	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Emplacement Pallet Function	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Emplacement Pallet Materials, Properties, and Configuration	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Materials Contacting the Waste Package	Control	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)
	Properties of the Host Rock Unit	Core	1.2.03.02.0A - Seismic Ground Motion Damages EBS Components (Included)

Source: Output DTN: MO0802ITWITABS.000.

Table 7-4. ITBC Features / Components and ITBC Parameter Characteristics of Lower Natural Barrier

Feature / Component	Characteristic	Type	Analysis Basis
UZ Below the Repository	Extent of Unsaturated Zone	Core	1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
	Properties of Host Rock Unit	Core	2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
	Radionuclide Inventory and Source Term Properties	Core	2.2.08.08.0B - Matrix Diffusion in the UZ (Included)
			2.2.08.09.0B - Sorption in the UZ (Included)
	Unsaturated Zone Chemical Environment	Core	2.2.08.08.0B - Matrix Diffusion in the UZ (Included)
			2.2.08.09.0B - Sorption in the UZ (Included)
	Unsaturated Zone Flow	Core	1.2.02.01.0A - Fractures (Included)
			1.2.02.02.0A - Faults (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.02.0A - Unsaturated Groundwater Flow in the Geosphere (Included)
			2.2.07.07.0A - Perched Water Develops (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.2.07.09.0A - Matrix Imbibition in the UZ (Included)
			2.2.07.15.0B - Advection and Dispersion in the UZ (Included)
	Unsaturated Zone Properties	Core	1.2.02.01.0A - Fractures (Included)
			1.2.02.02.0A - Faults (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.02.0A - Unsaturated Groundwater Flow in the Geosphere (Included)
			2.2.07.07.0A - Perched Water Develops (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.2.07.09.0A - Matrix Imbibition in the UZ (Included)
			2.2.07.15.0B - Advection and Dispersion in the UZ (Included)
			2.2.08.08.0B - Matrix Diffusion in the UZ (Included)
			2.2.08.09.0B - Sorption in the UZ (Included)

Table 7-4. ITBC Features / Components and ITBC Parameter Characteristics of Lower Natural Barrier (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
UZ Below the Repository (Continued)	Unsaturated Zone Transport	Core	1.2.02.01.0A - Fractures (Included)
			1.2.02.02.0A - Faults (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.02.0A - Unsaturated Groundwater Flow in the Geosphere (Included)
			2.2.07.07.0A - Perched Water Develops (Included)
			2.2.07.08.0A - Fracture Flow in the UZ (Included)
			2.2.07.09.0A - Matrix Imbibition in the UZ (Included)
			2.2.07.15.0B - Advection and Dispersion in the UZ (Included)
			2.2.08.08.0B - Matrix Diffusion in the UZ (Included)
			2.2.08.09.0B - Sorption in the UZ (Included)
SZ	Extent of Saturated Zone	Core	1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
	Radionuclide Inventory and Source Term Properties	Core	2.2.08.08.0A - Matrix Diffusion in the SZ (Included)
			2.2.08.09.0A - Sorption in the SZ (Included)
	Repository Elevation above the Water Table	Control	1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
	Saturated Zone Chemical Environment	Core	2.2.08.08.0A - Matrix Diffusion in the SZ (Included)
			2.2.08.09.0A - Sorption in the SZ (Included)
	Saturated Zone Flow	Core	1.2.02.01.0A - Fractures (Included)
			1.2.02.02.0A - Faults (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.12.0A - Saturated Groundwater Flow in the Geosphere (Included)
			2.2.07.13.0A - Water-Conducting Features in the SZ (Included)
			2.2.07.15.0A - Advection and Dispersion in the SZ (Included)

Table 7-4. ITBC Features / Components and ITBC Parameter Characteristics of Lower Natural Barrier (Continued)

Feature / Component	Characteristic	Type	Analysis Basis
SZ (Continued)	Saturated Zone Properties	Core	1.2.02.01.0A - Fractures (Included)
			1.2.02.02.0A - Faults (Included)
			1.3.01.00.0A - Climate Change (Included)
			1.4.01.01.0A - Climate Modification Increases Recharge (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.12.0A - Saturated Groundwater Flow in the Geosphere (Included)
			2.2.07.13.0A - Water-Conducting Features in the SZ (Included)
			2.2.08.08.0A - Matrix Diffusion in the SZ (Included)
			2.2.07.15.0A - Advection and Dispersion in the SZ (Included)
			2.2.08.09.0A - Sorption in the SZ (Included)
	Saturated Zone Transport	Core	1.2.02.01.0A - Fractures (Included)
			2.2.03.01.0A - Stratigraphy (Included)
			1.2.02.02.0A - Faults (Included)
			2.2.03.02.0A - Rock Properties of Host Rock and Other Units (Included)
			2.2.07.12.0A - Saturated Groundwater Flow in the Geosphere (Included)
			2.2.07.13.0A - Water-Conducting Features in the SZ (Included)
			2.2.08.08.0A - Matrix Diffusion in the SZ (Included)
			2.2.07.15.0A - Advection and Dispersion in the SZ (Included)
			2.2.08.09.0A - Sorption in the SZ (Included)

Source: Output DTN: MO0802ITWITABS.000.

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1]

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Subsurface Facilities	01-01	Repository Geographic & Geologic Location	The interface control mechanisms for the location of the subsurface facilities of the repository within the footprint of emplacement area boundary and the repository host horizon (RHH) within the lithostratigraphic detail are the Subsurface Facilities Layout Geographical Data IED(s) and Geotechnical and Thermal Parameters IEDs.	Yes	No
Subsurface Facilities	01-02	Repository Layout	The interface control mechanism for the general layout and configuration of the subsurface facilities, including shafts, portals, ramps, mains, emplacement drifts, observation drifts, and other subsurface features, and waste package nominal endpoint coordinates, elevations, and available drift lengths is the Subsurface Facilities Layout Geographical Data IED(s).	No	No
Subsurface Facilities	01-03	Repository Geologic Location	The interface control mechanism for the repository areas, emplacement area by geologic unit, fault intersection coordinates, and borehole locations is the Subsurface Facilities Geological Data IED.	No	No
Subsurface Facilities	01-04	Repository Elevation – Standoff from Water Table	The base of the emplacement drifts shall be located at least 120 m above the maximum elevation of the present-day water table. Note: Based on its current location, the maximum elevation of the present-day water table beneath the emplacement area is ~850 m above sea level. Thus the minimum elevation of the base of the emplacement drifts shall be 970 m above sea level.	Yes	Yes
Subsurface Facilities	01-05	Repository Standoff from Quaternary Fault	The emplacement drifts shall be located a minimum of 60 m from a Quaternary fault with potential for significant displacement.	No	No
Subsurface Facilities	01-06	Repository Elevation – Overburden Thickness	The overburden thickness (i.e., the distance from the top of each emplacement drift to the topographic surface) shall be a minimum of 200 m.	Yes	Yes
Subsurface Facilities	01-07	Repository Standoff from Perched Water	The emplacement drifts shall be located a minimum of 30 m from the top of the Tptpv2 (Topopah Spring Tuff Crystal-poor Vitric Zone) because perched water may occur at the base of the Topopah Spring Tuff Unit.	No	No
Subsurface Facilities	01-08	Orientation of Emplacement Drifts	The emplacement drifts will be nominally parallel. The design azimuth shall be the same for all emplacement drifts, and shall be within a range of 70° to 80°.	No	No
Subsurface Facilities	01-09	Excavation Methods	The repository ramps, access mains, exhaust mains, and emplacement drifts shall be constructed by tunnel boring machines (TBM). The starter tunnel to support each unique TBM advance shall be excavated by blasting or mechanical excavation methods.	No	No
Subsurface Facilities	01-10	Emplacement Drift Configuration	The emplacement drift excavations shall be circular in cross section with a nominal diameter of 5.5 m.	Yes	Yes
Subsurface Facilities	01-11	Emplacement Drift Gradient	The grade of the emplacement drift shall be nominally horizontal so that overall water drainage is directly into the rock to prevent water accumulation.	No	No
Subsurface Facilities	01-12	Non-Emplacement Opening Gradient	The repository non-emplacement openings shall provide a repository grade so overall water drainage and accumulation is away from emplacement areas.	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Subsurface Facilities	01-13	Emplacement Drift Spacing	The subsurface facility shall be designed to locate the emplacement drifts nominally 81 m apart to prevent thermal interaction between adjacent drifts and to allow drainage of thermally mobilized water within the rock pillars to percolate past the drifts.	No	No
Subsurface Facilities	01-14	Verification of Design Rock Properties	The emplacement openings shall provide for post-excavation investigations of each drift that will be conducted under the Performance Confirmation Program. The objective of post-excavation investigations is to verify that host rock properties are bounded by the rock properties described within the in situ observations and model assumptions used in postclosure analyses. Post-excavation investigations will include geologic mapping to confirm that fracture geometric variability and initial rock properties are within the model input parameter range used in rockfall calculations.	Yes	No
Subsurface Facilities	01-15	Design of Ground Support System	The interface control mechanisms for the design and materials used for ground support are the Subsurface Facilities Ground Support Configuration and Subsurface Facilities Committed Materials IEDs.	No	No
Subsurface Facilities	01-16	Air Circulation through Ground Support	The permanent ground support shall be perforated to allow air circulation between the host rock and the in-drift environment.	No	No
Subsurface Facilities	01-17	Emplacement Drift Ground Support	The unfailed emplacement drift ground support system shall prevent raveling or rockfall during preclosure in the emplacement drifts that could induce residual tensile stresses in the waste package above 257 MPa. In the event the ground support system fails, the waste packages that have come into contact with fallen rock or ground support materials shall be inspected for surface damage and remediated as required prior to closure.	No	No
Subsurface Facilities	01-18	Unheated Drift Length	As boundary conditions for the thermo-hydrologic model in the postclosure, in the event that access main and exhaust main drifts are backfilled, areas at both ends of the emplaced waste will be free of backfill. The two areas will each be a minimum of 15 m long and their combined length will total a minimum of 75 m. Note: Emplacement areas will not be backfilled (see Parameter 05-04).	No	No
Subsurface Facilities	01-19	Flood Protection	The portal and shaft collar locations shall be situated such that they can be protected from water inflow as a result of the probable maximum flood.	No	No
Subsurface Facilities	01-20	Repository Standoff from Paintbrush Nonwelded Hydrogeologic Unit	The minimum distance between the top of each emplacement drift and the base of the Paintbrush nonwelded hydrogeologic unit shall be 100 m.	Yes	Yes
Subsurface Facilities	01-21	Minimum Thickness of the Paintbrush Nonwelded Hydrogeologic Unit above the Repository	The minimum thickness of the Paintbrush nonwelded hydrogeologic unit above the repository shall be 10 m.	Yes	Yes

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Subsurface Facilities	01-22	Repository Standoff from Calico Hills Nonwelded Hydrogeologic Unit	The minimum distance between the base of each emplacement drift and the top of the Calico Hills nonwelded hydrogeologic unit shall be 60 m.	No	No
EBS In-Drift Configuration	02-01	As-Emplaced Waste Configuration	The interface control mechanism for the emplaced waste packages shall be the Emplacement Drift Configuration and Environment IED.	No	No
EBS In-Drift Configuration	02-02	As-Emplaced Waste Package-Drip Shield Configuration	The interface control mechanism for the minimum distance from top-of-waste-package to interior-height-of-drip-shield is the Emplacement Drift Configuration and Environment IED(s).	Yes	No
EBS In-Drift Configuration	02-03	Committed Materials	During construction of the emplacement drifts, and operation and closure of the repository, administrative controls will be imposed to prevent impact on waste isolation from materials used, lost, or left in the repository. These controls will be supported by technical evaluation. The following constraints will be imposed on the administrative control of TFMs, construction materials and committed materials: a) All material not technically evaluated and determined acceptable prior to the permanent closure of the repository will be removed from subsurface facilities prior to permanent closure. b) Committed materials that are proposed to remain in the underground repository following permanent closure period will be technically evaluated and determined acceptable prior to use. c) Administrative controls will include accounting and inspection, as appropriate to confirm that controls on the approved TFM quantities and compositions are met. d) Concrete dust generation shall be kept to a minimum through the use of surface coatings and / or the use of dust suppression and ventilation control during concrete installation and / or removal. e) Various IED(s) list materials which are intended to be present in the repository at closure, and which have been found to be acceptable by analysis. All tracers, fluids, and materials (TFMs) that may be used during construction, operation, or closure, will be controlled. An historical summarization of TFM quantities that have been approved for use is listed in the TFM IDD(s).	Yes	Yes
EBS In-Drift Configuration	02-04	Invert & EBS Components In Situ Stress & Thermal Response	The invert and EBS components shall be designed to accommodate at least a 10 mm displacement to account for potential in situ stress and thermal response.	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
EBS In-Drift Configuration	02-05	EBS Materials Interactions	EBS materials shall be inert relative to each other so that physical contact between EBS materials minimizes dissimilar material interaction mechanisms. The waste package outer corrosion barrier shall not contact EBS components other than the Alloy 22 support surfaces of the pallet.	No	No
EBS In-Drift Configuration	02-06	EBS Material Interactions – Copper	For the as-emplaced configuration, the drip shields and waste packages shall not contact any copper that may be present in other EBS components such as parts of the emplacement vehicle rail system. The total mass of elemental copper per meter of emplacement drift shall be less than 5.0 kg/m.	Yes	No
EBS In-Drift Configuration	02-07	Emplacement Drift Invert Function	The emplacement drift invert (ballast) shall provide a nominally level surface that supports the drip shield, waste package, and waste package emplacement pallet for static loads and that limits degradation associated with ground motion (but excluding faulting displacements) after closure of the repository.	No	No
EBS In-Drift Configuration	02-08	Invert Materials	a) The interface control mechanism for the components and materials used in the invert and for the gradation and placement of the invert ballast material is the Emplacement Drift Invert IED(s). b) The invert material will be carbon steel and crushed tuff. The crushed tuff shall have properties consistent with the repository host rock excavated by mechanical means.	Yes	No
EBS In-Drift Configuration	02-10	Emplacement Drift Invert Configuration	The interface control mechanism for the general configuration, plan, and details of the emplacement drift invert is the Emplacement Drift Invert IED.	No	No
Waste Package	03-01	Waste Package Dimensions & Component Masses	The interface control mechanism for the waste package dimensions and component masses is the Waste Package Configuration IED.	No	No
Waste Package	03-02	Waste Package Quantities	The interface control mechanism for the waste packages in the LA-design inventory, including quantities, dimensions, materials, and characteristics, is the Waste Package Configuration IED(s).	Yes	No
Waste Package	03-03	Waste Package Outer Barrier	The waste package outer barrier shall be comprised of Alloy 22 with a minimum thickness of 25 mm for codisposal, naval, and TAD waste packages. Note: See Parameter 03-19, Waste Package Outer Barrier Material Specifications for Alloy 22 material composition.	Yes	Yes
Waste Package	03-04	Waste Package Radial Gap	The difference between the waste package inner vessel outer diameter and the outer corrosion barrier inner diameter shall be a minimum of 2 mm and a maximum of 10 mm for the as fabricated package.	No	No
Waste Package	03-05	Waste Package Longitudinal Gap	The difference between the inner vessel overall length and the outer corrosion barrier cavity length, from the top surface of the interface ring to the bottom surface of the top lid, shall be a minimum of 30 mm.	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Waste Package	03-06	Waste Package Internal Pressurization	The waste package shall be designed to accommodate internal pressurization of the waste package including effects of a high temperature of 350°C and fuel rod gas release.	No	No
Waste Package	03-07	Waste Package Corrosion Allowance	For postclosure mechanical calculations and analysis, a corrosion allowance of at least 2 mm per side shall be accounted for on exposed waste package surfaces. Calculations will be performed using mechanical properties at 150°C or greater.	Yes	No
Waste Package	03-08	Seismic Design of Waste Package	The interface control mechanism for the seismic design spectra, time histories, and ground accelerations for the subsurface facilities is the Seismic Data IED.	Yes	No
Waste Package	03-09	Waste Package Worst-Case Dose Rate	The waste package containing the TAD canister with 21 PWR fuel assemblies shall represent the worst-case dose rate (80 GWd/MTU burnup, 5% U-235 enrichment and 5 years decay).	No	No
Waste Package	03-10	Waste Package Design Basis Bounding Dose Rate	The interface control mechanism for the design basis bounding dose rate calculations for waste packages and representative neutron flux is the Waste Package Radiation Characteristics IED.	No	No
Waste Package	03-11	Waste Package Decay Heat	The interface control mechanisms for the postclosure design basis waste package decay heat are the Waste Package Decay Heat Generation IEDs.	No	No
Waste Package	03-12	Waste Package Fabrication	The waste package outer corrosion barrier cylinder shall be fabricated from no more than 3 sections with longitudinal welds offset. The waste package will be inspected and evaluated per applicable criteria, e.g., Parameter 03-18, at the fabricator location and upon receipt at the repository location.	Yes	Yes
Waste Package	03-13	Waste Package Fabrication Weld Inspections	The waste package outer corrosion barrier fabrication welds shall be nondestructively examined by means of radiographic examination (RT) and ultrasonic testing (UT) for flaws equal to or greater than 1/16 inch. Outer corrosion barrier fabrication welds shall also be examined using liquid penetrant per the applicable specification.	Yes	Yes
Waste Package	03-14	Waste Package Welding Materials	The waste package fabrication welds shall be conducted in accordance with standard nuclear industry requirements.	Yes	Yes
Waste Package	03-15	Waste Package Fabrication Welding Flaws	The welding techniques for the fabrication welds shall be constrained to GMAW (gas metal arc welding) except for short-circuiting mode, and automated GTAW (gas tungsten arc welding) for Alloy 22 (UNS N06022) material, limited to <45 kJ/in. Welding flaws 1/16 inch and greater will be repaired for the outer corrosion barrier in accordance with written procedures that have been accepted by the design organization prior to their usage.	Yes	Yes

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Waste Package	03-16	Waste Package Annealing	a) After fabrication and before inserting the inner vessel, the waste package outer corrosion barrier shall be solution annealed and quenched. b) The minimum time for solution annealing will be 20 minutes at 2,050 °F (1,121°C) + 50 °F (28°C) / -0 °F (0°C). c) The waste package shall be quenched at a rate greater than 275 °F (153°C) per minute to below 700 °F (371°C). d) The annealing-induced oxide film shall be removed by means of electrochemical polishing or grit blasting. e) After solution annealing and quenching, the waste package surface temperature will be kept below 300°C to eliminate postclosure issues (i.e., phase stability), except for short-term exposure (closure-weld, etc.).	Yes	Yes
Waste Package	03-17	Waste Package Closure	a) The Alloy 22 outer lid will be sealed utilizing the gas tungsten arc weld (GTAW) process, limited to <45 kJ/in. The weld mass shall be less than 0.104 lb/in (18.5 g/cm) of weld. b) The Alloy 22 outer lid weld will be nondestructively examined using VT, ET, and UT. Flaws greater than 1/16 inch (1.6 mm) shall be repaired. c) The Alloy 22 outer lid weld will be stress mitigated using low-plasticity burnishing to a compressive depth of at least 3 mm. d) Process control to ensure there has been adequate stress mitigation on the welds will be performed. Following the stress mitigation, the final closure weld will be reexamined using VT, ET, and UT.	Yes	Yes
Waste Package	03-18	Waste Package Surface Marring Prior to Emplacement	The waste package shall be certified as suitable for emplacement by process control and/or inspection to ensure surface marring is acceptable per derived internal constraint. The surface marring constraints are: The damage to the waste package corrosion barrier that displaces material (i.e. scratches) shall be limited to 1/16 inch (1.6 mm) in depth. Modifications to the waste package corrosion barrier that deform the surface, but do not remove material (i.e. dents), shall not leave residual tensile stresses greater than 257 MPa.	Yes	Yes
Waste Package	03-19	Waste Package Outer Barrier Material Specifications	The waste package Alloy 22 will be manufactured to ASTM B575-99a [DIRS 147465] with the additional more restrictive, elemental and chemical composition allowable specifications: (a) Cr = 20.0 to 21.4%, (b) Mo = 12.5 to 13.5%, (c) W = 2.5 to 3.0%, and (d) Fe = 2.0 to 4.5%.	Yes	Yes
Waste Package	03-20	Materials Contacting the Waste Package	After fabrication final cleaning, the waste package shall be prepared for shipment. Materials or objects contacting the waste package outer surfaces during transportation, loading, and emplacement will be evaluated to ensure that any physical degradation and contamination are within allowable limits.	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Waste Package	03-21	Waste Package Handling	The waste package shall be handled in a controlled manner during fabrication, handling, transport, storage, emplacement, installation, operation, and closure activities to minimize damage; surface contamination; and exposure to adverse substances.	Yes	Yes
Waste Package	03-22	Waste Package Handling & Emplacement	Waste package handling and emplacement activities shall be monitored through equipment with resolution capable of detecting waste package damage. An operator and an independent checker shall perform the operations. Records demonstrating compliance shall be maintained.	No	No
Waste Package	03-23	Waste Package Surface Finish	The waste package surface finish shall be specified to be at least 125 roughness as defined in ASME B46.1 [DIRS 166013].	Yes	Yes
Waste Package	03-24	Waste Package Surface Damage Prior to Closure	The emplacement drift ground support system shall be inspected prior to drip shield installation. Waste packages that have come in contact with fallen rock or ground support materials will be inspected to ensure the damage to the waste package corrosion barrier that displace material (i.e. scratches), shall be limited to 1.6 mm (1/16 in) in depth. Modifications to the waste package corrosion barrier that deform the surface, but do not remove material (i.e. dents), shall not leave residual tensile stresses greater than 257 MPa.	Yes	Yes
Waste Package	03-26	Waste Package Moisture Removal & Inerting	All waste packages shall be vacuum dried and backfilled with helium in a manner consistent with that described in *Standard Review Plan for Dry Cask Storage Systems* (NUREG-1536) (NRC 1997 [DIRS 101903], Section 8.V.1).	Yes	Yes
Waste Form & TAD Canister	04-01	Loading of Waste Forms	To minimize waste form damage, waste package and TAD canister-loading activities shall be performed and monitored in accordance with industry standard practices including an operator and an independent checker. Records demonstrating compliance shall be maintained.	No	No
Waste Form & TAD Canister	04-02	Handling of Bare SNF	Bare SNF shall be handled in a standard industry fashion to limit damage and prevent unzipping of fuel rod cladding.	No	No
Waste Form & TAD Canister	04-03	Waste Form CSNF Fuel Rod Maximum Burnup Limit	The CSNF fuel rod or assembly maximum burnup shall be less than 80 GWd/MTU (this is bounded by the PWR burnup).	No	No
Waste Form & TAD Canister	04-04	Waste Form Moisture Removal & Inerting	All TAD canisters shall be vacuum dried and backfilled with helium in a manner consistent with that described in *Standard Review Plan for Dry Cask Storage Systems* (NUREG-1536) (NRC 1997 [DIRS 101903], Section 8.V.1). [Note: For postclosure moisture removal purposes, NUREG-1567 (NRC 2007 [DIRS 149756], Section 9.5.4.1) is equivalent to NUREG-1536 and is therefore acceptable.][2]	Yes	Yes
Waste Form & TAD Canister	04-05	Cladding Temperature Limit	The maximum temperature of the CSNF cladding upon emplacement shall not exceed 350°C (to prevent damage from creep or hydride reorientation).	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Waste Form & TAD Canister	04-06	Maximum Temperature of HLW Glass Canisters – Waste Form	The maximum HLW glass temperature shall be less than 400°C.	No	No
Waste Form & TAD Canister	04-07	Waste Package Capacities	Waste package capacities shall be as follows: a) TAD-Bearing Waste Package: 1 CSNF TAD canister. b) Naval Waste Packages: 1 NSNF canister. c) 2-MCO/2-DHLW Waste Package: 2 N-Reactor MCOs and 2 HLW glass canisters (short loading allowed). d) 5-HLW/DOE SNF Co-disposal Waste Packages: Either: 5 HLW glass canisters (including no more than 1 LaBS glass canister) and 1 DSNF canister in the center position (short loading allowed), or: 1 24-inch DSNF canister and 4 HLW canisters (center position empty and no LaBS glass canisters) (short loading allowed).	Yes	Yes
Waste Form & TAD Canister	04-08	Handling of Waste Forms	Waste form handling operations shall be performed in a standard industry fashion to limit damage. An operator and an independent checker shall perform the operations. Records demonstrating compliance shall be maintained.	No	No
Waste Form & TAD Canister	04-09	Waste Package & TAD Canister Excluded Materials	Materials that have not been previously analyzed and included in the Waste Package Configuration IEDs shall not be placed in the waste package, or in the TAD canister that will be placed into the waste package.	Yes	Yes
Emplacement & Retrieval	05-01	Waste Package Handling & Emplacement	Waste package handling and emplacement activities shall be monitored through appropriate equipment. An operator and an independent inspector shall verify proper waste package installation. Records demonstrating compliance shall be maintained.	No	No
Emplacement & Retrieval	05-02	Waste Package Spacing	Adjacent waste packages in a given emplacement drift shall be emplaced 0.1 m (nominal) apart, from the top surface of the upper sleeve of one waste package to the bottom surface of the lower sleeve of the adjacent waste package.	Yes	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Emplacement & Retrieval	05-03	Waste Package Thermal Limits	The waste package emplacement shall be within an envelope such that the emplacement of waste packages does not exceed the other relevant thermal limits of mid-pillar temperature, drift wall temperature, waste package temperature, and cladding temperature. In addition, the local-average line-load (over any 7 waste package segment) in the emplaced repository will not exceed 2.0 kW/m, and no waste package shall exceed thermal output of 18 kW. Finally, the calculated Thermal Energy Density of any seven adjacent as-emplaced waste packages shall not exceed 96°C at the mid-pillar calculated using mean host-rock thermal properties and representative saturation levels for wet and dry conditions, as described in the Geotechnical and Thermal Parameters IED(s). [Note: The thermal loading limits for the naval SNF waste packages are lower than the thermal limits for commercial SNF. These limits are (BSC 2007 [DIRS 182131], Section 8.2.1.5): • Maximum emplacement thermal power of 11.8 kW for waste packages emplaced on either side of a naval SNF waste package • Maximum emplacement thermal line load limit of 1.45 kW/m for any seven-waste-package segment containing a naval SNF waste package.][3]	Yes	Yes
Emplacement & Retrieval	05-04	No Backfill in Emplacement Drifts	Engineered backfill shall not be present in the space between the drip shield and the drift wall.	No	No
Subsurface Ventilation	06-01	Duration of Ventilation Period	The duration of the ventilation period shall be a minimum of 50 years after final emplacement.	No	No
Subsurface Ventilation	06-02	Drift Wall Temperature	The maximum preclosure emplacement drift wall temperature shall not exceed 200°C to avoid possible adverse conditions (e.g. mineralogical transitions, rock weakening etc.).	No	No
Subsurface Ventilation	06-03	Waste Package Temperature Limit	The waste package surface temperature shall be kept below 300°C for the first 500 years and below 200°C for the next 9,500 years to eliminate postclosure issues (i.e. phase stability). Note: Compliance with this constraint after repository permanent closure is demonstrated in postclosure analyses (only). Parameters 05-03, 06-01, and 06-06 support compliance with this constraint during both the preclosure and postclosure periods.	Yes	Yes
Subsurface Ventilation	06-04	Cladding Temperature Limit -- Ventilation	The maximum temperature of the CSNF cladding upon emplacement shall not exceed 350°C (to prevent damage from creep or hydride reorientation).	No	No
Subsurface Ventilation	06-05	Maximum Temperature of HLW Glass Canisters	The maximum HLW glass temperature shall be less than 400°C.	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Subsurface Ventilation	06-06	Average Airflow Rate for Preclosure Ventilation of Emplacement Drifts	During the preclosure phase, the nominal inlet airflow rate per emplacement drift shall be 15 m^3/sec. The range of airflow rate in a given drift shall be 15 m^3/sec ± 2 m^3/sec, based on integrated ventilation efficiency and drift length.	No	No
Drip Shield	07-01	Drip Shield Design	The interface control mechanism for the drip shields dimensions and characteristics is the Interlocking Drip Shield IED.	Yes	No
Drip Shield	07-02	Drip Shield Design & Installation	The drip shield shall be designed to interlock and overlap in a manner that prevents a liquid drip path from above the drip shield to the waste package. The drip shield handling and emplacement activities shall be monitored through appropriate equipment. An operator and an independent inspector shall verify proper drip shield installation. Records demonstrating compliance shall be maintained.	Yes	Yes
Drip Shield	07-03	Drip Shield Corrosion Allowance	For mechanical calculations and analysis, a corrosion allowance of at least 1mm per side shall be accounted for on all drip shield surfaces. Calculations will be performed using mechanical properties at 150°C or greater.	Yes	No
Drip Shield	07-04	Drip Shield Materials & Thicknesses	The drip shield shall be constructed of Titanium Grade 7, with a minimum thickness of 15 mm. The drip shield structural material shall be manufactured of Titanium Grade 29.	Yes	Yes
Drip Shield	07-07	EBS Drip Shield / Emplacement Drift Materials Interactions	Alloy 22 bases shall be attached to the drip shield to preclude titanium contact with the invert (including transport equipment rails).	Yes	Yes
Drip Shield	07-08	Drip Shield Seismic Performance	The interface control mechanism for the drip shield design is the Interlocking Drip Shield IED such that during a seismic event it resists separation through failure of the DSC Connector Guides, the DSC Left/Right Support Beams, and the Left/Right Support Beam Connectors. Note: Compliance with the postclosure performance aspects of the drip shield within this constraint is demonstrated in postclosure analyses (only).	Yes	No
Drip Shield	07-09	Drip Shield Fabrication	The drip shield shall be fabricated in accordance with standard nuclear industry practices, including material control, welding, weld flaw detection and repair and heat treatment.	Yes	Yes
Drip Shield	07-10	Drip Shield Fabrication Weld Inspections	The drip shield full penetration fabrication welds shall be nondestructively examined by visual (VT), liquid penetrant (PT), and ultrasonic testing (UT), for flaws. Fillet welds shall be inspected by means of PT and VT for flaws. All flaws larger than code standards shall be repaired.	Yes	Yes
Drip Shield	07-11	Drip Shield Fabrication Welding Flaws	The welding techniques for the fabrication welds shall be constrained to GMAW (gas metal arc welding) except for short-circuiting mode, and automated GTAW (gas tungsten arc welding). Welding flaws will be repaired in accordance with written procedures that have been accepted by the design organization prior to their usage.	Yes	Yes

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Drip Shield	07-12	Drip Shield Fabrication Weld Materials	All drip-shield welding shall be conducted in accordance with standard nuclear industry practices. For Ti-7 (Titanium Grade 7) to Ti-7 welds, Ti-7 weld filler material shall be used. For Ti-29 (Titanium Grade 29) to Ti-29 welds, Ti-29 shall be used. For Ti-7 to Ti-29 welds Ti-28 weld filler shall be used.	Yes	Yes
Drip Shield	07-13	Drip Shield Heat Treatment	After fabrication the drip shield assembly and lifting feature assemblies shall be stress-relieved. After completion of all required work except for the final machining, the drip shield assembly and lifting feature assemblies shall be furnace heated for stress relief at 1100 °F +/- 50 °F for a minimum of 2 hours. To prevent pickup of hydrogen, a slightly oxidizing atmosphere shall be used; air-cooling is allowed.	Yes	Yes
Drip Shield	07-14	Drip Shield Handling	a) The drip shield shall be handled in accordance with standard nuclear industry practices to minimize damage, surface contamination, exposure to adverse substances, and impacts. b) Drip shield installation shall be controlled and monitored through appropriate equipment to minimize possible waste package/drip shield damage and/or misinstallation. Installation shall include the use of equipment with an alarm, an operator, and an independent checker. Records demonstrating compliance shall be maintained.	Yes	Yes
Drip Shield	07-15	Drip Shield Thermal Expansion Constraint	To account for volume increase of corrosion products the drip shield shall not be constrained laterally or longitudinally, or rigidly mounted to the invert. Drip shield connectors shall be designed to allow thermal expansion without binding to 300°C.	No	No
Drip Shield	07-16	As-emplaced Waste Configuration	The interface control mechanism for the minimum distance from top-of-waste-package to interior-height-of-drip-shield is the Emplacement Drift Configuration and Environment IED(s).	No	No
Emplacement Pallet	08-01	Emplacement Pallet Design	The interface control mechanism for the emplacement pallet dimensions and characteristics is the Emplacement Pallet IED.	No	No
Emplacement Pallet	08-02	Emplacement Pallet Function	For the design static load, the emplacement pallet shall maintain the waste package emplacement nominal position for at least 300 years, and maintain a nominally horizontal waste package emplacement for 10,000 years.	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Emplacement Pallet	08-03	Emplacement Pallet Fabrication & Corrosion Allowance	a) The interface control mechanism for the emplacement pallet material properties is the Emplacement Pallet IED b) The emplacement pallet shall be fabricated of Alloy 22 plates and square stainless steel tubes c) The contacts between the waste package and emplacement pallet shall be Alloy 22. d) The corrosion allowance for the Alloy 22 components shall be at least 2 mm. e) The corrosion allowance for the stainless steel components shall be at least 2 mm. f) The mechanical properties at 150°C or higher shall be used for postclosure analysis.	No	No
Emplacement Pallet	08-04	EBS Materials Interactions – Emplacement Pallet Function	EBS materials shall be inert relative to each other so that physical contact between EBS materials minimizes dissimilar material interaction mechanisms. The Emplacement Pallet shall be designed such that, for the nominal scenario (e.g. not seismic or igneous), the waste package outer corrosion barrier shall not contact EBS components other than the Alloy 22 support surfaces of the pallet.	No	No
Emplacement Pallet	08-05	Waste Package & Emplacement Pallet Static Stresses	For the nominal scenario emplacement configuration, the tensile stresses imposed on the Alloy 22 components of both the waste package and the emplacement pallet shall be less than 257 MPa (the approximate stress corrosion cracking threshold for Alloy 22).	No	No
Closure	09-01	Closure of Shafts & Ramps	Closure of the shafts shall include backfilling for the entire depth of the opening. Closure of ramps shall include backfilling along the entire length of the opening.	No	No
Closure	09-03	Closure of Boreholes	Site investigation boreholes within or near the footprint of the repository block will be backfilled with material compatible with the host rock and plugged.	No	No

Table 7-5. Summary of Classification of Control Parameter Characteristics by Engineering Subsystem Categorization[1] (Continued)

Category	Number	Control Characteristic	Derived Internal Constraint	ITBC	ITWI Relevant
Closure	09-04	Reclamation of Land Disturbed by Repository	Lands disturbed by the repository shall be reclaimed following the *Reclamation Implementation Plan* (YMP 2001 [DIRS 154386], Section 1) as established in *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 2002 [DIRS 155970], Sections 2.1.2.4, 4.1.3.2, 4.1.3.3, and 4.1.4.4) to ensure that there are no preclosure disturbances that will impact postclosure performance.	Yes	Yes

Source: Output DTN: MO0802ITWIBARR.000.

Modified from BSC 2008 [DIRS 183627], Table 1.

NOTES: [1] Additional constraints beyond the control parameters listed are placed on some features or SSCs. Table 7-1 lists these additional controlling mechanisms as control parameter characteristics for the features or SSCs where they apply. These include: the *Transportation, Aging, and Disposal Canister System Performance Specification* (DOE 2007 [DIRS 181403]), and the *Waste Acceptance System Requirements Document* (DOE 2007 [DIRS 169992]).

[2] NUREG-1536 and NUREG-1567 are equivalent in their requirements for moisture removal and is therefore acceptable.

[3] The thermal loading limits for the naval SNF waste packages are lower than the thermal limits for commercial SNF. These limits are (BSC 2007 [DIRS 182131], Section 8.2.1.5):

- Maximum emplacement thermal power of 11.8 kW for waste packages emplaced on either side of a naval SNF waste package
- Maximum emplacement thermal line load limit of 1.45 kW/m for any seven-waste-package segment containing a naval SNF waste package.

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8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

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8.3 PRODUCT OUTPUT, LISTED BY DATA TRACKING NUMBER

MO0801TABLITWI.000 ITWI FEATURES, submitted 1/31/2008

MO0802ITWIBARR.000. Classification of Control Parameter Characteristics. Submittal date: 2/22/2008.

MO0802ITWITABS.000. ITBC Features/Components and ITBC Parameter Characteristics. Submittal date: 2/22/2008.

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APPENDIX A
ITBC EVALUATION AND PARAMETER DESCRIPTION FOR THE BARRIERS

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Topography and Surficial Soils	1.2.02.01.0A Fractures **Included**	The hydrologic characteristics of fractured bedrock below the surficial soils are significant in affecting the amount of net infiltration into the repository, as the fractures and fracture properties affect the rate of water movement below the soil–bedrock contact, especially in areas of thin soils. Uncertainty in the fracture hydrologic characteristics, in particular fracture permeability and fracture filling, has been incorporated into the net infiltration model. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.01.0A	Yes	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	**ITBC:** Repository Geographic and Geologic Location
Topography and Surficial Soils	1.2.07.01.0A Erosion / Denudation **Excluded**	Erosion and weathering processes occur in the high, steep, and relatively wet uplands. The rate of large-scale denudation processes due to various surface material-loss processes over the next 10,000 years is expected to be less than 10 cm, which is within the range of existing surface irregularities (or surface roughness) and is negligible compared to the overburden thickness of 200 m above the repository. Although erosion can affect soil depth and local net infiltration, such increase will have an insignificant effect on seepage, as a result of the damping and attenuation of percolation fluxes by the Paintbrush nonwelded hydrogeologic unit. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.07.01.0A	No	**Non-ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	**Non-ITBC:** Reclamation of Lands Disturbed by Repository Repository Elevation below the Surface Repository Geographic and Geologic Location
Topography and Surficial Soils	1.2.07.02.0A Deposition **Excluded**	Deposition will not cause significant changes in surficial topography and morphology and therefore will not impact net infiltration except in areas with shallow soils, where deposition will lead to a reduction in localized net infiltration. In addition, although a dominant process in Fortymile Wash, deposition has little effect on recharge to the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.07.02.0A	No	**Non-ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	**Non-ITBC:** Reclamation of Lands Disturbed by Repository Repository Elevation below the Surface Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Topography and Surficial Soils	1.3.01.00.0A Climate Change **Included**	Climate change affects the amount and distribution of water that infiltrates into the surficial soils and underlying bedrock. Future climate analyses indicate that the climate at Yucca Mountain will evolve to a warmer and wetter monsoon climate followed by a cooler, wetter glacial-transition climate within the first 10,000 years after disposal. The effects of climate change on groundwater flow in the unsaturated zone above the repository are incorporated into the TSPA using time-dependent infiltration rates as a boundary condition to the Site-Scale UZ Flow Model for the first 10,000 years and for the post-10,000-year period, using the distribution for the deep percolation rate that implements the requirements of the proposed rule. The climate change effects the amount of water available for infiltration into the UZ. **FEP Source:** SNL 2008 [DIRS 183041] – 1.3.01.00.0A	Yes	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	**ITBC:** Repository Geographic and Geologic Location
Topography and Surficial Soils	1.4.01.01.0A Climate Modification Increases Recharge **Included**	Future climate change significantly affects the amount and timing of precipitation and temperature, which in turn affects net infiltration into surficial soils. The net effect of climate change after repository closure is to increase the amount of water that precipitates and can infiltrate through the surficial soils, eventually percolating through the unsaturated zone as recharge to the water table. The climate effect on net infiltration has been directly included in the assessment of performance and barrier capability by developing infiltration scenarios for each of three climates for the first 10,000 years after closure: present-day, monsoon, and glacial transition. After that and through the period of geological stability (as proposed by 40 CFR 197 [DIRS 177357]), the climate modification on percolation and recharge is incorporated into the performance assessment using the distribution of deep percolation rate as specified in the proposed rule. **FEP Source:** SNL 2008 [DIRS 183041] – 1.4.01.01.0A	Yes	**ITBC:** Infiltration and Seepage **Non-ITBC:** Surface Soil Properties (including vegetation)	**ITBC:** Repository Elevation below the Surface Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Topography and Surficial Soils	2.2.03.02.0A Rock Properties of Host Rock and other Units **Included**	The hydrologic characteristics (e.g., permeability, porosity, capillarity, storage capacity) of the surficial soils and shallow bedrock above the repository are significant in affecting the amount of net infiltration following a precipitation event. The characteristics of the surficial soils also affect the soil retention and the time infiltrating water takes to pass below the root zone to become net infiltration (i.e., where it is not subject to further evapotranspiration processes). The hydrologic characteristics of the surface soils and shallow bedrock at Yucca Mountain, including associated uncertainty, most notably the permeability, are included in the assessment of the net infiltration and determined to be ITBC. **FEP Source:** SNL 2008 [DIRS 183041] — 2.2.03.02.0A	Yes	**ITBC:** Infiltration and Seepage Surface Soil Properties (including vegetation)	**None**
Topography and Surficial Soils	2.2.06.04.0A Effects of Subsidence **Excluded**	THM modeling showed that subsidence distances would be indistinguishable from natural variations in the ground surface, and are too small to affect run off or infiltration, or to create impoundments. In addition, corroborative mining data indicate no subsidence for the size of the drift opening relative to drift spacing. Stress relieved enhancements to fracture permeability and capillarity due to the excavation have been included in the uncertainty of permeability and capillarity used in the seepage models. The changes to fracture characteristics around emplacement drifts due to stress relief have been found to be too small to cause adverse effects on seepage. Subsidence induced stress effects on UZ flow are negligible. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.04.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone Properties	**Non-ITBC:** Emplacement Drift Diameter Emplacement Drift Spacing Repository Layout Repository Elevation below the Surface Repository Geographic and Geologic Location
Topography and Surficial Soils	2.2.07.01.0A Locally Saturated flow at Bedrock/ Alluvium Contact **Excluded**	The possibility of locally saturated flow conditions at the bedrock–alluvium contact has been excluded in the assessment of net infiltration for two reasons. First, most of the infiltration model domain is characterized by relatively low slope, which corresponds to a small lateral hydraulic gradient. Second, bulk bedrock saturated hydraulic conductivity values are generally higher than the saturated hydraulic conductivity values in the overlying soil and, therefore, once water reaches the soil–bedrock interface, it would tend to enter bedrock instead of flowing laterally along the interface. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.01.0A	No	**Non-ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Topography and Surficial Soils	2.2.07.08.0A Fracture Flow in the UZ **Included**	The hydrologic characteristics of the surficial soils above the repository are significant in affecting the amount of net infiltration following a precipitation event. Fracture flow in the bedrock beneath the surficial soils, affects the rate of water movement below the soil and bedrock contact, especially in areas of thin soils. **FEP Source:** SNL 2008 [DIRS 183041] — 2.2.07.08.0A	Yes	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	**ITBC:** Repository Geographic and Geologic Location
Topography and Surficial Soils	2.3.01.00.0A Topography and Morphology **Included**	Surficial topography significantly affects the amount of runoff of precipitation events. The topography and morphology of the ground surface above the repository are such that a portion of the precipitation that falls at Yucca Mountain is unavailable for infiltration due to surface runoff. Generally, the steeper slopes have more runoff and less infiltration than the more gentle slopes. Variability in slope angles and orientation and permeability of surficial rock and soil has been included in the infiltration model. **FEP Source:** SNL 2008 [DIRS 183041] – 2.3.01.00.0A	Yes	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	**ITBC:** Repository Geographic and Geologic Location Reclamation of Lands Disturbed by Repository
Topography and Surficial Soils	2.3.11.01.0A Precipitation **Included**	Precipitation is important in the evaluation of the net infiltration into the bedrock below the surficial soils. The temporal and spatial distribution of precipitation affects the amount of water available to potentially run off, evaporate, transpire, or infiltrate. Given the semiarid climate at Yucca Mountain, there are long periods of time when there is a net evapotranspiration from the surficial soils, interrupted by short-duration precipitation events that can result in some infiltration. Generally, greater infiltration occurs when precipitation occurs in cooler months when there is less potential for evapotranspiration. Net infiltration under present-day and future climates during the first 10,000 years after repository closure is calculated in the infiltration model. Historical precipitation cycles were used in the development of the future climate states. For the post-10,000-year period up to geologic stability (as proposed by 40 CFR 197 [DIRS 177357]), the precipitation effect is implicitly incorporated into the performance assessment by using the distribution of deep percolation rate as specified in the proposed rule. **FEP Source:** SNL 2008 [DIRS 183041] – 2.3.11.01.0A	Yes	**ITBC:** Infiltration and Seepage **Non-ITBC:** Surface Soil Properties (including vegetation)	**ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Topography and Surficial Soils	2.3.11.02.0A Surface Runoff and Evapotranspiration **Included**	Surface runoff may redistribute precipitation to areas away from the repository footprint where it may infiltrate. Surface water runoff and evapotranspiration are components in the water balance together with precipitation, infiltration, and change in storage. Surface runoff may produce erosion and could result in increased recharge through the washes and impoundments in low-lying areas. Both of these processes are included in the infiltration model for the first 10,000 years following repository closure. For the post-10,000-year period up to geologic stability, their effects are implicitly incorporated into the performance assessment by using the distribution of deep percolation rate as specified in the proposed rule. **FEP Source:** SNL 2008 [DIRS 183041] – 2.3.11.02.0A	Yes	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	**ITBC:** Repository Geographic and Geologic Location
Topography and Surficial Soils	2.3.11.03.0A Infiltration and Recharge **Included**	Infiltration is the net result of all surficial processes related to the availability of water. These processes, include the effects of seasonal and climate variations, climate change, surface-water runoff, evapotranspiration. These processes result in a spatial distribution of water available to percolate through the unsaturated zone beneath the surficial soils as infiltration. Uncertainty in infiltration is a result of uncertainty in soil and rock characteristics, precipitation, and surface topography. The rate of net infiltration and its associated uncertainty are evaluated using the infiltration model for the first 10,000 years following repository closure. For the post-10,000-year period up to geologic stability, the effects of infiltration are implicitly incorporated into the performance assessment by using the distribution of deep percolation rate as specified in the proposed rule 40 CFR 197 [DIRS 177357]. **FEP Source:** SNL 2008 [DIRS 183041] – 2.3.11.03.0A	Yes	**ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage	**ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	1.1.01.01.0A Open Site Investigation Boreholes **Excluded**	Existing open site investigation boreholes are expected to be backfilled and plugged to the upper 10 ft with cement according to NAC 534.4371 [DIRS 151873], and any boreholes that are found to intercept waste emplacement drifts have additional plugging requirements. Open boreholes will not contribute significantly to infiltration due to their small area relative to the footprint area. Based on the subsurface design layout, **None** of the 15 boreholes in or near the repository block will intersect emplacement drifts. Water entering boreholes will continue to flow through the boreholes to the water table, bypassing waste emplacement drifts. Therefore these boreholes will not provide enhanced pathways for flow and transport because their cross-sectional area available to intercept lateral flow is negligible compared to that of fractures and faults present in the unsaturated zone. Where such boreholes intersect perched water, radionuclide transport by perched water flowing through boreholes is not expected to be significant because overall transport is dominated by transport to the perched water zones instead of transport from these zones to the water table. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.01.01.0A	No	**Non-ITBC:** Infiltration and Seepage Seepage Water properties Seals and Backfill Materials, Properties, and Configuration	**Non-ITBC:** Closure of Boreholes Reclamation of Lands Disturbed by Repository
Unsaturated Zone above the Repository	1.1.01.01.0B Influx through Holes Drilled in Drift Wall or Crown **Excluded**	Existing holes drilled into the drift wall or crown (e.g., for rock bolts) have an insignificant effect on flow properties around the emplacement drift and the likelihood for initiating seepage. A sensitivity study of the Seepage Model for Performance Assessment also found both grouted and ungrouted holes to have only an insignificant effect on enhancing seepage. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.01.01.0B	No	**Non-ITBC:** Properties of the Host Rock Unit	**Non-ITBC:** Design of Ground Support System Verification of Design Rock Properties

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	1.2.02.01.0A Fractures **Included**	Above the repository, the unsaturated zone consists of a network of fractures through which the infiltrated water flows principally by gravity. Because of their importance to flow in the unsaturated zone and seepage into emplacement drifts (see FEP 2.2.07.08.0A Fracture Flow in the UZ), fractures are incorporated into both the Site-Scale UZ Flow Model and the Drift Seepage Model. The Site-Scale UZ Flow Model uses a dual continuum approach, whereas the Drift Seepage Model uses the single fracture continuum approach for ambient seepage evaluations and the dual continuum approach for thermal seepage analyses. Fracture continuum properties such as permeability and van Genuchten α are derived from model calibration to test data, and their associated uncertainties are evaluated with the flow and seepage models. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.01.0A	Yes	**ITBC:** Unsaturated Zone Properties Infiltration and Seepage	**ITBC:** Repository Geographic and Geologic Location Repository Elevation below the Surface
Unsaturated Zone above the Repository	1.2.02.02.0A Faults **Included**	The series of north-striking normal faults tilted eastward and displaced hundreds of meters, predominantly down and to the west generally can serve as localized fast flow conduits for water flow that has been diverted laterally due to the presence of low permeability regions. As a result, during episodic infiltration events, transient water flow may occur within faults in the unsaturated zone above the repository. For the mean glacial-transition climate, the fraction of percolation flux through faults over the entire unsaturated zone model domain increases from 3.75% at the base of the TCw, to 24.27% at the repository horizon. Within the repository footprint, however, flow through faults accounts for 1.42% at the base of the TCw, and 1.36% at the repository horizon. Therefore, major faults are incorporated into the Site-Scale UZ Flow Model because they have the potential to significantly affect the flow processes in the unsaturated zone. However, within the repository footprint and above the level of the repository, faults do not seem to have a significant effect on water. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.02.0A	No	**Non-ITBC:** Interpretation of Fault Displacement Unsaturated Zone Properties Infiltration and Seepage	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation below the Surface Repository Standoff from Quaternary Fault

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	1.2.04.02.0A Igneous Activity Changes Rock Properties **Excluded**	Studies of natural analogue sites show that the effect of unlikely intrusive igneous events is generally to alter the properties in the immediate vicinity (a few meters) from the intrusive sill or dike. These changes (which may be increases or decreases in permeability and porosity) are of limited spatial extent. In addition, because of their geometrical similarity and because of the limited lateral diversion effect, dikes are expected to be similar to faults, to have very limited impact on unsaturated zone flow behavior above the base of the TSw unit. Furthermore, because dikes would be nearly vertical, the formation of a significant perched water zone associated with a dike is not expected. Therefore, igneous activity-induced rock property changes do not significantly affect the capabilities of the unsaturated zone above the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.02.0A	No	**Non-ITBC:** Unsaturated Zone Properties Properties of the Host Rock Unit Infiltration and Seepage Characterization of Igneous Events	**None**
Unsaturated Zone above the Repository	1.2.04.05.0A Magma or Pyroclastic Base Surge Transports Waste **Excluded**	The transport of waste by magma or pyroclastic base surge following an unlikely eruptive igneous event is insignificant in areal extent compared to the transport of the waste in the resulting ash and tephra eruption. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.05.0A	No	**Non-ITBC:** Characterization of Igneous Events	**Non-ITBC:** Repository Elevation below the Surface Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	1.2.06.00.0A Hydrothermal Activity **Excluded**	Hydrothermal activity resulting from a non-magmatic heat source is not expected in the Yucca Mountain area. Any other possible hydrothermal activity in the vicinity of Yucca Mountain requires a predecessor igneous event. However, there is no clear evidence of extensive hydrothermal activity resulting from previous igneous events at or near Yucca Mountain. Even in the unlikely event of an igneous intrusion or eruption, the possible effects of hydrothermal activity are inconsequential to repository performance (see discussion of FEP 1.2.04.02.0A, Igneous Activity Changes Rock Properties). Due to the limited scale of effects from basaltic dikes, the potential effects of hydrothermal alteration on unsaturated zone flow (i.e., flow pathways and velocities) above the repository are considered negligible. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.06.00.0A	No	**Non-ITBC:** Characterization of Igneous Events	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	1.2.10.01.0A Hydrologic Response to Seismic Activity **Excluded**	Seismic activity may alter the rock, fracture, and fault characteristics, which may affect the hydrogeology of the unsaturated zone in the vicinity of the repository. Investigations focusing on the potentiometric hydrologic response, given changes in rock properties adjacent to a fault, demonstrate that the changes in water-table elevation are not expected to exceed 50 m and are transient and local in nature. Because the emplacement drifts are located at least 120 m above the current water table, such transient perturbations will not have any significant long-term effect to the unsaturated zone flowpaths or velocities above the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.10.01.0A	No	**Non-ITBC:** Infiltration and Seepage properties Properties of the Host Rock Unit Unsaturated Zone Properties Characterization of Seismic Events	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation below the Surface
Unsaturated Zone above the Repository	1.2.10.02.0A Hydrologic Response to Igneous Activity **Excluded**	Igneous intrusions that might occur in the time frame of 10,000 years after closure would affect a relatively small volume of the host rock and are expected to be oriented subparallel to existing flow directions. Consequently, future intrusions would not have a significant effect on groundwater flow patterns or rates in the unsaturated zone above repository. Given the limited area of any thermal or geochemical alteration, and the consequent change of rock properties around an intrusion, any geochemical effects would be minimal. The potential development of a hydrothermal system from igneous activity is not expected based on analogue studies and would be of low consequence due to its limited size relative to the repository footprint. Any possible changes to topography and soils from extrusive activity are also of low consequence. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.10.02.0A	No	**Non-ITBC:** Infiltration and Seepage processes Properties of the Host Rock Unit Unsaturated Zone Properties Characterization of Igneous Events	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	1.3.01.00.0A Climate Change **Included**	Climate change affects the amount and distribution of water that infiltrates into the surficial soils and underlying bedrock. Future climate analyses indicate that the climate at Yucca Mountain will evolve to a warmer and wetter monsoon climate followed by a cooler, wetter glacial-transition climate within the first 10,000 years after disposal and then by a even wetter full glacial climate within the period of geologic stability. The effects of climate change on groundwater flow in the unsaturated zone above the repository are incorporated into the TSPA using time-dependent infiltration rates as a boundary condition to the Site-Scale UZ Flow Model for the first 10,000 years and for the post-10,000-year period, using the distribution for the deep percolation rate that implements the requirements of the proposed rule. The climate change effects l the amount of water available for infiltration into the UZ. **FEP Source:** SNL 2008 [DIRS 183041] – 1.3.01.00.0A	Yes	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	**ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	1.4.01.01.0A Climate Modification Increases Recharge **Included**	Future climate change significantly affect the amount and timing of precipitation and net infiltration into the UZ. The net effect of climate change after repository closure is to increase the amount of water that can infiltrate and percolate through the unsaturated zone as recharge to the water table. The climate effect on unsaturated zone flow above the repository has been directly included in the Site-Scale UZ Flow Model by using variable infiltration rates for each of three climates for the first 10,000 years following repository closure: present-day, monsoon, and glacial transition. After that and through the period of geological stability (as proposed by 40 CFR 197 [DIRS 177357]), the effect of climate modification on percolation and recharge is incorporated into the Site-Scale UZ Flow Model using the distribution of deep percolation rate as specified in the proposed rule. The effect of climate change is also included in the drift seepage model through percolation fluxes at the PTn/TSw interface predicted by the Site-Scale UZ Flow Model. Climate modification has a direct and strong effect on the infiltration rate as a boundary condition to the Site-Scale UZ Flow Model. **FEP Source:** SNL 2008 [DIRS 183041] – 1.4.01.01.0A	Yes	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	**ITBC:** Repository Elevation below the Surface Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	1.4.06.01.0A Altered Soil or Surface Water Chemistry **Excluded**	Human (e.g., agricultural or industrial) activities may affect soil and surface water chemistry, which in turn may impact the chemistry of infiltrating water. Current agricultural and industrial activities in the Yucca Mountain region are already included in the characterization of the unsaturated zone above the repository. Future changes in these activities are excluded based on regulatory requirements (10 CFR 63.305(b) [DIRS 178394]). Impacts of industrial activities associated with the repository itself on soil and water chemistry will be minor, and will have no significant adverse impacts on long-term repository performance **FEP Source:** SNL 2008 [DIRS 183041] – 1.4.06.01.0A	No	**Non-ITBC:** Seepage Water Chemistry	**Non-ITBC:** Repository Geographic and Geologic Location Reclamation of Lands Disturbed by Repository
Unsaturated Zone above the Repository	2.1.08.01.0A Water Influx at the Repository **Included**	Influx of liquid water is the same as seepage into the emplacement drifts. Seepage occurs when the downward percolation flux in the host rock is not completely diverted around underground openings by capillary flow processes. The principal factors that determine the occurrence and magnitude of seepage, in addition to the percolation flux, are the bulk permeability and the capillary strength of the fractured host rock. Uncertainty in these parameters, based on observations from in situ testing, is included in the performance assessment. Representativeness of the seepage parameter distributions used in the performance assessment (SNL 2007 [DIRS 181244], Section 6.6) within the repository host rock is considered important to capability of the upper natural barrier. Note that effects from rock excavation and committed materials are addressed for other FEPs (1.1.01.01.0B, 2.1.06.04.0A, 2.1.08.02.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.01.0A	Yes	**ITBC:** Unsaturated Zone Properties Infiltration and Seepage Properties of the Host Rock Unit	**Non-ITBC:** Emplacement Drift Diameter No Backfill in Emplacement Drifts Repository Elevation below the Surface Repository Geographic and Geologic Location Repository Layout Repository Standoff from Quaternary Fault Repository Standoff from Paintbrush Nonwelded

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository (Continued)	2.1.08.01.0A Water Influx at the Repository **Included** (Continued)				Hydrogeologic Unit Verification of Design Rock Properties Minimum Thickness of PTn Unit Above the Repository
Unsaturated Zone above the Repository	2.1.08.01.0B Effects of Rapid Influx into the Repository **Excluded**	This FEP pertains to the potential quenching effect from rapid water influx during the thermal period. Transient pulses of water in the unsaturated zone at the repository horizon, whether caused by episodic infiltration events or transient effects associated with climate change, are not expected to significantly reduce drift wall temperature unless subject to strong episodic infiltration or focused flow. Sensitivity analyses of the Site-Scale UZ Flow Model show that the PTn unit dampens and homogenizes episodic infiltration pulses, resulting in a steady flow condition below. In addition, drift seepage studies also indicate that saturation buildup around the boiling zone is insignificant, and penetration of episodic and preferential flows originating from the condensation zone above drifts is not expected during the thermal period. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.01.0B	No	**Non-ITBC:** Unsaturated Zone Properties Infiltration and Seepage	**Non-ITBC:** Flood Protection Repository Elevation below the Surface Repository Geographic and Geologic Location Repository Standoff from Paintbrush Nonwelded Hydrogeologic Unit Minimum Thickness of PTn Unit above the Repository Standoff from Quaternary Faults

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.1.08.02.0A Enhanced Influx at the Repository **Included**	The impact of an underground opening on the unsaturated flow and drift seepage (including capillary barrier effect and flow diversion around the drifts) is captured in the data acquired from in situ field testing, which were used to develop seepage parameters. In addition, the impact is explicitly captured in the ambient and thermal seepage process models used for the seepage abstraction. However, this effect has been found to not significantly affect the likelihood or amount of seepage into the emplacement drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.02.0A	No	**Non-ITBC:** Infiltration and Seepage Unsaturated Zone Properties	**Non-ITBC:** Emplacement Drift Configuration
Unsaturated Zone above the Repository	2.1.08.03.0A Repository Dryout due to Waste Heat **Included**	Repository dryout, included in thermal hydrology and thermal seepage models, has a minor effect on the timing of seepage. The effects of dryout of the host rock around the emplacement drifts due to waste heat are significant processes for the first several hundred to approximately 1,000 years which is a small fraction of the period of geologic stability (as proposed by 40 CFR 197 [DIRS 177357]) depending on the location in the repository. Repository dryout effects on in-drift thermal-hydrologic conditions are addressed by other EBS FEPs (see Table A-2), but those effects are not important to the UNB's capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.03.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Infiltration and Seepage Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing Verification of Design Rock Properties

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.1.08.11.0A Repository Resaturation due to Waste Cooling **Included**	Repository resaturation is included in thermal hydrology and thermal seepage models, but has only a minor effect on seepage. The condensate that exists above the drifts drains into the drift pillars and does augment liquid-phase saturation during the post-boiling rewetting period (BSC 2005 [DIRS 172232], Section 6.2.4). Therefore, the reflux from the condensate zone to the dryout zone does not cause the seepage into the drifts to be greater than that which would occur under ambient (unheated) conditions. The effects of resaturation of the host rock around the emplacement drifts due to waste cooling are only significant for the first several hundred to 1,000 years which is a small fraction of the period of geologic stability (as proposed by 40 CFR 197 [DIRS 177357]), depending on the location in the repository (SNL 2007 [DIRS 181244], Section 6.4.3.3; BSC 2005 [DIRS 172232], Section 6.2.4). Repository resaturation effects on in-drift thermal-hydrologic conditions are addressed by other EBS FEPs (see Table A-2), but those effects are not important to the UNB's capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.11.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Infiltration and Seepage Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing Verification of Design Rock Properties
Unsaturated Zone above the Repository	2.1.09.12.0A Rind (chemically Altered zone) Forms in the Near Field **Excluded**	Thermal-hydrologic-chemical effects in the vicinity of the emplacement drifts induced by the evolution of the pore waters due to coupled thermal processes have been studied using the THC Seepage Model. This model was used to examine near-field and drift seepage flow and chemistry. Changes in fracture permeabilities resulting from mineral precipitation or dissolution were found to be on the order of the natural variation in these properties already included in the seepage models, with most of the substantial effects limited to regions above and to the side of the drift within about a drift diameter. While these changes would tend to reduce permeability in the affected regions and lead to a reduction in drift seepage, they are considered insignificant because they are within the natural variation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.12.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Seepage Water Properties In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.01.01.0A Mechanical Effects of Excavation and Construction in the Near Field **Included**	The mechanical effects of excavation and construction on rock mass mechanical properties have been included in models of drift degradation. In addition, the effects on hydrologic properties are taken into account in the air injection and seepage tests conducted in the ESF, which are used to derive seepage-relevant parameters that are incorporated into the drift seepage analyses. Furthermore, to preclude any potential deleterious effects, construction and operational management, and administrative controls will be developed (10 CFR 63.51(a)(3)(i−iii), 10 CFR 63.72(a), and 10 CFR 63.72(b)(1−11) [DIRS 180319]). The mechanical effects of excavation and construction are not considered in the Site-Scale UZ Flow Model, where these local changes are not relevant. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.01.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Infiltration and Seepage	**Non-ITBC:** Excavation Methods Design of Ground Support System Verification of Design Rock Properties
Unsaturated Zone above the Repository	2.2.01.01.0B Chemical Effects of Excavation and Construction in the Near Field **Excluded**	Excavation and construction has little effect on the chemistry in the near field rock mass that is dominated by water−rock interactions, because of the limited amount of water introduced, the limited amount of water limits evaporation induced salt precipitation. In addition, even with relatively large quantities of low-alloy steels used in the invert, negligible changes in water chemistry are expected. Furthermore construction and operational management and administrative controls will be developed to ensure that committed materials have no deleterious effects **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.01.0B	No	**Non-ITBC:** In-Drift Chemical Environment Infiltration and Seepage	**Non-ITBC:** Excavation Methods Committed Materials

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.01.02.0A Thermally-induced Stress Changes in the Near Field **Excluded**	Thermally induced stress changes could potentially affect drift degradation and thermal-hydrologic properties in the vicinity of the emplacement drifts. The drift degradation models explicitly evaluate thermal-mechanical effects on drift environment. The seepage models and THM model have also considered the effects of thermal-mechanical stress alteration, but determined that stress-induced changes in hydrologic properties and the flow field are either insignificant or beneficial to the performance of the UNB due to decreases in the vertical permeability and increases in the horizontal permeability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.02.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Seepage Water Properties In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing Waste Package Thermal Limits
Unsaturated Zone above the Repository	2.2.01.02.0B Chemical Changes in the Near-Field from Backfill **Excluded**	Changes in host rock properties may result from chemical effects of backfill. Properties that may be affected include permeability and sorption. Since backfill is not to be placed in the drift, this process is not relevant and does not contribute to barrier capability. Deviation from design could negatively impact barrier capability. Deviation from design is managed through the change-control process, which requires postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.02.0B	No	**Non-ITBC:** In-Drift Chemical Environment	**Non-ITBC:** No Backfill in Emplacement Drifts Committed Materials

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	**FEP Number Name, and Screening Decision**	**Discussion of Effect on Barrier Capability**	**Relates to ITBC[1]**	**Core Parameter Characteristic[2]**	**Control Parameter Characteristic[3]**
Unsaturated Zone above the Repository	2.2.03.01.0A Stratigraphy **Included**	The stratigraphic sequence of unsaturated strata defines the hydrologic characteristics through which percolating water flows between the surface and the repository horizon. This sequence of both welded and nonwelded tuffs affects the transient propagation of infiltration pulses and tends to spatially redistribute the locally variable infiltration rates. This sequence has been directly included in the Site-Scale UZ Flow Model, which also generates percolation fluxes that are used in the seepage and seepage chemistry analyses. Stratigraphy forms the basic framework for the modeling and analysis of rock properties, mineral distributions, faulting and fracturing, hydrologic flow, and radionuclide transport. For the unsaturated zone above the repository, stratigraphy provides the framework in which the percolation processes occur. The quantity as well as the spatial and temporal variations in percolation flux will directly affect (1) the amount of water flowing into waste emplacement drifts, and (2) moisture conditions and the corrosion environment of waste packages within the drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.03.01.0A	Yes	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	**ITBC:** Repository Geographic and Geologic Location Verification of Design Rock Properties Minimum Thickness of PTn Unit Above the Repository
Unsaturated Zone above the Repository	2.2.03.02.0A Rock Properties of Host Rock and Other Units **Included**	Rock properties, such as fracture capillarity and permeability, significantly affect the distribution of percolation flux in the unsaturated zone and the amount of flow diversion for a given percolation flux around emplacement drifts. Rock properties and their associated variabilities have been incorporated into both the Site-Scale UZ Flow Model and the drift seepage models. The UZ Flow Model uses layer-specific hydrologic properties and fault properties to represent the large-scale heterogeneity, because smaller-scale heterogeneity within a hydrogeologic unit has an insignificant effect on site-scale flow processes. Permeability differences at stratigraphic interfaces contribute to lateral diversion of percolation flux in the stratigraphic units above the repository. In addition, the Drift Seepage Model uses stochastic parameter distributions to capture small-scale heterogeneity and other uncertainties in fracture permeability and capillarity. Key rock properties such as fracture permeability control percolation in the unsaturated zone and seepage into emplacement drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.03.02.0A	Yes	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	**ITBC:** Repository Geographic and Geologic Location Verification of Design Rock Properties

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.06.01.0A Seismic Activity Changes Porosity and Permeability of Rock **Excluded**	Seismic activity-induced changes in the porosity and permeability of the rock matrix in the unsaturated zone above the repository is found to be insignificant given the permeable nature of the rock, the predominant gravity-driven vertical flow, and the cumulative effects on permeability of the host rock from past seismic activity. The rock matrix is largely unaffected by strain redistribution caused by expected levels of intensity of seismic activity and no significant new faults or fractures are likely to form in the Yucca Mountain vicinity within the next 10,000 years. The seismic displacement for intact rock is comparable to measured thermal stress in the Drift-Scale Test, which has been shown to have negligible effects on flow. The dominant mode for stress-induced permeability change for THM model processes was found to be elastic fracturing caused by changes in stress normal to the fractures, as opposed to changes in matrix permeability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.01.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Infiltration and Seepage Unsaturated Zone Properties Characterization of Seismic Events	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.06.02.0A Seismic Activity Changes Porosity and Permeability of Faults **Excluded**	It is inferred from the PSHA expert elicitation study that formation of significant new faults are unlikely in the Yucca Mountain vicinity within the next 10,000 years. In addition, although seismic events may reactivate existing faults, the resulting fault displacements are limited to a few meters with insignificant changes in hydrologic properties of faults. Furthermore, seismically induced changes in fault porosity and permeability have little impact on flow above the repository because faults carry only a small fraction of flow. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.02.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Infiltration and Seepage Unsaturated Zone Properties Characterization of Seismic Events	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.06.02.0B Seismic Activity Changes Porosity and Permeability of Fractures **Excluded**	The recent PSHA expert elicitation study supports the interpretation that formation of significant new fractures are unlikely in the Yucca Mountain vicinity within the next 10,000 years. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.02.0B	No	**Non-ITBC:** Properties of the Host Rock Unit Infiltration and Seepage Unsaturated Zone Properties Characterization of Seismic Events	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.06.03.0A Seismic Activity Alters Perched Water Zones **Excluded**	Perched water has only been found at Yucca Mountain near the TSw-CHn interface. In particular, the presence of perched water appears to be correlated with the presence of zeolitically altered minerals within the Calico Hills nonwelded (CHn). The fact that the perched water occurrence is strongly correlated with the zeolitic lithology indicates that the effects of seismic and tectonic processes do not play a significant role in the formation and persistence of perched water. Perched-water conditions do not presently exist in the unsaturated zone above the repository, and are not expected even under future climate changes (SNL 2007 [DIRS 184614], Sections 6.2.2.2 and 7.7.4.2. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.03.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Infiltration and Seepage Unsaturated Zone Properties Characterization of Seismic Events	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.06.04.0A Effects of Subsidence **Excluded**	THM modeling showed that subsidence distances would be indistinguishable from natural variations in the ground surface, and are too small to affect run off or infiltration, or to create impoundments. In addition, corroborative mining data indicate no subsidence for the size of the drift opening relative to drift spacing. Stress relieved enhancements to fracture permeability and capillarity due to the excavation have been included in the uncertainty of permeability and capillarity used in the seepage models. The changes to fracture characteristics around emplacement drifts due to stress relief have been found to be too small to cause adverse effects on seepage. Subsidence induced stress effects on UZ flow are negligible. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.04.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone Properties	**Non-ITBC:** Emplacement Drift Diameter Emplacement Drift Spacing Repository Layout Repository Elevation below the Surface Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.07.01.0A Locally Saturated Flow at Bedrock/ Alluvium Contact **Excluded**	The possibility of locally saturated flow conditions at the bedrock–alluvium contact has been excluded in the assessment of net infiltration for two reasons. First, most of the infiltration model domain is characterized by relatively low slope, which corresponds to a small lateral hydraulic gradient. Second, bulk bedrock saturated hydraulic conductivity values are generally higher than the saturated hydraulic conductivity values in the overlying soil and, therefore, once water reaches the soil–bedrock interface, it would tend to enter bedrock instead of flowing laterally along the interface. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.01.0A	No	**Non-ITBC:** Surface Soil Properties (including vegetation) Infiltration and Seepage Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.07.02.0A Unsaturated Groundwater Flow in the Geosphere **Included**	Unsaturated groundwater flow defines the flow fields including distribution of percolation flux in space and time, the seepage into emplacement drifts, and the PTn / TSw boundary fluxes. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.02.0A	Yes	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties	**ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.07.04.0A Focusing of Unsaturated Flow (fingers, weeps) **Included**	Uncertainty in flow focusing has been included in the assessment of the likelihood and magnitude of seepage into the emplacement drifts (SNL 2007 [DIRS 181244], Sections 6.6.5.2 and 6.7.1). Flow focusing is used with the local percolation flux to produce the percolation flux used as input to the seepage models. This allows bridging the gap between the Site-Scale Model of unsaturated flow, the drift-scale seepage models, and accounting for variability induced by stochastic heterogeneity (BSC 2004 [DIRS 167652], Section 6.8). Flow focusing substantially impacts percolation flux, which controls seepage into emplacement drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.04.0A	No	**Non-ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.07.05.0A Flow in the UZ from episodic infiltration **Excluded**	Although episodes of high precipitation and infiltration are expected to occur during rain storms, modeling demonstrates that the PTn, which lies above the TSw containing the repository, would attenuate episodic percolation fluxes, smoothing out any near-surface transients. As a result, flow below the PTn is expected to be steady. Rapid flow through preferential pathways formed by fractures in the PTn is considered to be volumetrically insignificant because it carries only a small volume of the flow compared to flow through the matrix. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.05.0A	No	**Non-ITBC:** Infiltration and Seepage Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location Repository Standoff from Quaternary Fault Minimum Thickness of the PTn Unit Above the Repository

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.07.07.0A Perched Water Develops **Included**	Potential effects of perched water above the repository (diversion and subsequent drainage of flow) are indirectly captured in the seepage abstraction model through the use of flow focusing and spatial variability. However, the flow fields predicted by the UZ flow model do not contain perched water bodies above the repository, and no perched water was observed in boreholes drilled through the UZ above the repository **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.07.0A	No	**Non-ITBC:** Infiltration and Seepage Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.07.08.0A Fracture Flow in the UZ **Included**	Above the repository, the infiltrated water flows principally by gravity through a network of fractures in the TCw, PTn, and TSw units in the unsaturated zone. Fracture flow dominates in the welded units with a high density of interconnected fractures. Fracture flow is also significant even in the nonwelded PTn unit where the relatively high matrix permeability/porosity and the relatively low fracture density, convert the predominant fracture flow in the TCw unit to dominant matrix flow. Within the repository footprint, fracture flow accounts for more than 90% of total water percolation flux at the repository horizon. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.08.0A	Yes	**ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	**ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.07.09.0A Matrix Imbibition in the UZ **Included**	Flow in the unsaturated zone occurs predominantly in the fractures. Matrix imbibition affects the distribution of flow between fractures and the matrix in the fractured rock, and is captured in the Site-Scale UZ Flow Model through the use of matrix and fracture properties. Matrix imbibition is also important in damping the effect of episodic infiltration, resulting in steady flow conditions below the PTn. Although imbibition effects are relevant for transport, they are not as significant in the models of unsaturated zone flow, seepage, and thermal seepage, which are more significantly affected by the rock properties of the fractures, in particular the permeability and capillarity (BSC 2004 [DIRS 170035], Section 6.1). Transport of radionuclides in the UNB is not a consideration because flow and transport paths are from the repository downward. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.09.0A	No	**Non-ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	**Non-ITBC:** Repository Geographic and Geologic Location Minimum Thickness of the PTn Unit above the Repository

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.07.10.0A Condensation Zone Forms Around Drifts **Included**	Moisture will be redistributed by evaporation and condensation in the host rock around the emplacement drifts. This process is included in the thermal-seepage and thermal-hydrologic models, which are abstracted for inclusion in the performance assessment. During boiling, condensate develops above drifts and sheds in cooler regions between drifts (pillars). After boiling condensate has a negligible effect on both flow and seepage chemistry. Condensation in the near-field host rock does not produce liquid flux conditions sufficient to cause influx of water into the drifts (BSC 2005 [DIRS 172232], Sections 6.1.1 and 6.2.4); hence the effect of condensation is limited. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.10.0A	No	**Non-ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit In-Drift Thermal Environment, Convection, Condensation, and Evaporation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Repository Geographic and Geologic Location Repository Layout Emplacement Drift Configuration Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing
Unsaturated Zone above the Repository	2.2.07.11.0A Resaturation of Geosphere Dryout Zone **Included**	Resaturation of the rocks around the emplacement drifts during the thermal pulse is included in thermal-hydrologic and thermal-seepage models but has only a minor effect on seepage. The effects of resaturation of the host rock around the emplacement drifts due to waste cooling are only significant for the first several hundred to a few 1,000 years, and are insignificant over the period of geologic stability (BSC 2005 [DIRS 172232], Section 8.1). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.11.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Infiltration and Seepage Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Verification of Design Rock Properties

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.07.18.0A Film Flow into the Repository **Included**	The primary parameters controlling drift seepage and flow diversion are the capillary strength parameter and permeability (BSC 2004 [DIRS 171764], Section 6.6.3.1). These parameters implicitly capture effects such as film flow (BSC 2004 [DIRS 171764], Section 6.3.3.2). An analysis using a film-flow model as an alternative to the Site-Scale UZ Flow Model indicates that the UZ Flow Model, which incorporates the active fracture concept, captures the fast flow behavior of water film. Film flow is considered to be a small-scale effect relative to the overall capillary effect (BSC 2004 [DIRS 171764], Section 6.6.3.1. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.18.0A	No	**Non-ITBC:** Properties of Unsaturated Zone Infiltration and Seepage	**None**
Unsaturated Zone above the Repository	2.2.07.19.0A Lateral Flow from Solitario Canyon Fault Enters Drifts **Included**	Lateral flow from the Solitario Canyon Fault is not expected to be a significant fraction of the total percolation flux at the repository horizon. In addition, because the emplacement drifts do not intersect the Solitario Canyon Fault, the fault is not expected to have a substantial effect on seepage into the drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.19.0A	No	**Non-ITBC:** Infiltration and Seepage Unsaturated Zone Properties Properties of the Host Rock Unit	**Non-ITBC:** Repository Geographic and Geologic Location Repository Layout
Unsaturated Zone above the Repository	2.2.07.20.0A Flow Diversion Around Repository Drifts **Included**	Downward percolation flux in the near-field host rock tends to be diverted around drift openings by capillary flow processes. When the flux is not fully diverted, then seepage results. The effectiveness of diversion is a function of the percolation rate, the permeability and capillarity strength of the host rock, and the opening geometry. The key parameters affecting flow diversion, and the associated parameter uncertainties, are included in the performance assessment through the seepage models (BSC 2004 [DIRS 171764], Section 6.3.2). Flow diversion is an important function of the upper natural barrier, so the key parameters of this FEP are considered important to barrier capability. The parameters affecting flow diversion, and the associated parameter uncertainties, have been obtained from the analyses of liquid release tests performed at several locations at the Exploratory Studies Facility (ESF) that capture the unsaturated flow process in the presence of openings, including flow diversion around drifts and seepage, and have been included in the seepage models. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.20.0A	Yes	**ITBC:** Unsaturated Zone Properties Infiltration and Seepage Properties of the Host Rock Unit	**Non-ITBC:** Emplacement Drift Configuration Waste Package Thermal Limits No Backfill in Emplacement Drifts Repository Geographic and Geologic Location Verification of Design Rock Properties

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.10.01.0A Repository-Induced Thermal Effects on Flow in the UZ **Excluded**	This FEP deals with potential impacts of the thermal effects of the repository, on large scale flow patterns in the unsaturated zone. Repository-induced thermal-hydrologic effects on flow, are insignificant (SNL 2008 [DIRS 183041] – 2.2.10.01.0A). Whereas the local effects of evaporation and condensation in the host rock are included in the performance assessment (see FEP 2.2.07.10.0A; SNL 2007 [DIRS 181244], Section 6.5), the potential larger-scale effects, associated with gas-phase circulation, on the characteristics of far-field percolation in the unsaturated zone, are insignificant. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.01.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of the Host Rock Unit Unsaturated Zone Properties Infiltration and Seepage Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Emplacement Drift Spacing Verification of Design Rock Properties Drift Wall Temperature Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.10.03.0B Natural Geothermal Effects on Flow in the UZ **Included**	Although this process has been included in the UZ Flow Model through the use of observed ambient temperature profile in the unsaturated zone and measured thermal conductivity, flow in the unsaturated zone is not expected to be substantially affected by natural geothermal gradients because they are small compared to thermal gradients that exist from the transient thermal pulse from the emplaced nuclear waste. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.03.0B	No	**Non-ITBC:** Infiltration and Seepage In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of the Host Rock Unit Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.10.04.0A Thermo-mechanical Stresses Alter Characteristics of Fractures Near Repository **Excluded**	Thermo-mechanical stresses imposed on unsaturated zone fractures within the vicinity of the repository do not significantly affect the hydrologic characteristics of the fractured rock mass, in particular the permeability or capillarity. Therefore, these processes do not significantly affect the predicted seepage into the emplacement drifts, and have been excluded from the performance assessment. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.04.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Seepage Water Properties In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.10.04.0B Thermo-mechanical Stresses Alter Characteristics of Faults Near Repository **Excluded**	Thermo-mechanical effects on faults in the vicinity of the emplacement drifts in response to coupled thermal processes do not significantly affect the hydrologic characteristics of the fractured rock mass, in particular the permeability or capillarity. In addition, these processes do not affect the overall flow in the fractured rock mass in the unsaturated zone. Therefore, these processes do not significantly affect the predicted seepage into the emplacement drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.04.0B	No	**Non-ITBC:** Properties of the Host Rock Unit Seepage Water Properties In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.10.05.0A Thermo-mechanical Stresses Alter Characteristics of Rocks Above and Below the Repository **Excluded**	Thermo-mechanical effects in the vicinity of the emplacement drifts in response to coupled thermal processes do not significantly affect the hydrologic characteristics of the fractured rock mass, in particular the permeability or capillarity. Therefore, these processes do not significantly affect the predicted seepage into the emplacement drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.05.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Seepage Water Properties In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing Repository Elevation below the Surface Repository Geographic and Geologic Location Repository Standoff from Paintbrush Nonwelded Hydrogeologic Unit
Unsaturated Zone above the Repository	2.2.10.10.0A Two-Phase Buoyant Flow/Heat Pipes **Included**	Two-phase buoyant flow (and heat pipe effect)is included in models of thermal seepage and thermal hydrology, the effect is limited to drift-scale redistribution of moisture, and does not significantly increase or decrease the availability of water for seepage or transport (SNL 2007 [DIRS 177404], Section 6.2.1.1). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.10.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of the Host Rock Unit Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Unsaturated Zone Properties Infiltration and Seepage	**Non-ITBC:** Emplacement Drift Spacing Verification of Design Rock Properties Drift Wall Temperature Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.10.11.0A Natural Air Flow in the UZ **Excluded**	Barometric pumping in the unsaturated zone may increase gas-phase axial transport of moisture in the emplacement drifts during the thermal period, with greater condensation occurring in cooler or unheated regions and lower relative humidity occurring in the heated regions. However, the potential effects are within the range of effects represented in the condensation model, and are minor compared with the thermal-hydrological responses represented by the multiscale model. Also, the effects of natural air flow on moisture movement in the unsaturated zone are found to be small, compared with the range of infiltration flux estimated for Yucca Mountain. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.11.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone above the Repository	2.2.10.12.0A Geosphere Dryout due to Waste Heat **Included**	Dryout of the host rock is included in thermal hydrologic and thermal-seepage models, and affects the timing of seepage (SNL 2008 [DIRS 183041] – 2.2.10.12.0A). The effects of dryout of the host rock around the emplacement drifts due to waste heat are significant processes for the first several hundred to approximately 1,000 years, depending on the location in the repository, which is a small fraction of the period of geologic stability (SNL 2007 [DIRS 181244], Section 6.5); (BSC 2005 [DIRS 172232], Section 6.2.4). These effects on flow are included through the abstractions of the THC and TH seepage models. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.12.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of Unsaturated Zone Infiltration and Seepage Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Drift Wall Temperature Waste Package Spacing Verification of Design Rock Properties
Unsaturated Zone above the Repository	2.2.11.02.0A Gas Effects in the UZ **Excluded**	The buildup of any significant gas pressure in the unsaturated zone is expected to be of low consequence, because permeable fracture pathways would divert gas away from its source, preventing the formation of high pressure gas pockets that might alter flow and transport patterns. Comparison of TH and THC calculations also show that potential sealing of fractures due to precipitation in the thermally perturbed repository environment would have a negligible effect on hydrogeologic response of the fractures. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.11.02.0A	No	**Non-ITBC:** Properties of Unsaturated Zone Infiltration and Seepage	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-1. ITBC Analysis of Upper Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone above the Repository	2.2.12.00.0A Undetected Features in the UZ **Excluded**	Discrete faults have been included in the Site-Scale UZ Flow Model. The possibility that a major, critical feature in the vicinity of Yucca Mountain, such as a large seismogenic fault zone, is not expected given the extensive site investigation. However, model results show existing major fault features carry only a small fraction of the flow (about 1%) within the repository footprint above the repository; therefore, the presence of undetected features would not significantly alter the fraction of flow-through features within the repository footprint, and therefore, would not significantly affect the likelihood or amount of seepage. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.12.00.0A	No	**Non-ITBC:** Properties of Unsaturated Zone Infiltration and Seepage	**Non-ITBC:** Repository Geographic and Geologic Location Repository Standoff from Quaternary Fault

[1] A FEP relates to a Parameter Characteristic if it directly influences or is directly influenced by the parameter characteristic. The Parameter is determined to be ITBC if for a particular Barrier and Barrier Feature, that Parameter Characteristic substantially affects the rate of movement of water and the release or release rate of radionuclides from the Yucca Mountain repository to the accessible environment.

[2] Entries in this column identify areas which support the analyzed basis and are not amenable to direct control or identified as a Control Parameter Characteristic.

[3] Control Parameter Characteristics identify the areas where controls for operations and design are required to support the analyzed basis. Any changes to the controls or the design will be evaluated through an established change control process, which will include an evaluation of the impacts of change on FEPs, ITBC, analysis and/or model reports, models, and assumptions that support the LA.

Table A-2. ITBC Analyses of Engineered Barrier System FEPs

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.1.01.01.0A Open Site Investigation Boreholes **Excluded**	Site investigation boreholes that have been left open, degraded, improperly sealed, or reopened, could modify flow and transport properties and produce enhanced pathways between the surface and the repository. This feature is excluded on the basis that: 1) existing boreholes from site characterization are known, 2) future drilling will be controlled, 3) the regulatory requirements for borehole sealing prior to repository closure will be met, and 4) administrative controls for repository construction and operations will be developed to ensure these outcomes. Accordingly, these features are considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.01.01.0A	No	**Non-ITBC:** Closure Materials, Properties, and Configuration	**Non-ITBC:** Repository Geographic and Geologic Location Closure Boreholes
Emplacement Drift	1.1.02.00.0A Chemical Effects of Excavation and Construction in EBS **Excluded**	Administrative controls for repository construction and operations will be developed to assure that emplacement drifts are developed in accordance with the repository design. Materials used during drift excavation and development will be controlled to preclude any potential deleterious effects on engineered barriers. While excluded from further consideration in the postclosure analyzed basis, this exclusion is based on controls being in place. The placement of arbitrary materials in the drift could negatively impact barrier capability; however, it is unlikely that these impacts would substantially effect the release or transport of radionuclides since deviation from these controls are managed through the Corrective Action Program, which may require postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.02.00.0A	No	**Non-ITBC:** In-Drift Chemical Environment	**Non-ITBC:** Excavation Methods EBS Drip Shield Emplacement Drift Invert Materials Interactions Committed Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.1.02.00.0B Mechanical Effects of Excavation and Construction in EBS **Excluded**	Mechanical effects of excavation and construction may affect performance of the EBS. Excavation-related effects include changes to rock properties due to boring and blasting. The extent of excavation damage in repository drifts will not affect mechanical response (Craig 2001 [DIRS 171411], p. 16). In addition, to prevent or limit potentially deleterious effects, construction and operational management and administrative controls will be developed and implemented. Accordingly, these effects are considered not to be important to barrier capability. Note that changes in rock properties that could affect seepage and transport are addressed separately (See FEP 2.2.01.01.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.02.00.0B	No	**Non-ITBC:** Properties of the Host Rock Unit	**Non-ITBC:** Excavation Methods Verification of Design Rock Properties Design of Ground Support System Repository Geographic and Geologic Location
Emplacement Drift	1.1.02.01.0A Site Flooding (during construction and operation) **Excluded**	The repository surface facilities are designed to avoid flooding at the ramp portals and shaft collars Accordingly, this process is not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.02.01.0A	No	**None**	**Non-ITBC:** Flood protection Repository Geographic and Geologic Location
Emplacement Drift	1.1.02.02.0A Preclosure Ventilation **Included**	Preclosure ventilation removes heat and moisture from the host rock during the ventilation period (SNL 2007 [DIRS 184433], Section 6.2.15[a], 6.2.17[a]). The heat removal effect is included explicitly in all postclosure thermal models, while the moisture removal effect is minor compared to postclosure hydrologic processes, and is not significant to postclosure performance. Preclosure removal of heat can be achieved within a wide range of operational parameters, including passive ventilation, and its effects on postclosure conditions are limited. Hence effects are not considered significant to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.02.02.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation	**Non-ITBC:** Drift Wall Temperature Duration of Ventilation Period Average Airflow Rate for Preclosure Ventilation of Emplacement Drifts

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.1.02.03.0A Undesirable Materials Left **Excluded**	To preclude any potential deleterious effects from undesirable materials, construction and operational management and administrative controls on undesirable materials, exist. The placement of arbitrary materials in the drift could negatively impact barrier capability; however, it is unlikely that these impacts would substantially effect the release or transport of radionuclides since deviation from these controls are managed through the Corrective Action Program, which require postclosure impact evaluation. Controls will be developed. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.02.03.0A	No	**Non-ITBC:** In-Drift Chemical Environment	**Non-ITBC:** Committed Materials
Emplacement Drift	1.1.03.01.0A Error in Waste Emplacement **Excluded**	Administrative controls for repository construction and operations will be developed to assure that emplacement drifts are developed in accordance with the repository design and that waste packages are emplaced in accordance with it. The application of operational management and administrative controls will prevent or limit errors in waste emplacement. In addition, errors in waste emplacement, even if they were to occur, are not expected to significantly affect the predicted thermal-hydrologic-chemical-mechanical environments in the emplacement drifts. **FEP Source:** SNL 2008 [DIRS 183041] -1.1.03.01.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation In-Package Chemical Environment In-Package Thermal Environment Criticality Characteristics	**Non-ITBC:** As-Emplaced Waste Package-Drip Shield Configuration Drip Shield Design and Installation Waste Package Handling and Emplacement Loading of Waste Forms Cladding Temperature Limit - - Ventilation Drift Wall Temperature Waste Form CSNF Fuel Rod Maximum Burnup Limit Waste Package Design Basis Bounding Dose Rate Waste Package Temperature Limit Waste Package Worst-Case Dose Rate

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.1.04.01.0A Incomplete Closure **Excluded**	Disintegration of society could result in incomplete closure, sealing, and decommissioning of the disposal vault. This FEP is excluded by regulation, and is therefore considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.04.01.0A	No	**None**	**None**
Emplacement Drift	1.1.07.00.0A Repository design **Included**	Repository design is the upper level control on the components used in the EBS, the method by which the components are interconnected, and how the EBS is interfaced with the natural barriers. This is an upper level FEP; specific design considerations relevant to barrier capability are fully captured in other EBS FEPs. This FEP is not considered ITBC because this is a high level FEP, which is redundant with more relevant specific FEPs. The parameters characteristics that would be associated with this FEP are identified for the specific relevant barrier features where the parameter characteristics matter (e.g., parameters that describe the drip shield and waste package). **FEP Source:** SNL 2007 [DIRS 183041], -1.1.07.00.0A	No	**None**	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.1.08.00.0A Inadequate Quality Control and Deviations from Design **Excluded**	To ensure that appropriate quality control processes are applied to the repository, compliant management and quality assurance processes will be implemented to ensure that the regulatory requirements will be met. Deviation from design could negatively impact barrier capability; however, it is unlikely that these impacts would substantially affect the release or transport of radionuclides, since deviation from the design is managed through the Corrective Action Program, which requires postclosure impact evaluation. This FEP refers to processes and regulatory requirements that are associated with Core and Control parameters that are identified elsewhere in this table under the barrier features to which they relate. **FEP Source:** SNL 2008 [DIRS 183041] – 1.1.08.00.0A	No	**None**	**None**
Emplacement Drift	1.2.02.03.0A Fault Displacement Damages EBS Components **Included**	The subsurface layout maintains a 60-meter standoff distance between the repository and the Solitario Canyon and Ghost Dance faults (SNL 2007 [DIRS 179466]). This standoff ensures that subsurface facilities are not damaged by displacement on these faults. Within the repository block, there are known secondary faults (Sundance fault, Drill Hole Wash fault, Sever Wash fault, Pagany Wash fault, and the western splay of the Ghost Dance fault) and hypothetical small faults with a 2-meter cumulative offset (SNL 2007 [DIRS 176828] Section 6.11.2). During operations, controls and checks will be in place that will minimize the subsurface facilities located on faults. The response of subsurface facilities to fault displacement is therefore not important for barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.03.0A	No	**None**	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness Repository Standoff from Quaternary Fault As-emplaced Waste Package-Drip Shield Configuration Emplacement Drift Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to cause seismically-induced rockfall that changes the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Sections 6.3.1.2 and 6.4.2.2) and changes the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). A change in the cross section of the emplacement drifts can alter the seepage into the drifts, and the presence of rockfall about the drip shield can alter the mechanical response and temperature time history of the EBS components. The response of the emplacement drift configuration and processes to vibratory ground motion is important to barrier capability (ITBC). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0A	Yes	**ITBC:** Properties of the Host Rock Unit Characterization of Seismic Events **Non-ITBC:** Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Characterization of Seismic Events	**ITBC:** Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location As-Emplaced Waste Package-Drip Shield Configuration Drip Shield Seismic Performance Seismic Design of Waste Package EBS Material Interactions - Copper Drip Shield Materials and Thicknesses **Non-ITBC:** Emplacement Pallet Fabrication and Corrosion Allowance Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.2.03.02.0B Seismic-induced Rockfall damages EBS Components **Excluded**	Seismically-induced rockfall in the emplacement drifts can change the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Section 6.3.1.2), and can change the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). For example, a change in the cross section of the emplacement drifts can alter the seepage into the drifts. As a second example, the presence of rockfall around the drip shield can alter the mechanical response and temperature time history of the EBS components. The response of the emplacement drift configuration and processes to seismically-induced rockfall is ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0B	Yes	**ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration **Non-ITBC:** Waste Package Materials, Properties, and Configuration Characterization of Seismic Events	**ITBC:** Drip Shield Seismic Performance Verification of Design Rock Properties Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location **Non-ITBC:** Seismic Design of Waste Package
Emplacement Drift	1.2.03.02.0C Seismic-induced Drift Collapse Damages EBS Components **Included**	Seismically-induced drift collapse in the emplacement drifts can change the cross-sectional shape and volume of the emplacement drifts (BSC 2004 [DIRS 166107], Section 6.4.2.2), and can change the configuration of the EBS components within the emplacement drifts (SNL 2007 [DIRS 176828], Sections 6.1.2 and 6.1.3). For example, a change in the cross section of the emplacement drifts can alter the seepage into the drifts. As a second example, the presence of rubble around the drip shield can alter the mechanical response and temperature time history of the EBS components. The response of the emplacement drift configuration and processes to seismically-induced drift collapse is ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0C	Yes	**ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration **Non-ITBC:** Waste Package Materials, Properties, and Configuration Characterization of Seismic Events	**ITBC:** Drip Shield Seismic Performance Verification of Design Rock Properties Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location **Non-ITBC:** Seismic Design of Waste Package Verification of Design Rock properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.2.03.02.0D Seismic-induced Drift Collapse Alters In-drift Thermal-Hydrology **Included**	The thermal-hydrologic effects from drift collapse induced by a seismic event have been included in the evaluation of barrier capability. These effects include an increase in the temperature and an increase in the probability and magnitude of seepage (SNL 2007 [DIRS 184433] section 6.3.17[a]); SNL 2007 [DIRS 181244], Section 6.4; BSC 2004 [DIRS 166107], Section 6.3). The increase in temperature is due to the insulating effect from rubble surrounding the drip shield. The increase in seepage is due to the irregular shape of a collapsed drift, which degrades the capability of the drift wall to act as a capillary barrier to the inflow of seepage. The response of the in-drift thermal-hydrology to seismic-induced drift collapse is ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0D	Yes	**ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Properties of the Host Rock Unit Infiltration and Seepage **Non-ITBC:** Characterization of Igneous Events	**Non-ITBC:** Drip Shield Thermal Expansion Constraint Drift Wall Temperature Waste Package temperature Limit Cladding Temperature Limit -- Ventilation Verification of Design Rock Properties
Emplacement Drift	1.2.03.02.0E Seismic-induced Drift Collapse Alters In-drift Chemistry **Excluded**	Possible alterations to in-drift chemistry that could occur specifically as a result of seismically-induced drift collapse are small compared to the effects from concurrent changes in temperature and humidity within the drifts on the in-drift chemistry, which are included (SNL 2007 [DIRS 177412], Section 6.15). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0E	No	**Non-ITBC:** In-Drift Chemical Environment Radionuclide Inventory and Source-Term Properties Corrosion Products Properties Invert Materials, Properties, and Configuration Characterization of Seismic Events	**Non-ITBC:** Drip Shield Corrosion Allowance Waste Package Corrosion Allowance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.2.03.03.0A Seismicity Associated with Igneous Activity **Included**	Because the damage to the EBS from an igneous event greatly dominates that of seismic events, the incremental damage associated with the seismic portion of a combined seismic/igneous event is not significant. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.03.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Characterization of Igneous Events Characterization of Seismic Events	**Non-ITBC:** Drip Shield Seismic Performance Seismic Design of Waste Package Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location
Emplacement Drift	1.2.04.03.0A Igneous Intrusion into repository **Included**	Unlikely igneous intrusion events have the potential to contact all of the waste packages and degrade the emplacement drifts, drip shields, waste packages, cladding, waste package internals and waste forms, and waste package emplacement pallets that are contacted by the magma. While, the number of drifts affected by such an unlikely event can be significant depending on characteristics of the igneous event, the probability of igneous an igneous event compromising waste emplacement drifts is very small (1.69×10^{-8}, SNL 2008 [DIRS 183478], Volume I, Section 6.5, Table 6.5-2) and dominated by aspects that are beyond the control of design. Drift spacing, drift orientation, and repository layout affect this probability. The impact of the lack of these controls would raise the probability by a maximum of only 2%. This increase is insignificant and does not support an ITBC determination. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.03.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Emplacement Drift Configuration	**Non-ITBC:** Emplacement Drift Spacing Orientation of Emplacement Drifts Emplacement Drift Configuration Repository Layout Repository Geographic and Geologic Location

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	1.2.04.04.0A Igneous Intrusion interacts with EBS Components **Included**	Unlikely igneous intrusion events have the potential to degrade the emplacement drifts, drip shields, waste packages, cladding, waste package internals and waste forms, and waste package emplacement pallets that are contacted by the magma. . While, the number of drifts affected by such an unlikely event can be a significant depending on characteristics of the igneous event, the probability of igneous an igneous event compromising waste emplacement drifts is very small (1.69 × 10^{-8}, SNL 2008 [DIRS 183478], Volume I, Section 6.5, Table 6.5-2) and dominated by aspects that are beyond the control of design. Drift spacing, drift orientation, and repository layout affect this probability. The impact of the lack of these controls would raise the probability by a maximum of only 2%. This increase is insignificant and does not support an ITBC determination. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.04.0A	No	**Non-ITBC:** Characterization of Igneous Events In-Drift Chemical Environment In-Drift Thermal Environment	**Non-ITBC:** Emplacement Drift Spacing Orientation of Emplacement Drifts Emplacement Drift Configuration Repository Layout Repository Geographic and Geologic Location
Emplacement Drift	1.2.04.04.0B Chemical Effects of Magma and Magmatic Volatiles **Included**	The impact of magmatic volatiles on water chemistry is limited by both time and space and is not considered in the performance assessment. However, following an unlikely magma intrusion into the repository, it is possible that the water chemistry in the emplacement drifts will be altered by basalt-water interactions (SNL 2007 [DIRS 177430], Section 6.7). These effects have been included in the TSPA but do not significantly contribute to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.04.0B	No	**Non-ITBC:** In-Drift Chemical Environment Radionuclide Inventory and Source-Term Properties Corrosion Products Properties Invert Materials, Properties, and Configuration Characterization of Igneous Events	**Non-ITBC:** EBS Materials Interactions - Copper

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Emplacement Drift	1.2.04.05.0A Magma or Pyroclastic Base Surge Transports Waste **Excluded**	Issues addressed by FEP 1.2.04.05.0A include near-surface eruption phenomena, magma-related transport of entrained wastes, and hydrovolcanic phenomena. Due to the distance, to the reasonably maximally exposed individual and the low probability of a magma crater extending to the repository depth and exhuming waste, these phenomena have been excluded from the performance assessment and do not contribute significantly to the barrier capability (SNL 2008 [DIRS 183041] – 1.2.04.05.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.05.0A	No	**None**	**Non-ITBC:** Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location
Emplacement Drift	1.2.04.06.0A Eruptive Conduit to Surface Intersects Repository **Included**	The potential consequence of an eruptive conduit, to the surface intersecting the repository is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the reasonably maximally exposed individual (SNL 2007 [DIRS 177432], Section 6). However, the number of affected waste packages is expected to be small and its contribution to barrier capability is not significant. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.06.0A	No	**Non-ITBC:** Waste Package Materials, Properties, and Configuration Characterization of Igneous Events	**Non-ITBC:** Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location
Emplacement Drift	2.1.01.04.0A Repository-scale Spatial Heterogeneity of Emplaced Waste **Included**	Spatial heterogeneity emplaced in waste has been considered in the development of the expected thermal-hydrologic environment in the emplacement drifts, as well as the waste form degradation processes and in-package chemistry. While this FEP is implicitly included in the performance assessment (SNL 2008 [DIRS 183041] – 2.1.01.04.0A), the package-to-package inventory variability is not significant. The heterogeneity of the inventory is included in through the characterization of uncertainty in parameters for the average inventory within the commercial spent nuclear fuel (CSNF) and codisposal packages (SNL 2007 [DIRS 180472], Section 6.4; 6.6). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.01.04.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation In-Drift Chemical Environment In-Package Chemical Environment Waste Form Degradation	**Non-ITBC:** Waste Package Temperature Limit As-emplaced waste package - Drip Shield Configuration Waste Package Handling and Emplacement Drip Shield Corrosion Allowance Waste Package Corrosion Allowance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.03.09.0A Copper Corrosion in EBS **Excluded**	Limited quantities of copper are planned to be committed in the emplacement drifts as part of the gantry rail system, and this system is not in contact with the drip shield or waste package. Accordingly, the effects of copper corrosion are insignificant to performance assessment. Even if the galvanic interaction occurs between the copper gantry rail system and the titanium drip shield, the limited amount of hydrogen absorption would have no effect on the degradation of the drip shield. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.09.0A	No	**Non-ITBC:** In-Drift Chemical Environment Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** EBS Materials Interactions - Copper Committed Materials
Emplacement Drift	2.1.04.01.0A Flow in the Backfill **Excluded**	Preferential pathways for flow and diffusion may exist within the backfill and may affect long-term performance of the waste packages. Backfill may not preclude hydrological, chemical, and thermal interactions between waste packages within a drift. Since backfill is not to be placed in the drift this process is not relevant and does not contribute to barrier capability. Deviation from design could negatively impact barrier capability. Deviation from design is managed through the Corrective Action Program, which requires postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.04.01.0A	No	**None**	**Non-ITBC:** No Backfill in Emplacement Drifts

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.04.02.0A Chemical Properties and Evolution of Backfill **Excluded**	The chemical properties of the backfill may affect groundwater flow, waste package and drip shield durability, and radionuclide transport in the waste disposal region. Properties of the backfill may change through time, due to processes such as alteration of minerals. Since backfill is not to be placed in the drift, this process is not relevant and does not contribute to barrier capability. Deviation from design could negatively impact barrier capability. If a deviation is found, it would be identified as a condition. The condition would be resolved appropriately in the CAP. This is Non-ITBC because deviations can be mitigated.. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.04.02.0A	No	**Non-ITBC:** In-Drift Chemical Environment	**Non-ITBC:** Committed Materials No Backfill in Emplacement Drifts
Emplacement Drift	2.1.04.03.0A Erosion or Dissolution of Backfill **Excluded**	Solid material in backfill may be carried away by flowing groundwater, either by erosion of particulate matter or by dissolution. Deviation from design is managed through the Corrective Action Program, which requires postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.04.03.0A	No	**None**	**Non-ITBC:** No Backfill in Emplacement Drifts
Emplacement Drift	2.1.04.04.0A Thermal-mechanical effects of backfill **Excluded**	Backfill may alter the mechanical evolution of the drift environment by providing resistance to rockfall and drift collapse, by changing the thermal properties of the drift, or by other means. Since backfill is not to be placed in the drift this process is not relevant and does not contribute to barrier capability. Deviation from design could negatively impact barrier capability. Deviation from design is managed through the Corrective Action Program, which requires postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.04.04.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation	**Non-ITBC:** No Backfill in Emplacement Drifts

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.04.05.0A Thermal-Mechanical Properties and Evolution of Backfill **Excluded**	The physical properties of the backfill may affect groundwater flow, waste package and drip shield durability, and radionuclide transport in the waste disposal region. Properties of the backfill may change through time, due to processes such as silica cementation, thermal effects, and physical compaction. Since backfill is not to be placed in the drift this process is not relevant and does not contribute to barrier capability. Deviation from design could negatively impact barrier capability. Deviation from design is managed through the Corrective Action Program, which requires postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.04.05.0A	No	**None**	**Non-ITBC:** No Backfill in Emplacement Drifts
Emplacement Drift	2.1.05.02.0A Radionuclide transport through seals **Excluded**	Groundwater flow through seals in the access ramps, ventilation shafts, and exploratory boreholes could affect long-term performance of the disposal system. Sealing concepts have been identified for the License Application, but the designs of these seals have not been determined. The designs will be supported by evaluations of performance, and the application of construction and operational management and administrative controls to ensure correct implementation. Accordingly, these features are considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.05.02.0A	No	**Non-ITBC:** Closure Materials, Properties, and Configuration	**Non-ITBC:** Repository Elevation - Overburden Thickness Repository Layout

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.06.01.0A Chemical Effects of Rock Reinforcement and Cementitious Materials in EBS **Excluded**	The effects of seepage water interacting with rock reinforcement and cementitious materials used in repository construction and operation, have been evaluated and determined to be insignificant with respect to postclosure performance. In addition, to prevent or limit potentially deleterious effects from rock reinforcement and cementitious materials, construction and operational management and administrative controls will be developed and implemented (SNL 2007 [DIRS 177412], Section 6.8). Therefore, these effects are considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.01.0A	No	**Non-ITBC:** In-Drift Chemical Environment Closure Materials, Properties, and Configuration	**Non-ITBC:** Committed Materials Excavation Methods Design of the Ground Support System Closure of Shafts and Ramps Closure Boreholes EBS Drip Shield / Emplacement Drift Invert Materials Interactions
Emplacement Drift	2.1.06.02.0A Mechanical Effects of Rock Reinforcement Materials in EBS **Excluded**	No postclosure barrier capability is attributed to the rock reinforcement materials used in the EBS. Postclosure models and analyses neglect the potential beneficial effects from rock reinforcement on the rock mass response to thermo-mechanical and seismic stresses. Therefore, these effects are considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.02.0A	No	**Non-ITBC:** Closure Materials, Properties, and Configuration Host Rock Properties	**Non-ITBC:** Committed Materials Excavation Methods Emplacement Drift Ground Support Design of Ground Support System

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.06.04.0A Flow Through Rock Reinforcement Materials in EBS **Excluded**	Groundwater flow and seepage are not significantly affected by the presence of rock reinforcement materials used during repository construction and operations (SNL 2008 [DIRS 183041] – 2.1.06.04.0A). Therefore, this process has been excluded from the performance assessment. This FEP is not considered ITBC because this does not substantially affect the rate of movement of water and the release or release rate of radionuclides from the Yucca Mountain repository to the accessible environment. This evaluation assumes that the proper controls for operations and design will be in place and that any changes to the controls or the design will be evaluated through an established corrective action program, which will include an evaluation of the impacts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.04.0A	No	**None**	**Non-ITBC:** Air Circulation Through Ground Support
Emplacement Drift	2.1.06.07.0A Chemical Effects at EBS Component Interface **Excluded**	Solid-to-solid interactions at the interfaces between the various features of the EBS have been considered in the design and analysis of the in-drift chemical environment such that galvanic coupling and other chemical interactions are insignificant to postclosure performance assessment. In addition, construction and operational management and administrative controls will be developed and applied to the use of materials in the emplacement drifts. Deviation from these controls is managed through the Corrective Action Program, which requires postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0A	No	**Non-ITBC:** In-Drift Chemical Environment Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration	**Non-ITBC:** EBS In-drift Materials Interactions

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.06.07.0B Mechanical Effects at EBS Component Interfaces **Excluded**	Physical effects of steady-state contact (static loading) that occur at the interfaces between materials in the drift may affect the performance of the system. The mechanical effects of static loading that occur at interfaces between materials in the emplacement drift are not significant to the postclosure performance of the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0B	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Emplacement Pallet Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Emplacement Pallet Design Emplacement Pallet Function Drip Shield Design Drip Shield Design and Installation Waste Package and Emplacement Pallet Static Stresses
Emplacement Drift	2.1.07.01.0A Rockfall **Excluded**	Rockfall resulting from gravitational stresses, excavation-induced stresses, and thermally induced stresses have been evaluated. The lithophysal rock units generally result in small blocks, while in the nonlithophysal rock units, larger rock blocks are possible. In either case, the effects of these rockfalls on drip shields have been considered and determined to be insignificant due to the limited extent of the rockfall, the limited stress-induced cracking of the drip shield, and the preclusion of flux through the cracked drip shield. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.01.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Surface Damage Prior to Closure As-emplaced Waste Package-Drip Shield Configuration Emplacement Drift Configuration Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.07.02.0A Drift Collapse **Excluded**	This FEP deals with non-seismically induced drift collapse that might be triggered by thermal effects, stress related to excavation, etc. It is determined that these effects do not significantly affect the flow of water or the release or transport of radionuclides. Drift collapse can occur in the lithophysal rock units given unlikely (i.e., less than an annual exceedance frequency of 10^{-5} per year) seismic events. However, the effects of seismically-induced drift collapse are addressed in separate FEPs (1.2.03.02.0C; 1.2.03.02.0D; 1.2.03.02.0E). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.02.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Emplacement Drift Configuration	**Non-ITBC:** Verification of Design Rock Properties Excavation Methods Emplacement Drift Configuration
Emplacement Drift	2.1.07.06.0A Floor Buckling **Excluded**	Buckling, or heave, of the drift floor may occur in response to changing stress. Floor buckling may affect the performance of EBS components such as the drip shield, the invert, and the pallet. Effects may include movement of EBS components and changes in the topography of the surface of the drift floor and invert that may affect water flow. Calculations for repository rock, including thermal effects, concluded that the magnitude of floor buckling is negligible. Floor buckling due to either thermal- or seismic-induced stresses is insignificant to postclosure performance due to the small differential values developed under either of these. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.06.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Properties of the Host Rock Unit	**Non-ITBC:** Drip Shield Design and Installation Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.08.01.0B Effects of Rapid Influx into the Repository **Excluded**	Rapid influx could quench the temperatures of EBS features, such as the drip shields or waste packages, during the thermal period. Damage to waste packages from rapid quenching would require flow rates in the host rock that are much greater than the range predicted for ambient and thermally altered conditions (see FEPs 2.2.07.02.0A, 2.2.07.04.0A, and 2.2.10.01.0A). The cause of rapid influx is not important to this FEP, but the effects from infiltration fluctuations on flow in the host rock deeper in the unsaturated zone, is effectively dampened by flow processes in the unsaturated zone (see FEP 2.2.07.05.0A). Accordingly, this process is considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.01.0B	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Infiltration and Seepage Properties Closure Materials, Properties, and Configuration Surface Soil Properties (including vegetation) Unsaturated Zone Properties	**Non-ITBC:** Repository Elevation - Overburden Thickness Reclamation of Lands Disturbed by Repository Repository Geographic and Geologic Location Repository Standoff from Quaternary Fault Repository Standoff from Perched Water Repository Standoff From Paintbrush Nonwelded Hydrogeologic Unit Minimum Thickness of PTn Unit above the Repository
Emplacement Drift	2.1.08.03.0A Repository Dry-out Due to Waste Heat **Included**	Repository dry-out, included in thermal-hydrology and thermal-seepage models, has a minor effect on the timing of seepage. The effects of dry-out of the host rock around the emplacement drifts due to waste heat are significant processes for the first several hundred to approximately 1,000 years which is a small fraction of the period of geologic stability (as proposed in 40 CFR 197 [DIRS 177357]) depending on the location in the repository. Repository dry-out effects on in-drift thermal-hydrologic conditions are addressed by other EBS FEPs (see Table B-1), but those effects are not important to the UNB's capability. **FEP Source:** SNL 2008 [DIRS 183041]– 2.1.08.03.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Properties of Unsaturated Zone Infiltration and Seepage Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing Waste Package Decay Heat Waste Package Thermal Limits Verification Of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.08.04.0A Condensation Forms on Roofs of Drifts (drift-scale cold traps) **Included**	Condensation can occur either locally at cooler waste package locations, or at the ends of the repository drifts (see FEP 2.1.08.04.0B). Both types are represented by the in-drift condensation model that is included in the performance assessment. Drift-wall condensation increases the fraction of waste package locations likely to experience dripping water, during the limited time periods when it occurs. Whereas drift-wall condensation is included in the TSPA, it does not cause releases or the transport of radionuclides until the waste packages are breached from other causes. Accordingly, the effect on dose is limited, and these condensation processes are considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.04.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** As-emplaced Waste Package-Drip Shield Configuration Drip Shield Design Drip Shield Design and Installation No Backfill in Emplacement Drifts Waste Package Spacing Waste Package Temperature Limit Waste Package Decay Heat Waste Package Thermal Limits **Non-ITBC:** Repository Layout Emplacement Drift Configuration Unheated Drift Length Air Circulation through Ground Support Duration of Ventilation Period Average Airflow Rate for Preclosure Ventilation of Emplacement Drifts Emplacement Drift Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.08.04.0B Condensation Forms at Repository Edges (repository-scale cold traps) **Included**	Condensation can occur either locally at cooler waste package locations, or at the ends of the repository drifts (see FEP 2.1.08.04.0B). Both types are represented by the in-drift condensation model that is included in the performance assessment. Condensation at the repository edges, when it occurs, increases the fraction of waste package locations that do not experience dripping water, because the water is evaporated and transported away from emplacement areas. Like drift-wall condensation, this process does not cause releases or the transport of radionuclides until the waste packages are breached from other causes. Accordingly, the effect on dose is limited, and this process is considered not to be ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.04.0B	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Repository Layout Emplacement Drift Configuration Unheated Drift Length Air Circulation through Ground Support As-emplaced Waste Package-Drip Shield Configuration Duration of Ventilation Period Average Airflow Rate for Preclosure Ventilation of Emplacement Drifts Drip Shield Design Drip Shield Design and Installation Emplacement Drift Configuration No Backfill in Emplacement Drifts Waste Package Spacing Waste Package Temperature Limit Waste Package Decay Heat Waste Package Thermal Limits
Emplacement Drift	2.1.08.06.0A Capillary Effects (wicking) in EBS **Included**	The effects of wicking in the invert of the EBS have been included in the Multiscale Thermal-Hydrologic Model. The effect of this wicking (without seepage) is to very slightly increase the advective flux through the invert (SNL 2007 [DIRS 184433], Section 6.3.3). The magnitude of the flux predicted is so small that the effect is not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.06.0A	No	**Non-ITBC:** Invert Materials, Properties, and Configuration In-Drift Thermal Environment Convection, Condensation, and Evaporation	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.08.07.0A Unsaturated Flow in the EBS **Included**	Unsaturated flow occurs through the features of the EBS due to seepage or condensation processes. The nature of this flow has been included in the abstractions for flow and transport through the EBS features (SNL 2007 [DIRS 177407], Sections 5 and 6). Unsaturated flow is important to barrier capability, because it is driven by the downward gravitational potential, and makes possible certain key functions of the UNB and EBS. Accordingly, the parameters that describe and control unsaturated flow conditions are considered to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.07.0A	Yes	**ITBC:** Infiltration and Seepage Properties **Non-ITBC:** Unsaturated Zone Properties Properties of the Host Rock Unit	**ITBC:** Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness **Non-ITBC:** Verification of Design Rock Properties
Emplacement Drift	2.1.08.09.0A Saturated Flow in the EBS **Excluded**	The flow regime in the EBS does not result in a significant development of saturated flow conditions (i.e., the EBS remains free draining for all expected hydrologic conditions). The flow paths considered in the EBS transport abstraction are applicable to all possible flow conditions. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.09.0A	No	**Non-ITBC:** Properties of Unsaturated Zone	**Non-ITBC:** Repository Elevation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.08.15.0A Consolidation of EBS Components **Excluded**	The chemical and mechanical degradation rates of the principal load-bearing features of the EBS (notably the drip shield, waste package, waste package internals, waste package emplacement pallet, and invert) are sufficiently slow that mechanical integrity of the EBS components is retained, and consolidation will not occur even given unlikely seismic events. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.15.0A	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Properties of the Host Rock Unit	**Non-ITBC:** Waste Package Outer Barrier Material Specifications Waste Package Quantities Verification of Design Rock Properties Waste Package and Emplacement Pallet Static Stresses Repository Geographic and Geologic Location Drip Shield Design Drip Shield Design and Installation Drip Shield Materials and Thicknesses Seismic Design of Waste Package Drip Shield Seismic Performance
Emplacement Drift	2.1.09.01.0A Chemical Characteristics of Water in Drifts **Included**	The chemical characteristics of water in the drift are affected by the incoming water chemistry (due to seepage, condensation, or wicking) and evaporation, and other thermal-chemical processes in the drift that are a function of the thermal-hydrologic environment. These chemical characteristics affect the likelihood of potential degradation, deterioration, and alteration of the other EBS components, as well as affecting the transport characteristics of any radionuclides released from the waste package to the invert (SNL 2007 [DIRS 177412], Section 6.13). The results of the models for evaluating the evolution of the in-drift chemical Environment combined with the degradation characteristics and models of the drip shield and waste package, significantly affect the barrier capability of the EBS.	Yes	**ITBC:** Seepage Water Properties In-Drift Chemical Environment Radionuclide Inventory and Source-Term Properties In-Drift Thermal Environment Convection, Condensation, and Evaporation	**ITBC:** Committed Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift (Continued)	2.1.09.01.0A Chemical Characteristics of Water in Drifts **Included** (Continued)	**FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.01.0A		**Non-ITBC:** Waste Form Degradation Corrosion Products Properties Invert Materials, Properties, and Configuration	
Emplacement Drift	2.1.09.02.0A Chemical Interaction with Corrosion Products **Included**	Just as the chemical characteristics of water in the drift are affected by the incoming water chemistry, they are also significantly affected by the water's interaction with the corrosion products in the drift (e.g., waste form, metallic portions of the waste package, rock bolts, steel in the invert, gantry rails). These chemical characteristics affect the likelihood of potential degradation, deterioration, and alteration of the other EBS components as well as affecting the transport characteristics of any radionuclides released from the waste package to the invert (SNL 2007 [DIRS 177412], Section 6.8). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.02.0A	No	**Non-ITBC:** In-Drift Chemical Environment Waste Package Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Corrosion Products Properties Invert Materials, Properties, and Configuration Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration	**Non-ITBC:** Invert Materials Committed Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.09.03.0C Volume Increase of Corrosion Products Impacts other EBS Components **Excluded**	Corrosion of invert structural material, although causing some volume increase, does not significantly affect the barrier capability of the invert or other features of the EBS. The absorption of radionuclides on corrosion products is conservatively ignored. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.03.0C	No	**Non-ITBC:** Invert Materials, Properties, and Configuration	**Non-ITBC:** Invert and EBS Components in Situ Stress and Thermal Response Invert Materials Waste Package Radial Gap Handling of Bare SNF
Emplacement Drift	2.1.09.09.0A Electrochemical Effects in EBS **Excluded**	Potential electrochemical effects between the different features of the EBS have been considered and determined to have an insignificant effect on barrier capability or postclosure performance. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.09.0A	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration	**Non-ITBC:** EBS Materials Interactions - Copper EBS Drip Shield / Emplacement Drift Invert Materials Interactions Waste Package Welding Materials Drip Shield Fabrication Weld Inspection Drip Shield Fabrication Weld Materials Drip Shield Materials and Thicknesses Waste Package Outer Barrier Material Specifications Drip Shield Corrosion Allowance Waste Package Corrosion Allowance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.10.01.0A Microbial Activity in EBS **Excluded**	Microbial effects have been evaluated and determined to not significantly affect the in-drift chemical environment, including water chemistry. The effects of microbial activity on general corrosion of the waste package have been considered and are included in the performance assessment but are insignificant with respect to barrier capability. Biological activity is expected to be limited due to the absence of nutrients. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.10.01.0A	No	**Non-ITBC:** Seepage Water Properties In-Drift Chemical Environment Drip Shield Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Committed Materials Waste Package and TAD Canister Excluded Materials Drip Shield Materials and Thicknesses Invert Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.11.01.0A Heat Generation in EBS **Included**	The heat generated by radioactive decay has multiple effects on repository-relevant processes, including degradation, deterioration, and alteration of the EBS. The heat generation in the emplacement drifts affects the timing of the onset of seepage processes and the distribution of in-drift. Convection and condensation. The heat generation and resultant temperature also affect the water chemistry in the rock and emplacement drifts. The temperature resulting from heat generation, as well as seepage and condensation processes, affects the corrosion of the waste packages and drip shields. The temperature resulting from heat generation also affects the initiation of waste form alteration and radionuclide transport processes dependent on the presence of an aqueous film (SNL 2007 [DIRS 184433], Section 6.2.1[a]), SNL 2007 [DIRS 181648], Executive Summary). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.01.0A	Yes	**ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Seepage Water Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat **Non-ITBC:** Invert Materials, Properties, and Configuration Waste Form Degradation Properties of the Host Rock Unit	**ITBC:** Drip Shield Materials and Thicknesses Waste Package Corrosion Allowance Waste Package Thermal Limits Waste Package Decay Heat Waste Package Spacing Waste Package Thermal Limits **Non-ITBC:** Waste Package Temperature Limit Drift Wall Temperature As-emplaced Waste Package-Drip Shield Configuration Waste Package Handling and Emplacement Verification of Design Rock properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.11.02.0A Nonuniform Heat Distribution in EBS **Included**	Nonuniform heat distribution results from the variability of the heat output from different waste packages, as well as the variability in the location of the waste packages across the repository horizon. This nonuniform heat has been considered in the models of in-drift thermal hydrology (SNL 2007 [DIRS 184433], Section 6.2[a]); SNL 2007 [DIRS 181648], Executive Summary). These gradients only exist for a very short period of time relative to the period of geologic stability (as proposed in 40 CFR 197 [DIRS 177357]) and do not affect chemistry. **FEP Source:** SNL 2008 [DIRS 183041] - 2.1.11.02.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Properties of the Host Rock Unit Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limits Waste Package Decay Heat Waste Package Spacing Waste Package Temperature Limit As-emplaced Waste Package-Drip Shield Configuration Waste Package Handling and Emplacement Verification of Design Rock Properties
Emplacement Drift	2.1.11.03.0A Exothermic Reactions in the EBS **Excluded**	Exothermic reactions in EBS will not significantly increase heat generation beyond the expected thermal output from other sources. Therefore, the omission of exothermic reactions will not lead to additional radionuclide releases to the accessible environment or radiological exposures to the RMEI. This FEP is therefore excluded on the basis of low consequence and is not ITBC.**FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.03.0A	No	**Non-ITBC:** In-Drift Thermal Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drip Shield Corrosion Allowance Waste Package Corrosion Allowance EBS Drip Shield / Emplacement Drift Invert Materials Interactions Committed Materials Waste Package & TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.11.07.0A Thermal Expansion/ Stress of In-drift EBS Components **Excluded**	Although thermal expansion of EBS features occurs, no significant thermal stresses develop in the different features. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.07.0A	No	**Non-ITBC:** In-Drift Thermal Environment Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Pallet Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limits Waste Package Decay Heat Waste Package Temperature Limit Waste Package Thermal Limits Waste Package Decay Heat Drift Wall Temperature Invert and EBS Components In Situ Stress and Thermal Response Drip Shield Design Drip Shield Thermal Expansion Constraint EBS Drip Shield / Emplacement Drift Invert Materials Interactions Waste Package Longitudinal Gap Waste Package Radial Gap

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.11.08.0A Thermal Effects on Chemistry and Microbial Activity in the EBS **Included**	The in-drift temperature substantially affects the evolution of the in-drift chemistry but its impact on microbial activity in the Yucca Mountain environment does not significantly impact barrier capability. Environmental factors will severely limit microbial activity in the repository (see FEP 2.1.13.03.0A). The effects from microbial activity on the in-drift chemical environment are not significant (see FEP 2.1.10.01.0A). The potential for microbially influenced corrosion of the waste package outer barrier is included, although it does not significantly impact barrier capability. (FEP 2.1.03.05.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.08.0A	Yes	**ITBC**: In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Form Degradation Radionuclide Inventory and Source-Term Properties Corrosion Products Properties	**ITBC:** Waste Package Corrosion Allowance Waste Package Thermal Limits Waste Package Decay Heat **Non-ITBC:** Drift Wall Temperature Duration of Ventilation Period Average Airflow Rate for Preclosure Ventilation of Emplacement Drifts Maximum Temperature of HLW Glass Canisters Waste Package Temperature Limit Waste Package Spacing As-emplaced Waste Package-Drip Shield Configuration Verification of Design Rock Properties EBS Drip Shield / Emplacement Drift Invert Materials Interactions

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.11.09.0A Thermal Effects on Flow in the EBS **Included**	The thermal environment has a direct effect on temperature and humidity in the emplacement drifts, which control the corrosion environment, and the conditions for radionuclide mobilization and release (SNL 2007 [DIRS 181648], Executive Summary; SNL 2007 [DIRS 177407], Section 6.3.2.4). Thermal effects on flow dissipate within a few thousand years, and are likely to be insignificant when other barrier degradation processes, such as general corrosion of the drip shield or waste package, lead to release of radionuclides. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.09.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone properties In-Drift Thermal Environment Convection, Condensation, and Evaporation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limits Waste Package Decay Heat Waste Package Spacing Waste Package Temperature Limit As-emplaced Waste Package-Drip Shield Configuration Verification of Design Rock Properties
Emplacement Drift	2.1.11.09.0C Thermally-Driven Flow (convection) in Drifts **Included**	Convective flow of air and moisture in the emplacement drifts has been included in models of in-drift thermal hydrology. However, it does not create an additional source of moisture (SNL 2007 [DIRS 181648], Executive Summary, Table 6.1.2-1, Sections 6.1, 6.2, 6.3 and 6.4). Like other thermal effects on flow (see FEP 2.1.11.09.0A) this process will dissipate within a few thousand years after closure. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.09.0C	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation. Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limits Waste Package Decay Heat Waste Package Spacing Waste Package Temperature Limit As-emplaced Waste Package-Drip Shield Configuration
Emplacement Drift	2.1.12.01.0A Gas Generation (repository pressurization) **Excluded**	The potential effects from gas generation on the total pressure in the emplacement drifts are insignificant because of the potential for dissipative flow, given the ample gas permeability of the fractured host rock **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.01.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone Properties	**Non-ITBC:** Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.12.03.0A Gas Generation (H2) from Waste Package Corrosion **Excluded**	Gas generation can affect the mechanical behavior of the host rock and engineered barriers, chemical conditions, and fluid flow, and, as a result, the transport of radionuclides. Gas generation due to oxic Waste Package Corrosions, cladding, and/or structural materials will occur at early times following closure of the repository. Anoxic corrosion may follow the oxic phase if all oxygen is depleted. The formation of a gas phase around the waste package may exclude oxygen from the iron, thus inhibiting further corrosion. The quantity of hydrogen generated in the waste package is calculated to not have a significant impact on in-package chemistry. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.03.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone Properties Waste Package Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Infiltration and Seepage Properties Seepage Water Properties	**Non-ITBC:** Verification of Design Rock Properties Waste Package Outer Barrier Material Specifications Waste Package Quantities Drip Shield Design Drip Shield Design and Installation Drip Shield Materials and Thicknesses Drip Shield Seismic Performance
Emplacement Drift	2.1.12.04.0A Gas Generation (CO2, CH4, H2S) from Microbial Degradation **Excluded**	The effects of microbial activity on the bulk chemical environment in the emplacement drifts, are not significant because the activity is limited by a range of environmental factors **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.04.0A	No	**Non-ITBC:** Seepage Water Properties In-Package Chemical Environment In-Drift Chemical Environment Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Committed Materials Drip Shield Materials and Thicknesses Waste Package and TAD Canister Excluded Materials Waste Package Outer Barrier Material Specifications

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.12.08.0A Gas Explosions in EBS **Excluded**	Although some explosive gases may exist in the emplacement drifts, these gases are of sufficiently low concentration and there is no viable ignition source for the gas; this process is very unlikely to occur. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.08.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment In-Package Chemical Environment In-Package Thermal Environment	**Non-ITBC:** Committed Materials Waste Package & TAD Canister Excluded Materials
Emplacement Drift	2.1.13.01.0A Radiolysis **Excluded**	Radiolysis will not significantly affect the chemical environment in the emplacement drifts, nor on the surfaces of engineered barrier features. Gamma flux from the waste packages is of limited magnitude and duration, and radiolytic-chemical species will readily disperse. Radiolysis will not affect the in-package chemical environment in a manner that could impact waste form degradation or radionuclide release. While radiolysis may result in some gas generation, the impacts of gas generation also do not significantly impact barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.13.01.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation In-Package Chemical Environment In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Seepage Water Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Design Basis Bounding Dose Rate Waste Package Decay Heat

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.1.13.02.0A Radiation Damage in EBS **Excluded**	Because the estimated neutron fluence is significantly below the neutron fluence threshold for EBS materials, the mechanical properties of EBS features will not be altered by radiation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.13.02.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Worst-Case Dose Rate Waste Package decay Heat Waste Package Design Basis Bounding Dose Rate
Emplacement Drift	2.1.13.03.0A Radiological Mutation of Microbes **Excluded**	Because all potential pathways for microbial activity are already considered possible in the natural environment of the repository, any radiological mutation of microbes is not expected to significantly alter the amount or nature of microbial activity. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.13.03.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Package Chemical Environment	**Non-ITBC:** Waste Package and TAD Canister Excluded Materials Committed Materials
Emplacement Drift	2.2.01.01.0B Chemical Effects of Excavation and Construction in the near field **Excluded**	Excavation and construction have an insignificant effect on the chemistry in the near field, which is dominated by water-rock interactions. In addition, to preclude any potential deleterious effects, construction and operational management and administrative controls will be developed. Therefore, the parameter characteristic associated with this process is not considered ITBC because this does not substantially affect the rate of movement of water and the release or release rate of radionuclides from the Yucca Mountain repository to the accessible environment. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.01.0B	No	**Non-ITBC:** In-Drift Chemical Environment	**Non-ITBC:** Committed Materials Excavation Methods

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.2.01.02.0A Thermally-Induced Stress Changes in the Near Field **Excluded**	Thermally-induced stress changes, could potentially affect drift degradation and thermal-hydrologic processes in the vicinity of the emplacement drifts. Models of drift degradation and coupled thermal-hydrological-mechanical processes, including potential effects on seepage flow into drifts, have shown that these processes will be insignificant. Seismically induced rockfall and drift collapse are evaluated separately (see FEPs 1.2.03.02.0B and 1.2.03.02.0C). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.02.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Properties of the Host Rock Unit Unsaturated Zone Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limit Waste Package Decay Heat Waste Package Spacing Waste Package Temperature Limit As-emplaced Waste Package-Drip Shield Configuration Verification of Design Rock Properties
Emplacement Drift	2.2.01.02.0B Chemical Changes in the Near-Field from Backfill **Excluded**	Changes in host rock properties may result from chemical effects of backfill. Properties that may be affected include permeability and sorption. Since backfill is not to be placed in the drift, this process is not relevant and does not contribute to barrier capability. Deviation from design could negatively impact barrier capability. Deviation from design is managed through the Corrective Action Program, which requires postclosure impact evaluation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.02.0B	No	**Non-ITBC:** In-Drift Chemical Environment	**Non-ITBC:** No Backfill in Emplacement Drifts Committed Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Emplacement Drift	2.2.07.06.0B Long-Term Release of Radionuclides from the Repository **Included**	The release of radionuclides from the repository may occur over a long period of time, as a result of the timing and magnitude of the waste packages and drip shield failures, waste form degradation, and radionuclide transport through the invert. However, this is a high level FEP, which results form the collective impact of a number of more fundamental FEPs. This FEP therefore, is not associated with any additional core or control parameters that have not already been accounted for in the fundamental FEPs that result in the long-term release of radionuclides from the repository. For this reason only, this FEP is considered as Non-ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.06.0B	No	**None** Captured in supporting FEPs	**None**
Emplacement Drift	2.2.08.03.0B Geochemical Interactions and Evolution in the UZ **Excluded**	Chemistry, temperature, and other characteristics of waters in the host rock may change through time, as a result of repository thermal evolution of from mixing with other waters. Effects of repository heating and the resulting coupled processes on flow and transport in the unsaturated zone, will be insignificant because temperature changes will be of limited magnitude, and the hydrological, chemical, and mechanical processes in the siliceous host rock units are only moderately sensitive to temperature. Effects from heating on the near field, and on the chemistry of water flowing into drifts, are addressed separately (see FEPs 2.2.08.12.0A and 2.2.08.04.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.03.0B	No	**Non-ITBC:** Seepage Water Properties In-Drift Chemical Environment Unsaturated Zone Properties Radionuclide Inventory and Source-Term Properties	**Non-ITBC:** EBS Materials Interactions – Copper EBS Drip Shield / Emplacement Drift Invert Materials Interactions No Backfill in Emplacement Drifts Committed Materials Waste Package & TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Emplacement Drift	2.2.08.04.0A Re-Dissolution of Precipitates Directs more Corrosive Fluids to Waste Packages **Excluded**	Re-dissolution of precipitates in the host rock, and transport of affected waters to the in-drift environment, is excluded because this set of processes is a transient response that occurs only at the end of the boiling period. Seepage of affected waters into the drifts will be mitigated by the drip shields, which protect the waste packages from corrosive waters, and are made from titanium which exhibits no significant dependence of corrosion rates on water composition. Thermal-hydrologic-chemical and near-field chemistry models show that after the thermal period, the composition of seepage will closely resemble that of far-field and pre-heating formation waters. Accordingly, this transient response will have no significant impact on degradation of the engineered barrier. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.04.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone Properties In-Drift Chemical Environment Seepage Water Properties	**Non-ITBC:** EBS Materials Interactions - Copper EBS Drip Shield / Emplacement Drift Invert Materials Interactions No Backfill in Emplacement Drifts Committed Materials Waste Package and TAD Canister Excluded Materials Drip Shield Design Drip Shield Design and Installation
Emplacement Drift	2.2.08.12.0A Chemistry of Water Flowing into the Drift **Included**	The chemistry of the seepage water is evaluated in the near-field chemistry model, and in supporting thermal-hydrologic-chemical models. These models have evaluated the range of expected water composition in the host rock, and how these waters change in response to repository heating. Seepage composition can affect corrosion of the waste package outer barrier, if the water contacts the waste package when other conditions such as temperature, promote initiation of localized corrosion. In addition, seepage composition and evaporative evolution in the drift environment can affect the transport of dissolved and colloid radionuclides in the invert. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.12.0A	Yes	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Seepage Water Properties Radionuclide Inventory and Source-Term Properties Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Decay Heat Waste Package Thermal Limits Waste Package Spacing Waste Package Temperature Limit As-emplaced Waste Package-Drip Shield Configuration Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	1.2.02.03.0A Fault Displacement Damages EBS Components **Included**	The core and control parameter characteristics identified are not considered to be ITBC because with administrative controls in place, only a very small number of waste packages and drip shields would be impacted by undetected faults. It is not expected that faults will significantly affect the degradation of the EBS, at annual recurrence intervals of about 10^{-7} per year and less (SNL 2007 [DIRS 176828], Section 6.11.4), and only a small number of drip shields are affected. This degradation process is much less significant than the more likely seismically-induced ground motion effects (SNL 2007 [DIRS 176828], Section 6.7). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.03.0A	No	**Non-ITBC:** Characterization of Fault Displacement Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness Repository Standoff from Quaternary Fault As-Emplaced Waste Package-Drip Shield Configuration
Drip Shield	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	This damage mode substantially impacts the release of radionuclides from the repository. Vibratory ground motion has the potential to cause plastic deformation of drip shield components or separation of adjacent drip shields. Plastic deformation of drip shield components may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. However, the presence of a crack network in drip shield components does not compromise its ability to divert seepage away from the waste package because advective flow through stress corrosion cracks on the drip shield is excluded in FEP 2.1.03.10.0B, Advection of Liquids and Solids Through Cracks in the Drip Shield. Drip shield separation is defined as an axial or vertical gap between two adjacent drip shields that allows seepage to flow directly onto a waste package. Axial separation could occur during a ground motion because of high plastic deformation in the drip shield's connector subassemblies or because of large vertical displacements between adjacent drip shields. Axial separation of adjacent drip shields is excluded from the TSPA model because a kinematic	No	**Non-ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration Characterization of Seismic Events Waste Package Materials, Properties, and Configuration Characterization of Igneous Events	**Non-ITBC:** Repository Elevation – Standoff from the Water Table Repository Geographic and Geologic Location As-Emplaced Waste Package-Drip Shield Configuration EBS Material Interactions -- Copper Drip Shield Seismic Performance Emplacement Pallet Function Seismic Design of Waste Package Waste Package Outer Barrier Material Specifications Waste Package Quantities Verification of Design Rock Properties
Drip Shield	1.2.03.02.0A	study indicates that small static loads from rubble or			

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
(Continued)	Seismic Ground Motion Damages EBS Components **Included** (Continued)	frictional loads between EBS components are sufficient to eliminate axial separation of drip shields (SNL 2007 [DIRS 176828], Section 6.7.3.1). Significant vertical separation between adjacent drip shields is limited by the same physical mechanisms that limit axial separation, and the effects of a vertical separation are also mitigated by the presence of the drip shield connector subassembly which provides an overlap between adjacent drip shields (SNL 2007 [DIRS 176828, Section 6.7.3.2). Vibratory ground motion may also cause waste package-to-drip shield impacts. Lateral impacts of a waste package to the sidewalls of a drip shield do not cause catastrophic failure of the drip shields (SNL 2007 [DIRS 176828], Section 6.8.5). Longitudinal impacts of a waste package to an interior bulkhead on the underside of the drip shield have the potential to tear the bulkhead and rupture the welds that attach the plates to the bulkhead. High-velocity longitudinal impacts with the potential to damage the bulkhead support beams occur with much lower probability than the probability of buckling the sidewalls of the drip shield, as discussed in (SNL 2007 [DIRS 176828] Section 6.8.5). It follows that the drip shield sidewalls are likely to buckle before longitudinal impacts damage the bulkhead support beams and, after the sidewalls buckle, high-velocity longitudinal impacts are eliminated because the waste package can no longer move freely beneath the drip shield. It follows that the drip shield response to vibratory ground motion does not affect the release of radionuclides from the repository to the accessible environment, and is not important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0A			

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	1.2.03.02.0B Seismic-Induced Rockfall Damages Drip Shield **Excluded**	This FEP deals with large block rock fall. Rubble rock fall is dealt with separately under FEP 1.2.03.02.0C. The range of seismic effects encompasses a range of probabilities (both likely and unlikely). _For unlikely peak ground velocities above about 2 m/s, the lithophysal host rock is expected to collapse into the emplacement drifts. (SNL 2007 [DIRS 176828], Section 6.11.1.3). The parameter characteristics associated with this FEP and failure mode are not considered ITBC because seismically induced rockfall calculations demonstrate that rockfall does not damage the drip shield enough to impair its mechanical or hydrological performance. Seismically-induced rockfall in the emplacement drifts has the potential to damage or rupture the drip shields as barriers to flow and as barriers to rockfall. Large rock blocks, primarily in the nonlithophysal units of the repository, may fall out of the roof and walls of an emplacement drift during a seismic event. The impact of these blocks on the drip shields may cause plastic deformation of the drip shield plates, rupture of the drip shield plates, or rupture of the axial stiffeners beneath the crown of the drip shield. Plastic deformation of drip shield plates may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. However, the presence of a crack network in the plates does not compromise the drip shields' capability to divert seepage away from the waste package because advective flow through stress corrosion cracks on the drip shield plates is excluded in FEP 2.1.03.10.0B, Advection of Liquids and Solids Through Cracks in the Drip Shield.	No	**Non-ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration Characterization of Seismic Events	**ITBC:** Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location As-Emplaced Waste Package-Drip Shield Configuration Drip Shield Seismic Performance Drip Shield Design Drip Shield Design and Installation Drip Shield Materials and Thicknesses **Non-ITBC:** Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Drip Shield (Continued)	1.2.03.02.0B Seismic-Induced Rockfall Damages Drip Shield **Excluded** (Continued)	Rock block impacts may also cause rupture of the drip shield plates. However, plate rupture in the nonlithophysal zones has been shown to have low consequence for dose (SNL 2008 [DIRS 183041]–1.2.03.02.0B). Rupture or tearing of the axial stiffeners beneath the crown of the drip shield is also excluded from the TSPA model because the prediction of rupture of the axial stiffeners is based on a very conservative representation for an extreme rock block that occurs for a ground motion with an exceedance frequency below 10^{-8} per year, as explained in (SNL 2008 [DIRS 183041]–1.2.03.02.0B).It follows that the drip shield response to rock blocks induced by vibratory ground motion does not affect the release of radionuclides from the repository to the accessible environment and is not important to barrier capability.. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0B			
Drip Shield	1.2.03.02.0C Seismic-Induced Drift Collapse Damages EBS Components **Included**	This FEP deals with rubble rock fall and drift collapse. Large block rock fall is dealt with separately under FEP 1.2.03.02.0B. Seismically-induced drift collapse in the emplacement drifts has the potential to fail the drip shields as barriers to flow and as barriers to rockfall. Rupture of the drip shield plates or buckling of the sidewalls of the drip shield can occur if the static load from lithophysal rubble plus the dynamic load during a seismic event exceed the ultimate plastic load capacity of the plates or of the drip shield framework (SNL 2007 [DIRS 176828,] Section 6.8). The drip shield response to drift collapse is therefore important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0 C	Yes	**ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration Characterization of Seismic Events	**ITBC:** Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location As-Emplaced Waste Package-Drip Shield Configuration Drip Shield Seismic Performance Drip Shield Design Drip Shield Design and Installation Drip Shield Materials and Thicknesses **Non-ITBC:** Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.03.01.0B General Corrosion of Drip Shields **Included**	General corrosion rates of titanium in the range of likely environmental conditions are low during the regulatory period. This process has been included in models of drip shield degradation (SNL 2007 [DIRS 180778], Section 6). The slow degradation rate of the drip shield by this process is an important beneficial characteristic of the drip shield that substantially reduces the release of radionuclides and their contact with water. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.01.0B	Yes	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Infiltration and Seepage Properties Seepage Water Properties Drip Shield Materials, Properties, and Configuration	**ITBC:** Drip Shield Design Drip Shield Materials and Thicknesses
Drip Shield	2.1.03.02.0B Stress Corrosion Cracking of Drip Shields **Excluded**	Titanium has been shown to be potentially susceptible to the initiation of stress corrosion cracking under likely emplacement drift environments in the presence of mechanical damage from seismic response and rockfall. Although such cracks may be initiated, their propagation and characteristics (size and morphology) are such that they do not allow the advective flow of water through them. Even if some limited flow of water did occur through the cracks, the openings are expected to fill with corrosion products and evaporative mineral deposits, precluding advective flow (FEP 2.1.10.03.0B). Although it is possible that stress corrosion cracking of the titanium drip shield could occur in the regulatory period after closure, the presence of such cracks is insufficient to affect the capability of the drip shield to significantly reduce the amount of water that could directly contact the waste package. Although this process has been excluded from the performance assessment, the lack of significant degradation by this process is an important characteristic of the drip shield feature of the EBS. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.02.0B	Yes	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Drip Shield Materials, Properties, and Configuration	**ITBC:** Drip Shield Heat Treatment Drip Shield Corrosion Allowance Drip Shield Design Drip Shield Materials and Thicknesses Drip Shield Fabrication Drip Shield Fabrication Weld Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.03.03.0B Localized Corrosion of Drip Shields **Excluded**	Titanium is unlikely to be susceptible to localized corrosion over a wide range of expected emplacement drift environmental conditions. Uncertainty in the initiation of localized corrosion using corrosion potentials and critical repassivation potentials (whether by pitting or crevice corrosion) has been considered in the assessment of the likelihood of localized corrosion of the drip shield and excluded from the TSPA. The lack of significant degradation by this process is an important characteristic contributing to the barrier capability of the drip shield feature of the EBS. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.03.0B	Yes	**ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Drip Shield Materials, Properties, and Configuration	**ITBC:** Drip Shield Design Drip Shield Materials and Thicknesses Drip Shield Corrosion Allowance
Drip Shield	2.1.03.04.0B Hydride Cracking of Drip Shields **Excluded**	Hydride cracking of the titanium drip shield is unlikely in the expected emplacement drift environments. This is a function of both the expected environment and the corrosion resistance of the titanium. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.04.0B	No	**Non-ITBC:** In-Drift Chemical Environment Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Drip Shield Heat Treatment Drip Shield Materials and Thicknesses Drip Shield Fabrication Welding Flaws Drip Shield Fabrication Weld Materials EBS Drip Shield / Emplacement Drift Invert Materials Interactions
Drip Shield	2.1.03.05.0B Microbially-Influenced Corrosion of Drip Shields **Excluded**	Microbially influenced corrosion is not expected to significantly affect the degradation rate of the titanium drip shields in the expected emplacement drift environment. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.05.0B	No	**Non-ITBC:** Seepage Water Properties Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Drip Shield Materials and Thicknesses

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.03.07.0B Mechanical Impact on Drip Shield **Excluded**	This FEP deals with non-seismically-induced effects. Although mechanical impacts on the drip shield, induced by rockfall, are expected to occur, their effects will not cause structural failure. Rockfall effects can enhance the possibility of stress corrosion cracking. Stress-induced cracking of the drip shield has a minimal effect on barrier capability because of the size and morphology of the cracks. The effects of seismic ground motion are addressed in a separate FEP. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.07.0B	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Properties of the Host Rock Unit	**Non-ITBC:** As-emplaced Waste Package-Drip Shield Configuration Drip Shield Design Drip Shield Materials and Thicknesses Verification of Design Rock Properties
Drip Shield	2.1.03.08.0B Early Failure of Drip Shields **Included**	Administrative controls for repository construction and operations will be developed to assure that drip shields are manufactured in accordance with design specifications and are emplaced properly. This FEP is included in the TSPA; however, because of the very small number of drip shields associated with the various early failure mechanisms, the significance of the FEP is not substantial. It is ITBC because the design and handling must remain as analyzed for the number of early failures to stay insignificant. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.08.0B	Yes	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration	**ITBC:** Drip Shield Fabrication Drip Shield Handling Drip Shield Heat Treatment Drip Shield Fabrication Welding Flaws Drip Shield Fabrication Weld Inspections Drip Shield Fabrication Weld Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.03.10.0B Advection of Liquids and Solids through Cracks in the Drip Shield **Excluded**	Although cracks may occur in the drip shield (primarily as a result of stress corrosion cracks), the size of these cracks is sufficiently small (on the order of 0.1 to 0.2 mm) and the morphology of these cracks is sufficiently tight that advective flow of water through the cracks is not expected under the expected hydrologic environment in the emplacement drifts (notably, that drips from seepage or condensation on the drift walls are the most likely source of liquid water that could contact the drip shield surface). Although this process has been excluded from the TSPA, the lack of significant advection through cracks in the drip shield is an important characteristic of the drip shield barrier capability. The lack of advection through these cracks, limits or prevents localized corrosion of the waste package, which might otherwise occur under certain conditions. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.10.0B	Yes	**ITBC:** Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties	**ITBC:** Drip Shield Design Drip Shield Corrosion Allowance EBS Drip Shield / Emplacement Drift Invert Materials Interactions Drip Shield Materials and Thicknesses Drip Shield Heat Treatment
Drip Shield	2.1.03.11.0A Physical Form of Waste Package and Drip Shield **Included**	Administrative controls for repository construction and operations will be developed to assure that drip shields are manufactured in accordance with design specifications and are emplaced properly. The physical characteristics of the drip shield, consistent with the design of this feature, have been included in the analyses and models of environments in the emplacement drift and EBS degradation. These characteristics are significant contributors to the capability of the drip shield to limit the flow of water and release of radionuclides. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.11.0A	Yes	**Non-ITBC**: Drip Shield Materials, Properties, and Configuration	**ITBC**: Drip Shield Design Drip Shield Materials and Thicknesses Drip Shield Fabrication Weld Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.06.06.0A Effects of Drip Shield on Flow **Included**	The Importance of the diversion performance of the drip shield is directly related to the lack of significant degradation, or, to the slow rate of degradation, and the limited potential for liquid advection through stress corrosion cracks. The flow diversion, when combined with the lack of advection through the waste package, results in only the potential for diffusive releases from the waste form and waste package if the waste package has degraded features (SNL 2007 [DIRS 181648], Section 6.2.1); (SNL 2007 [DIRS 177407], Section 6.3.3). The drip shield also limits or prevents localized corrosion of the waste package, which might otherwise occur under certain conditions. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.06.0A	Yes	**ITBC:** Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties Seepage Water Properties In-Drift Thermal Environment Convection, Condensation, and Evaporation	**ITBC:** Drip Shield Design and Installation Drip Shield Corrosion Allowance Drip Shield Design Drip Shield Materials and Thicknesses EBS Drip Shield / Emplacement Drift Invert Materials Interactions
Drip Shield	2.1.06.06.0B Oxygen Embrittlement of Drip Shields **Excluded**	Oxygen embrittlement of titanium is not expected in the range of likely thermal-chemical conditions in the emplacement drifts (SNL 2008 [DIRS 183041] – 2.1.06.06.0B). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.06.0B	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment	**Non-ITBC:** Drip Shield Materials and Thicknesses
Drip Shield	2.1.06.07.0A Chemical Effects at EBS Component Interface **Excluded**	Solid-to-solid interactions at the interfaces between the various features of the EBS have been considered in the design and analysis of the in-drift chemical environment such that galvanic coupling and other chemical interactions are insignificant to postclosure performance assessment. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0A	No	**Non-ITBC:** In-Drift Chemical Environment Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Drip Shield Design Drip Shield Materials and Thicknesses Drip Shield Fabrication Weld Materials EBS Drip Shield / Emplacement Drift Invert Materials Interactions
Drip Shield	2.1.06.07.0B Mechanical Effects at EBS Component Interfaces **Excluded**	The mechanical effects of static loading that occur at interfaces between materials in the emplacement drift do not significantly impact the capability of the Drip Shield to limit the flow of water contacting the Waste package. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0B	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Drip Shield Design Drip Shield Design and Installation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.07.01.0A Rockfall **Excluded**	Rockfall may occur in the lithophysal region of the repository, but the rock size is too small to cause significant damage to the drip shield. Rockfall may also occur in the nonlithophysal region of the repository; however the bounding rock calculated, was calculated to not rupture the drip shield and to not deflect enough to contact the waste package. Seismic-induced rockfall is addressed in a separate FEP. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.01.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration	**Non ITBC**: As-emplaced Waste Package-Drip Shield Configuration Verification of Design Rock Properties Drip Shield Materials and Thicknesses Drip Shield Design Drip Shield Design and Installation
Drip Shield	2.1.07.04.0B Hydrostatic Pressure on Drip Shield **Excluded**	Because the emplacement drifts are located more than 120 m above the water table, hydrostatic pressures are unlikely in the drifts, and this process is, therefore, very unlikely to affect drip shield degradation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.04.0B	No	**Non-ITBC:** Properties of Unsaturated Zone	**Non-ITBC:** Repository Elevation-Overburden Thickness Repository Geographic and Geologic Location Repository Standoff From Perched Water
Drip Shield	2.1.07.05.0B Creep of Metallic Materials in the Drip Shield **Excluded**	Although creep of titanium may occur, the rates are sufficiently low in repository-relevant conditions that no significant degradation of the drip shield occurs, even for long durations so it is excluded from TSPA. It is ITBC because the design and handling must remain as analyzed for the number of early failures to stay insignificant. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.05.0B	Yes	**ITBC:** Drip Shield Materials, Properties, and Configuration **Non-ITBC:** In-Drift Thermal Environment	**ITBC:** Drip Shield Materials and Thicknesses

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.08.14.0A Condensation on Underside of Drip Shield **Excluded**	Significant condensation on the underside of the drip shield is not anticipated for the expected range of emplacement drift thermal-hydrologic conditions. Even if such condensation does occur, the resulting liquid flux would either run off the sides of the drip shield or waste package or fall onto cracks in the waste package that do not allow significant advective flux of water. Consequently, the mode of release from the waste package would be diffusive, rather than advective. Therefore, this process is excluded from the TSPA and is not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.14.0A	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Invert Materials Properties, and Configuration In-Drift Thermal Environment Convection, Condensation, and Evaporation	**Non-ITBC:** Drip Shield Design Emplacement Drift Invert Function Invert Materials As-emplaced Waste Package-Drip Shield Configuration
Drip Shield	2.1.09.28.0B Localized Corrosion on Drip Shield Surfaces due to Deliquescence **Excluded**	The potential for salts to deliquesce on the drip shield surface has been evaluated. Although the potential for salts to deliquesce exists, the effects of such deliquescence are insignificant due to the lack of initiation of localized corrosion on the drip shield for a wide range of environmental conditions, including deliquescent brine conditions. The lack of significant degradation by this process is an important characteristic contributing to the barrier capability of the drip shield feature of the EBS. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.28.0B	Yes	**ITBC**: Drip Shield Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Seepage Water Properties	**ITBC**: Drip Shield Materials and Thicknesses Drip Shield Corrosion Allowance Drip Shield Design EBS Drip Shield / Emplacement Drift Invert Materials Interactions

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Drip Shield	2.1.11.06.0B Thermal Sensitization of Drip Shields **Excluded**	Thermal sensitization of titanium is not expected for the range of likely thermal conditions in the emplacement. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.06.0B	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Drip Shield Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drip Shield Materials and Thicknesses Waste Package Temperature Limit As-emplaced Waste -Drip Shield Configuration Waste Package Spacing Waste Package Thermal Limit Waste Package Decay Heat Verification of Design Rock Properties
Drip Shield	2.1.11.07.0A Thermal Expansion/ Stress of In-drift EBS Components **Excluded**	Repository heat at Yucca Mountain could result in thermally-induced stresses. These stresses could affect the EBS components, thus causing the formation of pathways for groundwater flow through the EBS or altering and/or enhancing existing pathways. Although thermal expansion of the drip shield occurs, this expansion is not significant under repository conditions and the design of the drip shield accommodates thermal expansion up to a 300°C temperature, which is higher than calculated postclosure temperatures. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.07.0A	No	**Non-ITBC:** In-Drift Thermal Environment Drip Shield Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drip Shield Design Drip Shield Materials and Thicknesses Drip Shield Thermal Expansion Constraint Waste Package Spacing Waste Package Decay Heat Waste Package Thermal Limits Verification of Design Rock Properties As-emplaced Waste Package-Drip Shield Configuration
Drip Shield	2.1.13.02.0A Radiation Damage in EBS **Excluded**	Because the estimated neutron fluence is significantly below the waste package metals' damage thresholds, the mechanical properties of the EBS features will not be altered by radiation damage. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.13.02.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Design Basis Bounding Dose Rate Waste Package Worst-Case Dose Rate Waste Package Decay Heat

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	1.2.02.03.0A Fault Displacement Damages EBS Components **Included**	The subsurface layout maintains a 60 meter standoff distance between the repository and the Solitario Canyon and Ghost Dance faults. This standoff ensures that EBS components are not damaged by displacement on these faults, so these faults do not influence the release of radionuclides from the Yucca Mountain repository to the accessible environment. Within the repository block, waste packages will be emplaced on known secondary faults (Sundance fault, Drill Hole Wash fault, Sever Wash fault, Pagany Wash fault, and the western splay of the Ghost Dance fault) and on hypothetical faults with a cumulative offset of 2 meters (SNL 2007 [DIRS 176828] Section 6.11.2). The potential damage to the waste packages, its internals, and the waste forms from displacement on these faults is included in the TSPA model (SNL 2007 [DIRS 176828] Section 6.11.5). However, it is not expected that damage to the emplacement pallet from fault displacement will significantly affect dose because waste package failures occur for annual exceedance frequencies of less than 2.5×10^{-7} and because the emplacement pallet is affected at only a limited number of locations in the emplacement drifts. Additionally, This degradation process is much less significant than the more likely seismic-induced ground motion effects.	No	**Non-ITBC:** Characterization of Fault Displacement	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness Repository Standoff from Quaternary Fault As-emplaced Waste Package-Drip Shield Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package (Continued)	1.2.02.03.0A Fault Displacement Damages EBS Components **Included** (Continued)	The response of the waste form and waste package internals to fault displacement is not important to barrier capability. Naval SNF canisters have additional requirements related to emplacement away from faults. For naval SNF packages, these emplacement requirements are important to waste isolation. There is a specific criterion for naval waste packages that requires an 8.2-ft (2.5-m) minimum emplacement standoff distance from mapped faults with vertical displacements greater than 6.5 ft (2 m) (BSC 2007 [DIRS 182131], Section 8.2.3.1.1). Based on this evaluation, this is ITBC (and also ITWI) specifically for naval waste packages. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.03.0A			
Waste Package	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to damage the waste packages from waste package-to-waste package impacts and from waste package-to-pallet impacts that may occur during a seismic event. These impacts may cause plastic deformation of the waste packages outer corrosion barrier (OCB) or cause rupture/puncture of the OCB. Plastic deformation of the OCB may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. Once the OCB is breached by a crack network, diffusive releases of radionuclides can occur from the waste packages. Once the OCB is ruptured or punctured, advective release of radionuclides can occur from the waste packages. The response of waste packages to vibratory ground motion is important for barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0A	Yes	**ITBC:** Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Characterization of Seismic Events **Non-ITBC:** Pallet Materials, Properties, and Configuration Properties of the Host Rock Unit	**ITBC:** As-emplaced Waste Package-Drip Shield Configuration Seismic Design of Waste Package Drip Shield Seismic Performance Waste Package Outer Barrier Material and Thickness Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location Emplacement Pallet Function **Non-ITBC:** Emplacement Pallet Fabrication and Corrosion Allowance Verification of Design Rock Properties

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.03.01.0A General Corrosion of Waste Packages **Included**	General corrosion rates of Alloy 22 (UNS N06022) for a range of likely environmental conditions in the emplacement drifts are so low that failure by general corrosion is not predicted for several hundred thousand years. Uncertainty in these corrosion rates has been included in the model. The slow degradation rate of Alloy 22 under expected repository conditions is an important beneficial characteristic of the waste package feature. Although the stainless steel inner shell of the waste package provides resistance to general corrosion processes, this component of the waste package has been conservatively modeled to provide no delay of penetration of the waste package once the waste package Alloy 22 outer barrier has been breached (SNL 2007 [DIRS 178519], Section 1). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.01.0A	Yes	**ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Infiltration and Seepage Properties Seepage Water Properties	**ITBC:** Materials Contacting the Waste Package Waste Package Outer Barrier Material and Thickness Waste Package Design Basis Bounding Dose Rate Waste Package Quantities Drip Shield Corrosion Allowance Drip Shield Design Drip Shield Materials and Thicknesses
Waste Package	2.1.03.02.0A Stress Corrosion Cracking of Waste Packages **Included**	Stress-induced corrosion cracking of Alloy 22 may occur as a result of mechanical degradation following seismic events. Such stress cracks are sufficiently small and tight to allow only the diffusive transport of radionuclides through the cracks (SNL 2007 [DIRS 181953], Section 6.8.6). The lack of significant stress corrosion cracking of waste packages, except in the event of seismically-induced damage, is an important characteristic of the waste package. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.02.0A	Yes	**ITBC:** In-drift Chemical Environment In-drift Thermal Environment Waste Package Materials, Properties, and Configuration	**ITBC:** Waste Package Annealing Waste Package Closure Waste Package Surface Finish Waste Package Fabrication Welding Flaws Drip Shield Seismic Performance Seismic Design of Waste Package Waste Package and Emplacement Pallet Static Stresses Waste Package Outer Barrier Material and Thickness Waste Package Quantities **Non-ITBC:** As-emplaced Waste Package-Drip Shield Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.03.03.0A Localized Corrosion of Waste Packages **Included**	Localized corrosion mechanisms on the waste package surface are dependent on the thermal-hydrologic and thermal-chemical environment on the waste package surface. The likelihood of initiating localized corrosion is possible in those cases where the drip shield has degraded sufficiently that incoming seepage is allowed to contact the waste package, such as in the fault displacement modeling case of the Seismic Scenario Class. In this case, waste packages that are susceptible to localized corrosion will have already experienced mechanical damage failure. The possibility of localized corrosion also requires particular antecedent geochemical conditions that are generally not present (SNL 2007 [DIRS 178519], Section 6.4.4). The general absence of the conditions necessary to initiate localized corrosion is an important beneficial characteristic on the waste package. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.03.0A	Yes	**ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Infiltration and Seepage Properties Seepage Water Properties	**ITBC:** EBS Materials Interactions - Copper Waste Package Corrosion Allowance Drip Shield Design Drip Shield Corrosion Allowance Drip Shield Seismic Performance As-emplaced Waste Package-Drip Shield Configuration Waste Package Outer Barrier Material and Thickness Waste Package Quantities **Non-ITBC:** Drip Shield Design and Installation As-emplaced Waste Package-Drip Shield Configuration Waste Package and Emplacement Pallet Static Stresses Waste Package Surface Damage Prior to Closure
Waste Package	2.1.03.04.0A Hydride Cracking of Waste Packages **Excluded**	Hydride cracking of Alloy 22 is unlikely over the expected range of emplacement drift environmental conditions. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.04.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Waste Package Materials, Properties, and Configuration Waste Package Temperature Limit	**Non-ITBC:** EBS Materials Interactions - Copper Waste Package Outer Corrosion Barrier Material Specifications

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	**FEP Number, Name, and Screening Decision**	**Discussion of Effect on Barrier Capability**	**Relates to ITBC[1]**	**Core Parameter Characteristic[2]**	**Control Parameter Characteristic[3]**
Waste Package	2.1.03.05.0A Microbially-Influenced Corrosion of Waste Packages **Included**	General corrosion rates of Alloy 22 in a range of likely environmental conditions are sufficiently low to minimally affect the degradation characteristics of the waste package. Uncertainty in these corrosion rates has been included in the model (SNL 2007 [DIRS 178519], Section 6.4). The slow degradation rate of Alloy 22 under expected repository conditions is an important beneficial characteristic of the waste package feature. The consideration of microbially influenced corrosion of the waste packages still results in sufficiently low degradation rates of the waste package. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.05.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Seepage Water Properties	**Non-ITBC:** Waste Package Quantities Waste Package Outer Barrier Material Specifications Committed Materials Waste Package Corrosion Allowance
Waste Package	2.1.03.06.0A Internal corrosion of waste packages prior to breach **Excluded**	Due to the low humidity internal to the waste package, it is not expected that internal corrosion will occur prior to breaching of the waste package by other degradation modes. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.06.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms Waste Package Corrosion Allowance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.03.07.0A Mechanical Impact on Waste Package **Excluded**	Mechanical degradation of the waste package can lead to increased stresses and increased likelihood of stress corrosion cracking. Such mechanical degradation due to vibratory ground motion is included in the TSPA Model. In the absence of vibratory ground motions, mechanical impacts are insignificant to waste package degradation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.07.0A	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Properties of the Host Rock Unit Pallet Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Internal Pressurization Waste Package Surface Damage Marring Prior to Closure Waste Package Radial Gap Waste Package Surface Marring Prior to Emplacement Waste Package Quantities Materials Contacting the Waste Package Waste Package Outer Barrier Material Specifications EBS Drip Shield / Emplacement Drift Invert Materials Interactions Drip Shield Corrosion Allowance Drip Shield Design Drip Shield Handling Drip Shield Design and Installation Drip Shield Materials and Thicknesses

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.03.08.0A Early Failure of Waste Packages **Included**	The potential for and resultant consequences of early failure of the waste package by manufacturing defects or weld flaws exists, and has been considered in the TSPA Nominal Scenario Class (SNL [DIRS 181953], Section 6.2). Because of the very limited number of waste packages expected to be damaged by the early failure mechanisms, the impact is not substantial. It is ITBC because the design and handling must remain as analyzed for the number of early failures to stay insignificant. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.08.0A	Yes	**Non-ITBC:** Waste Package Materials, Properties, and Configuration	**ITBC:** Waste Package Annealing Waste Package Closure Waste Package Fabrication Waste Package Handling Waste Package Surface Damage Prior to Closure Waste Package Surface Finish Waste Package Fabrication Weld Inspections Waste Package Welding Materials Waste Package Fabrication Welding Flaws Non-ITBC Emplacement Drift Ground Support
Waste Package	2.1.03.10.0A Advection of Liquids and Solids through Cracks in the Waste Package **Excluded**	Cracks in the waste package, which may result from mechanical degradation associated with seismic activity, are of insufficient size to allow significant advective flux of water, and therefore this process is excluded from the performance assessment. However, cracks can allow moisture to enter the waste package via diffusion in sufficient amounts to initiate degradation and alteration of the materials and waste forms inside the waste package. In addition, diffusive transport through these cracks is the dominant transport process for radionuclides released from the waste. The lack of significant advection through cracks in the waste package is an important beneficial characteristic of the waste package feature. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.10.0A	Yes	**ITBC:** Infiltration and Seepage Properties Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**ITBC:** Seismic Design of Waste Package Waste Package Corrosion Allowance Drip Shield Corrosion Allowance Drip Shield Design Drip Shield Early Failure Drip Shield Design and Installation Drip Shield Materials and Thicknesses Drip Shield Seismic Performance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.03.11.0A Physical Form of Waste Package and Drip Shield **Included**	The physical characteristics of the waste package, consistent with the design of this feature, have been included in the analyses and models of waste package degradation. These characteristics are significant contributors to the capability of the waste package to limit the degradation of the waste package and limit the release of radionuclides into the EBS. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.11.0A	Yes	**Non-ITBC:** Waste Package Materials, Properties, and Configuration	**ITBC:** As-emplaced Waste Package-Drip Shield Configuration Waste Package Dimensions and Component Masses Waste Package Quantities
Waste Package	2.1.06.07.0B Mechanical Effects at EBS Component Interfaces **Excluded**	Administrative controls for the repository construction and operations will be developed to assure that waste packages and drip shields are placed in accordance with the repository design. Physical effects of steady-state contact (static loading) that occur at the interfaces between materials in the drift may affect the performance of the system. The mechanical effects of static loading that occur at interfaces between materials in the emplacement drift are not significant to the postclosure performance of the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0B	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Emplacement Pallet Design Emplacement Pallet Function EBS Materials Interactions – Emplacement Pallet Function Emplacement Pallet Fabrication and Corrosion Allowance Waste Package and Emplacement Pallet Static Stresses As-Emplaced Waste Configuration./ Waste Package Outer Barrier Material Specifications

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.07.01.0A Rockfall **Excluded**	Rockfall resulting from gravitational stresses, excavation-induced stresses, and thermally-induced stresses have been evaluated. The lithophysal rock units generally result in small blocks, while larger rock blocks are possible in the nonlithophysal rock units. In either case, the effects of rockfall on drip shields, have been considered and determined to be insignificant due to the limited extent of the rockfall, the limited stress-induced cracking of the drip shield, the preclusion of flux through the cracked drip shield, and the limited deformation of the drip shield such that it does not contact the waste package due to rockfall. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.01.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Seismic Design of Waste Package As-emplaced Waste Package-Drip Shield Configuration- Waste Package Dimensions and Component Masses Waste Package Quantities Drip Shield Corrosion Allowance Drip Shield Design Drip Shield Design and Installation Drip Shield Materials and Thicknesses Drip Shield Seismic Performance Verification of Design Rock Properties EBS Drip Shield / Emplacement Drift Invert Materials Interactions Waste Package Surface Damage Prior to Closure Design of Ground Support System Emplacement Drift Configuration Emplacement Drift Ground Support

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.07.04.0A Hydrostatic Pressure on Waste Package **Excluded**	Because the emplacement drifts are located more than 120 m above the water table, hydrostatic pressures are very unlikely in the drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.04.0A	No	**Non-ITBC:** Properties of Unsaturated Zone Infiltration and Seepage Properties	**Non-ITBC:** Repository Elevation – Standoff from the Water Table Repository Geographic and Geologic Location Flood Protection
Waste Package	2.1.07.05.0A Creep of Metallic Materials in the Waste Package **Excluded**	Creep of Alloy 22 is not expected in the range of likely thermal conditions in the emplacement drifts. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.07.05.0A	No	**Non-ITBC:** In-Drift Thermal Environment Waste Package Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Outer Barrier Material Specifications Waste Package Quantities Waste Package Welding Materials Waste Package Spacing Waste Package Thermal Limits Waste Package Decay Heat Waste Package Temperature Limit As-emplaced Waste Package-Drip Shield Configuration
Waste Package	2.1.08.15.0A Consolidation of EBS Components **Excluded**	The chemical and mechanical degradation rates of the principal load-bearing features of the EBS (notably the drip shield, waste package, waste package internals, waste package emplacement pallet, and invert) are sufficiently slow that the mechanical integrity of the EBS components does not lead to consolidation, even given unlikely seismic events. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.15.0A	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Properties of the Host Rock Unit	**Non-ITBC:** Waste Package Outer Barrier Material Specifications Waste Package Quantities Verification of Design Rock Properties Waste Package and Emplacement Pallet Static Stresses Repository Geographic and Geologic Location Drip Shield Design Drip Shield Design and Installation Drip Shield Materials and Thicknesses

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Waste Package (Continued)	2.1.08.15.0A Consolidation of EBS Components **Excluded** (Continued)				Seismic Design of Waste Package Drip Shield Seismic Performance Verification of Design Rock Properties
Waste Package	2.1.09.03.0B Volume Increase of Corrosion Products Impacts waste Package **Excluded**	Volume increases associated with degradation of Alloy 22 are not expected to have any deleterious effect on the waste package because these volumes are small and there is limited possibility of such corrosion products forming between the Alloy 22 and stainless steel shells of the waste packages. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.03.0B	No	**Non-ITBC:** Waste Package Materials, Properties, and Configuration Corrosion Products Properties	**Non-ITBC:** Waste Package Radial Gap Waste Package Corrosion Allowance Waste Package Outer Barrier Material Specifications Waste Package Quantities
Waste Package	2.1.09.28.0A Localized Corrosion on Waste Package Outer Surface due to Deliquescence **Excluded**	The potential for salts to deliquesce on the waste package outer surface has been evaluated. Although the potential for salts to deliquesce exists, the effects of such deliquescence have been determined to be insignificant to performance, localized corrosion processes are not expected to be initiated. Even if localized corrosion was initiated, due to the limited volumes, it is likely that the process would not propagate through the waste package outer surface. The lack of significant degradation by this process is an important characteristic contributing to the barrier capability of the drip shield feature of the EBS. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.28.0A	Yes	**ITBC**: Waste Package Materials, Properties, and Configuration Seepage Water Properties In-Drift Chemical Environment **Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation	**ITBC**: Committed Materials Waste Package Quantities Waste Package Outer Barrier Material Specifications Materials Contacting the Waste Package EBS Materials Interactions - Copper EBS Drip Shield / Emplacement Drift Invert Materials Interactions Repository Geographic and Geologic Location
Waste Package	2.1.11.03.0A Exothermic Reactions in the EBS **Excluded**	Exothermic reactions that could liberate heat in the waste and EBS, are insignificant in comparison to the heat generated by radioactive decay. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.03.0A	No	**Non-ITBC:** In-Drift Thermal Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drip Shield Corrosion Allowance Waste Package Corrosion Allowance EBS Drip Shield / Emplacement Drift Invert Materials Interactions Committed Materials Waste Package & TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.11.06.0A Thermal Sensitization of Waste Packages **Excluded**	Thermal sensitization of Alloy 22 is not expected in the range of likely thermal conditions in the emplacement. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.06.0A	No	**Non-ITBC:** In-Drift Thermal Environment Convection, Condensation, and Evaporation Waste Package Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Annealing Waste Package Temperature Limit Waste Package Spacing Waste Package Thermal Limits Waste Package Decay Heat As-emplaced Waste Package-Drip Shield Configuration Waste Package Outer Barrier Material Specifications Waste Package Quantities
Waste Package	2.1.11.07.0A Thermal Expansion/ Stress of In-drift EBS Components **Excluded**	Although thermal expansion of EBS features occurs, no significant stress differentials exist between the different features. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.07.0A	No	**Non-ITBC:** In-Drift Thermal Environment Waste Package Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Temperature Limit Waste Decay Heat Waste Package Thermal Limits Invert and EBS Components in Situ Stress and Thermal Response Waste Package Longitudinal Gap Waste Package Radial Gap

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.12.03.0A Gas Generation (H2) from Waste Package Corrosion **Excluded**	Gas generation can affect the mechanical behavior of the host rock and engineered barriers, chemical conditions, and fluid flow, and, as a result, the transport of radionuclides. Gas generation due to oxic Waste Package Corrosions, cladding, and/or structural materials will occur at early times following closure of the repository. Anoxic corrosion may follow the oxic phase if all oxygen is depleted. The formation of a gas phase around the waste package may exclude oxygen from the iron, thus inhibiting further corrosion. The quantity of hydrogen generated in the waste package is calculated to not have a significant impact on in-package chemistry. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.03.0A	No	**Non-ITBC:** Properties of the Host Rock Unit Unsaturated Zone Properties Waste Package Materials, Properties, and Configuration In-Drift Chemical Environment In-Drift Thermal Environment Infiltration and Seepage Properties Seepage Water Properties	**Non-ITBC:** Verification of Design Rock Properties Waste Package Outer Barrier Material Specifications Waste Package Quantities Drip Shield Design Drip Shield Design and Installation Drip Shield Materials and Thicknesses Drip Shield Seismic Performance
Waste Package	2.1.13.01.0A Radiolysis **Excluded**	Radiolysis will not significantly affect the chemistry of seepage water that may come into contact with the EBS components. Radiolysis will not affect the in-package chemistry in a manner that would impact the TSPA. While radiolysis may result in some additional gas generation, the impacts of gas generation on repository pressurization have been excluded. Thus, radiolysis can be excluded from this perspective as well. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.13.01.0A	No	**Non-ITBC:** In-Drift Chemical Environment Radionuclide Inventory and Source-Term Properties Seepage Water Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Design Basis Bounding Dose Rate Waste Package Decay Heat

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package	2.1.13.02.0A Radiation Damage in EBS **Excluded**	Because the estimated neutron fluence is significantly below the waste package metals' damage thresholds, the mechanical properties of the EBS features will not be altered by radiation damage. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.13.02.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Design Basis Bounding Dose Rate Waste Package Worst-Case Dose Rate Waste Package Decay Heat
Cladding	1.2.02.03.0A Fault Displacement Damages EBS Components **Included**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameters characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. Administrative controls for repository construction and operations will be developed to assure that waste packages are not emplaced on known faults.	No	**Non-ITBC:** Characterization of Fault Displacement	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness Repository Standoff from Quaternary Fault As-emplaced Waste Package-Drip Shield Configuration Emplacement Drift Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding (Continued)	1.2.02.03.0A Fault Displacement Damages EBS Components **Included** (Continued)	Naval SNF canisters have additional requirements related to emplacement away from faults. For naval SNF packages, these emplacement requirements are important to waste isolation. There is a specific criterion for naval waste packages that requires an 8.2-ft (2.5-m) minimum emplacement standoff distance from mapped faults with vertical displacements greater than 6.5 ft (2 m) (BSC 2007 [DIRS 182131], Section 8.2.3.1.1). Based on this evaluation, this is ITBC (and also ITWI) specifically for naval waste packages. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.03.0A			
Cladding	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF structure (including cladding) deals with Navy cladding separately. Seismic effects are included in the Seismic Ground Motion Modeling Case of the Seismic Scenario Class. Except for Naval SNF, no credit is taken for cladding integrity in the TSPA. However, cladding provides barrier capability and thus has core and control parameters characteristics that limit its degradation at high temperatures or from mechanical loads. The core and control parameter characteristics identified are not considered to be ITBC because this barrier feature/component is not accounted for in the technical basis. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0A	Yes	**ITBC:** Waste Package Materials, Properties, and Configuration Characterization of Seismic Events **Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Properties of the Host Rock Unit	**ITBC**: Seismic Design of Waste Package Drip Shield Seismic Performance Waste Package Outer Barrier Material Specifications EBS Material Interactions **Non-ITBC:** As-emplaced Waste Package-Drip Shield Configuration Emplacement Pallet Function Emplacement Pallet Fabrication and Corrosion Allowance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.11.0A Degradation of Cladding from Waterlogged Rods **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. Waterlogged rods are not expected in a waste package, and given the low volume of water in a degraded waste package; the degradation of cladding from waterlogged rods is not expected to affect the release of radionuclides from the waste. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.11.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Handling of Waste Forms Waste Package Moisture Removal and Inerting Waste Package and TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.12.0A Degradation of Cladding prior to Disposal **Included**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.12.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Handling of Waste Forms Loading of Waste Forms

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.13.0A General Corrosion of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. The general corrosion resistance of zirconium-clad waste forms is such that insignificant corrosion of this material is expected to occur, even after the waste packages containing these waste forms have been breached. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.13.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment In-Package Thermal Environment	**Non-ITBC:** Cladding Temperature Limit - - Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.14.0A Microbially Influenced Corrosion of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. The general corrosion resistance of zirconium-clad waste forms and the lack of susceptibility of this material to microbially influenced corrosion under expected emplacement drift environments are such that insignificant microbially influenced corrosion of this material is expected to occur, even after the waste package has been breached. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.14.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment In-Package Thermal Environment	**Non-ITBC:** Waste Package & TAD Canister Excluded Materials Cladding Temperature Limit - - Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.15.0A Localized (radiolysis enhanced) Corrosion of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. The localized corrosion resistance of zirconium and the lack of susceptibility of this material to radiolysis effects, are such, that insignificant degradation of zirconium is expected to occur, even after the waste package has been breached. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.15.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Design Basis Bounding Dose Rate Cladding Temperature Limit - - Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.16.0A Localized (pitting) Corrosion of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. The localized corrosion resistance of zirconium and the lack of susceptibility of this material to pitting corrosion are such that insignificant degradation of zirconium is expected to occur, even after the waste package has been breached. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.16.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Chemical Environment	**Non-ITBC:** Waste Package Design Basis Bounding Dose Rate Cladding Temperature Limit - - Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.17.0A Localized (crevice) Corrosion of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. The localized corrosion resistance of zirconium and the lack of susceptibility of this material to crevice corrosion are such that insignificant degradation of zirconium is expected to occur, even after the waste package has been breached. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.17.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment In-Package Thermal Environment	**Non-ITBC:** Cladding Temperature Limit - - Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.18.0A Enhanced Corrosion of Cladding from Dissolved Silica **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. The corrosion resistance of zirconium, even in the unexpected presence of dissolved silica, is sufficient to not allow significant degradation of the cladding feature, even after the waste package has been breached. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.18.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment In-Package Thermal Environment	None

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.19.0A Creep Rupture of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. Although cladding can creep, the thermal conditions in the emplacement drifts and waste package internals are such that this process does not lead to significant degradation of the cladding feature, even after the waste package has been breached. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.19.0A	No	**Non-ITBC:** In-Package Thermal Environment Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Cladding Temperature Limit -- Ventilation Waste Package Spacing Waste Package Temperature Limit Waste Package Decay Heat Waste Package Thermal Limits As-emplaced waste package-Drip Shield configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.20.0A Internal Pressurization of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. Under the likely range of thermal conditions in the emplacement drifts and waste package internals, there is insufficient internal pressurization to significantly degrade the zirconium-clad fuels. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.20.0A	No	**Non-ITBC:** In-Package Thermal Environment Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Form CSNF Fuel Rod Maximum Burnup Limit Cladding Temperature Limit - - Ventilation Waste Package Decay Heat Waste Package Thermal Limits

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.21.0A Stress Corrosion Cracking of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. Although cracking of cladding is conceivable, under the range of thermal-mechanical conditions expected in the waste package internals, stress corrosion cracking is not significant and does not affect the capability of the cladding feature to reduce radionuclide releases from the waste. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.21.0A	No	**Non-ITBC:** In-Package Thermal Environment Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Cladding Temperature Limit -- Ventilation Waste Form CSNF Fuel Rod Maximum Burnup Limit Waste Package Spacing Waste Package Temperature Limit Waste Package Decay Heat Waste Package Thermal Limits As-emplaced Waste Package-drip Shield configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.22.0A Hydride Cracking of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. Under the expected range of thermal-mechanical conditions in the waste package internals, hydride cracking of zirconium cladding is not expected to affect the capability of the cladding feature to reduce radionuclide releases from the waste. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.22.0A	No	**Non-ITBC:** In-Package Thermal Environment Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Cladding Temperature Limit -- Ventilation Waste Package Spacing Waste Package Temperature Limit Waste Package Decay Heat Waste Package Thermal Limits As-emplaced Waste Package-Drip Shield configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.23.0A Cladding Unzipping **Included**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. Cladding that contains a breach is assumed to split or unzip along its length when exposed to repository environments. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.23.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation	**Non-ITBC:** Cladding Temperature Limit - - Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.24.0A Mechanical Impact on Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. The mechanical degradation of cladding is very unlikely under nominal repository conditions. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.24.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration	**Non-ITBC:** Drip Shield Design Drip Shield Fabrication Drip Shield Design and Installation Drip Shield Materials and Thicknesses Waste Package Dimensions and Component Masses Waste Package Outer Barrier Material Specifications Waste Package Quantities
Cladding	2.1.02.25.0A DSNF Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.25.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.25.0B Naval SNF Cladding **Included**	The degradation characteristics of the naval SNF structure (including cladding) have been assessed separately from the commercial SNF cladding. These results are contained in a classified document and have been determined to be important to barrier capability. The naval waste package thermal limits are based on an evaluation of impact to naval SNF cladding performance that considers handling of the naval SNF canisters in the surface facilities and naval SNF waste packages in the subsurface facility, along with loss of ventilation events. Emplacement limits listed below are used to determine the maximum temperatures imposed on the naval SNF canister during normal or off normal operations following emplacement. The Naval Nuclear Propulsion Program has evaluated this relationship and determined that the integrated thermal effect on the clad properties of the naval SNF is not affected by limits imposed and therefore preserves the properties or characteristics of the clad as used in the preclosure and postclosure analyses. The thermal loading limits for the naval SNF waste packages are lower than the thermal limits for commercial SNF. These limits are (BSC 2007 [DIRS 182131], Section 8.2.1.5): • Maximum emplacement thermal power of 11.8 kW for waste packages emplaced on either side of a naval SNF waste package • Maximum emplacement thermal line load limit of 1.45 kW/m for any seven-waste-package segment containing a naval SNF waste package **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.25.0B	Yes	**ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	**ITBC:** Cladding Temperature Limit - - Ventilation [specifically the more stringent Naval SNF Structure Thermal Limit]

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Cladding	2.1.02.26.0A Diffusion- Controlled Cavity Growth in Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.26.0A	No	**Non-ITBC:** In-Package Thermal Environment Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Cladding Temperature Limit -- Ventilation Waste Package Spacing Waste Package Decay Heat Waste Package Thermal Limits Waste Package Temperature Limit As-emplaced waste Package-Drip Shield configuration
Cladding	2.1.02.27.0A Localized (fluoride enhanced) Corrosion of Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameters characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.27.0A	No	**Non-ITBC:** In-Package Chemical Environment In-Package Thermal Environment Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Cladding Temperature Limit -- Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Cladding	2.1.09.03.0A Volume Increase of Corrosion Products Impacts Cladding **Excluded**	This FEP does not consider Naval cladding. FEP 2.1.02.25.0B: Naval SNF Cladding deals with Navy cladding separately. Cladding has some barrier capability and thus has core and control parameter characteristics that limit its degradation at high temperatures or from mechanical loads. However, the barrier capability of CSNF cladding is not important because cladding can be damaged by seismic activity that does not damage the waste package (SNL 2007 [DIRS 176828], Section 6.7), and it is destroyed by igneous intrusion. Thus the only opportunity for cladding to support the barrier function is in the early failure scenario. In addition, except for Naval SNF structure, no credit is taken for this capability in the postclosure technical basis. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.03.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation	**Non-ITBC:** Handling of Bare SNF

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	1.2.02.03.0A Fault Displacement Damages EBS Components **Included**	The subsurface layout maintains a 60 meter standoff distance between the repository and the Solitario Canyon and Ghost Dance faults. This standoff ensures that EBS components are not damaged by displacement of these faults, so these faults do not influence the release of radionuclides from the Yucca Mountain repository to the accessible environment. Within the repository block, waste packages will be emplaced on known secondary faults (Sundance fault, Drill Hole Wash fault, Sever Wash fault, Pagany Wash fault, and the western splay of the Ghost Dance fault) and on hypothetical faults with a cumulative offset of 2 meters (SNL 2007 [DIRS 176828], Section 6.11.2). The potential damage to the waste packages, its internals, and the waste forms, from displacement on these faults, is included in the TSPA Model (SNL 2007 [DIRS 176828], Section 6.11.5). However, it is not expected that damage to the emplacement pallet from fault displacement will significantly affect dose because waste package failures occur for annual exceedance frequencies of less than 2.5×10^{-7} and because the emplacement pallet is affected at only a limited number of locations in the emplacement drifts. Additionally, this degradation process is much less significant than the more likely seismically-induced ground motion effects (SNL 2007 [DIRS 176828], Section 6.7). The response of the waste form and waste package internals to fault displacement is not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.03.0A	No	**Non-ITBC:** Characterization of Fault Displacement	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness Repository Standoff from Quaternary Fault As-emplaced Waste Package-Drip Shield Configuration Emplacement Drift Configuration Waste Package Handling and Emplacement

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to damage the waste forms and waste package internals from waste package-to-waste package impacts and from waste package-to-pallet impacts that may occur during a seismic event. These impacts may cause axial and lateral accelerations of the spent fuel assemblies that are large enough to buckle the waste form and the waste package internals. These impacts may also cause plastic deformation of waste package OCB. Plastic deformation of the OCB may result in residual stresses that exceed a tensile threshold for initiation and growth of stress corrosion cracks. Once the OCB is breached by a crack network, corrosion of the waste form and waste package internals will compromise their capacity to support structural loads and to isolate the waste form during vibratory ground motion. The response of the waste form and waste package internals to vibratory ground motion is ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0A	Yes	**ITBC:** Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Properties of the Host Rock Unit Characterization of Seismic Events **Non-ITBC:** Pallet Materials, Properties, and Configuration Invert Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Committed materials	**ITBC:** Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location As-Emplaced Waste-Drip Shield Configuration Drip Shield Seismic Performance Seismic Design of Waste Package EBS Material Interactions **Non-ITBC:** Emplacement Pallet Function Emplacement Pallet Fabrication and Corrosion Allowance Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials Verification of Design Rock Properties Emplacement Pallet Design

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.01.01.0A Waste Inventory **Included**	The waste inventory defines the amount of different radionuclides present in different waste forms (SNL 2007 [DIRS 180472], Section 6.1). While inventory controls the initial conditions in waste form, which is important to the release of radionuclide inventory, it is well characterized and any change to inventory will be managed by the change-evaluation process Additionally, in the evaluation of barrier capability, transport of radionuclides from the waste inventory are evaluated separately in transport-related FEPs. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.01.01.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Criticality Characteristics Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Radionuclide Inventory and Source-Term Properties	**Non-ITBC:** Waste Package Decay Heat Waste Package Thermal Limits Waste Form CSNF Fuel Rod Maximum Burnup Limit Waste Package Design Basis Bounding Dose Rate Waste Package Temperature Limit Cladding Temperature Limit -- Ventilation
Waste Form and Waste Package Internals	2.1.01.02.0A Interactions Between Co-located Waste **Excluded**	Although different waste forms have different inventories, and chemical and thermal characteristics (e.g., HLW glass waste forms versus SNF waste forms), these differences do not significantly affect the capability of the EBS. The models consider these differences in the evaluation of the releases from the waste form. However, there is no significant interaction between the co-located wastes and barrier capability is not substantially impacted. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.01.02.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Criticality Characteristics	**Non-ITBC:** Waste Package Capacities Waste Package Decay Heat Waste Package Thermal Limits Waste Package Temperature Limit Cladding Temperature Limit -- Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.01.02.0B Interactions Between Co-disposed Waste **Included**	The design analyzed considers that DOE SNF and HLW glass will be co-disposed. The different characteristics of these waste forms (in particular the hygroscopic nature of the HLW glass) have been considered in the waste form alteration models and is not found to substantially impact barrier capability of this feature. (SNL 2007 [DIRS 180506], Section 6.3.1.3.4). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.01.02.0B	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Criticality Characteristics	**Non-ITBC:** Waste Package Capacities Waste Package Decay Heat Waste Package Thermal Limits Waste Package Temperature Limit Cladding Temperature Limit - - Ventilation EBS Drip Shield / Emplacement Drift Invert Materials Interactions
Waste Form and Waste Package Internals	2.1.01.03.0A Heterogeneity of Waste Inventory **Included**	The differences in waste inventory of the different waste forms have been included in the evaluation of barrier capability (BSC 2004 [DIRS 169988], Section 6.9; SNL 2007 [DIRS 180472], Sections 6.4 and 6.6). Although there are different mass (or activity) loadings per waste package, these differences are insignificant to the release of solubility-controlled radionuclides, which dominate barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.01.03.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Criticality Characteristics	**Non-ITBC:** Waste Package Decay Heat Waste Package Thermal Limits Waste Package Temperature Limit Cladding Temperature Limit - - Ventilation

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Waste Form and Waste Package Internals	2.1.01.04.0A Repository-scale Spatial Heterogeneity of Emplaced Waste **Included**	Spatial heterogeneity emplaced in waste has been considered in the development of the expected thermal-hydrologic environment in the emplacement drifts, as well as the waste form degradation processes and in-package chemistry. The package-to-package inventory variability is not significant. The heterogeneity of the inventory is included in through the characterization of uncertainty in parameters for the average inventory within the CSNF and codisposal packages (SNL 2007 [DIRS 180472], Section 6.4; 6.6). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.01.04.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Criticality Characteristics	**Non-ITBC:** Waste Package Temperature Limit Cladding Temperature Limit -- Ventilation Waste Package Decay Heat Waste Package Thermal Limits
Waste Form and Waste Package Internals	2.1.02.01.0A DSNF Degradation (alteration, dissolution, and radionuclide release) **Included**	This FEP addresses the degradation, alteration, and dissolution of the DOE SNF waste form, as well as the effects of phase separation, oxidation of spent fuels, selective leaching, and the effects on DOE SNF canister degradation. The impact of these processes can influence the in-package chemistry and therefore the release of radionuclides. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.01.0A	Yes	**ITBC:** In-Package Chemical Environment In-Package Thermal Environment Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms Handling of Bare SNF Waste Package and TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.02.02.0A CSNF Degradation (alteration, dissolution, and radionuclide release) **Included**	This FEP not only encompasses the structure and composition of the CSNF, it also addresses alteration, degradation, and dissolution of the waste form. These processes can influence the mobilization of radionuclides (BSC 2004 [DIRS 169987], Sections 6.1 and 6.2). This FEP defines the essence of the CSNF waste form. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.02.0A	Yes	**ITBC:** In-Package Chemical Environment In-Package Thermal Environment Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**ITBC:** Waste Form CSNF Fuel Rod Maximum Burnup Limit **Non-ITBC:** Waste Package Moisture Removal and Inerting Waste Package & TAD Canister Excluded Materials Loading of Waste Forms Handling of Bare SNF
Waste Form and Waste Package Internals	2.1.02.03.0A HLW Glass Degradation (alteration, dissolution, and radionuclide release) **Included**	This FEP not only encompasses the structure and composition of the high level waste glass waste form, it also addresses alteration and degradation of the waste form. These processes, along with phase separation, congruent dissolution, precipitation of silicates, co-precipitation of other minerals, and selective leaching, substantially impacts the mobilization of radionuclides. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.03.0A	Yes	**ITBC:** In-Package Chemical Environment Parameter In-Package Thermal Environment Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms **Non-ITBC:** Handling of Bare SNF Waste Package and TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.02.04.0A Alpha Recoil Enhances Dissolution **Excluded**	The potential dissolution enhancement due to alpha recoil is insignificant in comparison to the waste form dissolution processes that result from chemical and thermal-chemical alteration. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.04.0A	No	**Non-ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Decay Heat
Waste Form and Waste Package Internals	2.1.02.05.0A HLW Glass Cracking **Included**	HLW glass cracking affects the exposed surface area of the glass that may potentially be contacted by water (whether humid air or liquid). The surface area affects the amount of radionuclides potentially Applicable for diffusion into a mobile phase and potentially Applicable for transport away from the waste. This process is included in the glass degradation model; however, it is not identified as ITBC because the amount of radionuclides that can be released from cracks is much smaller than from free surfaces. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.05.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms Maximum Temperature of HLW Glass Canisters

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.02.06.0A HLW Glass Recrystallization **Excluded**	HLW glass recrystallization affects the exposed surface area of the glass that may be potentially contacted by water. However, these effects are insignificant in comparison to the effects of HLW glass cracking and are not considered to be ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.06.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms Maximum Temperature of HLW Glass Canisters
Waste Form and Waste Package Internals	2.1.02.07.0A Radionuclide Release from Gap and Grain Boundaries **Included**	Radionuclides may be released to a mobile liquid phase upon degradation of the cladding. It is modeled to occur immediately following the degradation of the cladding (BSC 2004 [DIRS 169987], Sections 6.2.1 and 6.3.1). However, this release from the gap and grain boundaries is a small fraction of the total inventory (BSC 2004 [DIRS 169987], Section 6.3.1 and Table 6-2). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.07.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms
Waste Form and Waste Package Internals	2.1.02.08.0A Pyrophoricity from DSNF **Excluded**	This process, which is not expected to occur in the waste package internals, has no significant effect on the model degradation characteristics of DOE SNF, which is conservatively modeled to degrade instantaneously following the breach of the waste package. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.08.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.02.09.0A Chemical Effects of Void Space in Waste Package **Included**	Chemistry effects of voids in the waste package internals are included in models of in-package chemistry (SNL 2007 [DIRS 180506], Section 6.3.1.1). In-package chemistry contributes significantly to the solubility characteristics of radionuclides, the degradation of waste package internals and waste form, and the transport behavior of radionuclides released from the waste form. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.09.0A	Yes	**ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Corrosion Products Properties In-Package Chemical Environment **Non-ITBC:** In-Package Thermal Environment Waste Form Degradation	**Non-ITBC:** Waste Package & TAD Canister Excluded Materials Waste Package Corrosion Allowance Waste Package Moisture Removal and Inerting Waste Form Moisture Removal and Inerting
Waste Form and Waste Package Internals	2.1.02.10.0A Organic/ Cellulosic Materials in Waste **Excluded**	No organic or cellulosic material will be included in the waste form – with the possible exception of minor quantities of adventitious, possibly organic, carbon. This is not expected to substantially impact the barrier capability of this feature. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.10.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package and TAD Canister Excluded Materials
Waste Form and Waste Package Internals	2.1.02.28.0A Grouping of DSNF Waste Types into Categories **Included**	All DSNF fuel types and the quantities of each fuel type were considered when compiling the nominal radionuclide inventory in grams per package and uncertainty distributions for radionuclides important to dose calculations for the TSPA (SNL 2007 [DIRS 180472], Sections 6.4 and 6.6.2). An upper-bound model is used in TSPA to model degradation of all of the DSNF fuel types other than Naval SNF (BSC 2004 [DIRS 172453], Section 6.3)). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.28.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Decay Heat Waste Package Thermal Limits

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.02.29.0A Flammable Gas Generation from DSNF **Excluded**	This process, which is not expected to occur in the waste package internals, has no significant effect on the model degradation characteristics of DOE SNF. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.02.29.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Waste Package & TAD Canister Excluded Materials Loading of Waste Forms
Waste Form and Waste Package Internals	2.1.03.06.0A Internal corrosion of waste packages prior to breach **Excluded**	Due to the low humidity internal to the waste package, it is not expected that internal corrosion will occur prior to breaching of the waste package by other degradation modes. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.03.06.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Waste Package Moisture Removal and Inerting Loading of Waste Forms Waste Package Corrosion Allowance
Waste Form and Waste Package Internals	2.1.09.01.0B Chemical Characteristics of Water in Waste Package **Included**	The chemical characteristics of the water in contact with the waste package internals, including void spaces, and the waste form, affect the degradation characteristics of the waste form, the solubility of radionuclides in the dissolved phase, and the stability of colloidal particles. These chemical effects are significant in affecting release of low solubility radionuclides (e.g., ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) and radionuclides that may be released attached to colloidal particles (e.g., ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am) (SNL 2007 [DIRS 180506]). These characteristics, as well as uncertainty in the in-package chemistry, in particular the ionic strength and pH, which have the most significant effect on these coupled processes, are included in the in-package chemistry and solubility models (SNL 2007 [DIRS 180506], Sections 6.10.8 and 8.1). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.01.0B	Yes	**ITBC:** Waste Package Materials, Properties, and Configuration Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration In-Package Chemical Environment Radionuclide Inventory and Source-Term Properties Corrosion Products Properties **Non-ITBC:** In-Package Thermal Environment	**ITBC:** Waste Package Dimensions and Component Masses Waste Package Quantities **Non-ITBC:** Waste Package Internal Pressurization

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.02.0A Chemical Interaction with Corrosion Products **Included**	Just as the chemical characteristics of water in the drift are affected by the incoming water chemistry, they are also significantly affected by the water's interaction with the corrosion products in the drift (e.g., waste form, metallic portions of the waste package, rock bolts, steel in the invert, gantry rails). No credit is taken for the corrosion products affecting the transport characteristics of radionuclides released from the waste package to the invert, which acts to maximize the rate of radionuclide transport through the invert (SNL 2007 Radionuclide Transport AMR, ANL-WIS-PA-000001, rev 03 Section 5.6). Furthermore, the effects of chemical degradation of these components have been demonstrated to have a negligible effect on the composition of seepage waters (SNL 2007 [DIRS 177412], Section 6.8). Therefore the effects of chemical interactions with corrosion products are insignificant to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.02.0A	Yes	**ITBC:** In-Package Chemical Environment Waste Form/Package Internals Materials, Properties, and Configuration Corrosion Products Properties **Non-ITBC:** Waste Form Degradation	**Non-ITBC:** Waste Package Corrosion Allowance EBS Drip Shield / Emplacement Drift Invert Materials Interactions EBS Materials Interactions - Copper Waste Package Outer Barrier Material Specifications
Waste Form and Waste Package Internals	2.1.09.04.0A Radionuclide Solubility, Solubility Limits, and Speciation in the Waste Form and EBS **Included**	Solubility limits of low solubility dissolved radionuclides significantly affect the amount of these radionuclides that may be released from the waste form through the other EBS features (SNL 2007 [DIRS 180506]). The more soluble the radionuclide, generally the greater the mass flux of that radionuclide that will be released by diffusive or advective release mechanisms from the waste form. Uncertainty in these solubilities and the effects of waste package internal chemistry variability and uncertainty have been included in the models of waste form release (SNL 2007 [DIRS 177418], Section 8.1). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.04.0A	Yes	**ITBC:** In-Package Chemical Environment In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package and TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.05.0A Sorption of Dissolved Radionuclides in EBS **Included**	The degradation of the waste package internals (stainless steel) results in a significant quantity of iron/chromium/nickel oxide materials. These materials have a significant amount of retardation potential for a number of radionuclides potentially significant for the release from the waste form (SNL 2007 [DIRS 180506]). This sorption significantly reduces the release from the waste for these radionuclides in the event that a breach in the waste package has occurred. The significance of this process is illustrated in the mass flux releases from the waste form and waste package features (SNL 2007 [DIRS 180506])). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.05.0A	Yes	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties	**None**
Waste Form and Waste Package Internals	2.1.09.06.0A Reduction-oxidation Potential in Waste Package **Included**	The in-package redox state is assumed to be set by the oxidation state in the emplacement drifts once the waste package is breached and therefore set to 0.2 atmospheres (SNL 2007 [DIRS 180506] Table 6-1a). Therefore the oxidation potential inside the waste package prior to a breach does not affect the release or rate of release of radionuclide from the waste package. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.06.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties	**Non-ITBC:** Waste Package Thermal Limits Waste Package & TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.07.0A Reaction Kinetics in Waste Package **Included**	Reaction kinetics, limit the transport of a host of radionuclides and are implicitly accounted for in the In-Package Chemistry Model, the Dissolved Concentrations Model, and the EBS RTA. The parameter characteristics associated with this process substantially impact the transport of radionuclides from the waste form. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.07.0A	Yes	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties	**ITBC:** Waste Package Thermal Limits Waste Package and TAD Canister Excluded Materials
Waste Form and Waste Package Internals	2.1.09.08.0A Diffusion of Dissolved Radionuclides in EBS **Included**	Diffusion is an important transport mechanism for dissolved radionuclides from the waste form surface to the waste package internals and then through the degraded waste package to the invert. Diffusion is controlled by the degree of degradation of the waste package and the hydrologic characteristics within the waste package, which in turn, is a function of the type of waste. The diffusive transport is conservatively specified to occur through a continuous water film on the surfaces of the EBS features (SNL 2007 [DIRS 177407], Section 6.3.4). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.08.0A	Yes	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Properties	**Non-ITBC:** Waste Package Outer Barrier Material Specifications Waste Package Quantities Waste Package Decay Heat Waste Package Thermal Limits

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals (Continued)	2.1.09.08.0A Diffusion of Dissolved Radionuclides in EBS **Included** (Continued)			**Non-ITBC:** Waste Form Degradation Corrosion Products	
Waste Form and Waste Package Internals	2.1.09.08.0B Advection of Dissolved Radionuclides in EBS **Included**	Advection is an important transport mechanism for dissolved radionuclides from the waste form surface to the waste package internals and then through the degraded waste package to the invert. Advection is controlled by the degree of degradation of the waste package and the hydrologic characteristics within the waste package, which in turn, is a function of the type of waste. The conditions required for advective transport through a waste package are less likely to occur than those conditions required for diffusion. However, when advective transport through the waste package does occur its consequences are more significant compared to that from diffusion mechanisms because of the amount of water involved. Therefore, advection trough the waste package is identified as ITBC. **FEP Source:** SNL 2008 [DIRS 183041]- 2.1.09.08.0B	Yes	**ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration **Non-ITBC:** Waste Form Degradation Corrosion Products Properties	**Non-ITBC:** Waste Package Outer Barrier Material Specifications Waste Package Quantities Waste Package Decay Heat Waste Package Thermal Limits

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.10.0A Secondary Phase Effects on Dissolved Radionuclide Concentrations **Excluded**	Secondary uranium mineral phases, such as schoepite and uranium silicates, which are formed during the alteration of commercial and DOE SNF, can potentially reduce the Applicable dissolved concentration of several key radionuclides, including neptunium, which are chemically bound within the mineral structure of the secondary phase. This reduced concentration might reduce the release of these radionuclides in dissolved form from the waste. Accounting for this process would result in lower solubility limits, which might translate into lower rates of release. However, insufficient data is currently Applicable to include this beneficial process in the technical baseline. The process is currently considered not to be ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.10.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Radionuclide Inventory and Source-Term Properties In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Form Degradation In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.11.0A Chemical Effects of Waste-Rock Contact **Excluded**	Direct contact of the waste with rock particles is not expected due to the lack of advective flux of liquids and solids through cracks in the drip shield or waste package. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.11.0A	No	**Non-ITBC:** Drip Shield Materials, Properties, and Configuration Drip Shield Corrosion Allowance Emplacement Pallet Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Drip Shield Corrosion Allowance Drip Shield Design Drip Shield Materials and Thicknesses EBS Materials Interactions – Copper EBS Drip Shield / Emplacement Drift Invert Materials Interactions Emplacement Pallet Function Emplacement Pallet Design Emplacement Pallet Fabrication and Corrosion Allowance Waste Package Corrosion Allowance Waste Package Dimensions and Component Masses As-emplaced Waste Package-Drip Shield Configuration Waste Package Outer Barrier Material Specifications
Waste Form and Waste Package Internals	2.1.09.15.0A Formation of True (intrinsic) Colloids in EBS **Excluded**	True colloids are not expected to form in the waste package internals due to the large amount of other sorbing materials inside the waste package. This is insignificant to the release of colloidal materials from the waste form. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.15.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Corrosion Products Properties	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.16.0A Formation of Pseudocolloids (natural) in EBS **Included**	Radionuclides can sorb onto pseudocolloids. The pseudocolloids are included in the colloid models. Although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered ITBC (SNL 2007 [DIRS 177423], Sections 6.3.1 and 6.3.9). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.16.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package & TAD Canister Excluded Materials
Waste Form and Waste Package Internals	2.1.09.17.0A Formation of Pseudocolloids (corrosion product) in EBS **Included**	Corrosion product colloids sorb several key radionuclides, notably ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am. These colloids are included in the colloid models environment (SNL 2007 [DIRS 177423], Section 6.3.1). These radionuclides may be released in colloidal form by diffusion through a continuous water film. Although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.17.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Radionuclide Inventory and Source-Term Properties Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Corrosion Allowance
Waste Form and Waste Package Internals	2.1.09.18.0A Formation of Microbial Colloids in EBS **Excluded**	Microbial colloids, which are not expected to form in the waste package internal environment, have an insignificant effect on colloidal formation and release of radionuclides, which are dominated by inorganic pseudocolloids. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.18.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Waste Package and TAD Canister Excluded Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.19.0A Sorption of Colloids in EBS **Excluded**	Although colloids routinely sorb onto mineral surfaces, such sorption is insignificant in reducing the rate of radionuclides released from the waste, because over 90% of the mass flux of radionuclides irreversibly sorbed on colloids is considered to be transportable through the EBS. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.19.0A	No	**Non-ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.19.0B Advection of Colloids in EBS **Included**	Advection of colloids is the fastest way to move colloid-borne radionuclides. Although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.19.0B	No	**Non-ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.20.0A Filtration of Colloids in EBS **Excluded**	Filtration has the potential to trap or retard the movement of colloids as they travel through degrade waste form and corrosion products inside the waste package. Filtration of colloids is conservatively excluded from the TSPA calculation and is not expected to substantially reduce the transport of radionuclides **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.20.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Package Materials, Properties, and Configuration Properties of corrosion products	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.23.0A Stability of Colloids in EBS **Included**	The stability of colloids is a function of the chemical environment in the waste package internal environment (SNL 2007 [DIRS 177423], Sections 4.1.2 and 6.5.1) and determines how many colloids remain suspended in water Although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.23.0A	No	**Non-ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Radionuclide Inventory and Source-Term Properties	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.24.0A Diffusion of Colloids in EBS **Included**	Diffusion of colloids is not a significant mode of release (SNL 2007 [DIRS 177407], Section 6.3.4 and Table 6.6-1). Additionally, although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.24.0A	No	**Non-ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.09.25.0A Formation of Colloids (waste-form) by Co-Precipitation in EBS **Included**	Co-precipitation of colloids due to the degradation of HLW glass waste forms has been included in the assessment of total colloidal release from the codisposal waste packages environment (SNL 2007 [DIRS 177423], Table 4-2; Section 6.3.2.2, 7.0). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.25.0A	No	**Non-ITBC:** Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**None**
Waste Form and Waste Package Internals	2.1.11.05.0A Thermal Expansion/ Stress of In-Package EBS Components **Excluded**	Thermal-mechanical expansion caused by degradation of the waste package internals following a breach in the waste package does not significantly affect any other degradation, deterioration, or alteration process inside the waste package, and therefore, is insignificant to the release of radionuclides from the waste. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.05.0A	No	**Non-ITBC:** In-Package Thermal Environment Waste Package Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Thermal Limits Waste Package Radial Gap Waste Package Longitudinal Gap

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Waste Form and Waste Package Internals	2.1.11.09.0B Thermally-Driven Flow (convection) in Waste Packages **Excluded**	Thermally driven processes inside the waste package can redistribute moisture that may be introduced through cracks or other degradation modes of the waste package. Although it is possible that these processes may cause moisture to be driven out of the waste package, especially in the case of the CSNF waste packages, this moisture efflux is not considered to substantially contribute to the capability of this feature. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.09.0B	No	**Non-ITBC:** In-Package Thermal Environment Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**None**
Waste Form and Waste Package Internals	2.1.12.02.0A Gas Generation (He) from Waste Form Decay **Excluded**	Gas generation has an insignificant effect on release and transport from the waste form through the waste package internals. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.02.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Package Materials, Properties, and Configuration Waste Form/Package Internals Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.15.0A In-Package Criticality (intact configuration) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature (SNL 2007 [DIRS 173869], Section 6.3). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.15.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Drip Shield Corrosion Allowance Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Loading of Waste Forms Waste Package and TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.16.0A In-Package Criticality (degraded configurations) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.3). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.16.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties Radionuclide Inventory and Source-Term Properties Drip Shield Seismic Performance Properties of the Host Rock Unit Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Radionuclide Inventory and Source-Term Properties	**Non-ITBC:** Drip Shield Seismic Performance Drip Shield Corrosion Allowance Seismic Design of Waste Package As-emplaced Waste Package-Drip Shield Configuration Loading of Waste Forms Repository Layout Waste Package and TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting Waste Package Spacing Waste Package Capacities

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.18.0A In-Package Criticality Resulting from a Seismic Event (intact configuration) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.4). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.18.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Drip Shield Corrosion Allowance Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Loading of Waste Forms Waste Package and TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.19.0A In-Package Criticality Resulting from a Seismic Event (degraded configurations) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.4). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.19.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties Radionuclide Inventory and Source-Term Properties Properties of the Host Rock Unit Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drip Shield Seismic Performance Seismic Design of Waste Package As-emplaced Waste Package-Drip Shield Configuration Loading of Waste Forms Repository Layout Waste Package and TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting Waste Package Spacing Drip Shield Corrosion Allowance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.21.0A In-Package Criticality Resulting from Rockfall (intact configuration) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.5). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.21.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Loading of Waste Forms Waste Package & TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.22.0A In-Package Criticality Resulting from Rockfall (degraded configurations) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.5). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.22.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties Radionuclide Inventory and Source-Term Properties Properties of the Host Rock Unit Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drip Shield Seismic Performance Seismic Design of Waste Package As-emplaced Waste Package-Drip Shield Configuration Loading of Waste Forms Repository Layout Waste Package and TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting Waste Package Spacing Drip Shield Corrosion Allowance

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.24.0A In-package Criticality Resulting from an Igneous Event (intact configuration) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.6). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.24.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form Properties, and Configuration Waste Package Materials, Properties, and Configuration Radionuclide Inventory and Source Term Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Loading of Waste Forms Waste Package and TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.1.14.25.0A In-Package Criticality Resulting from an Igneous Event (degraded configurations) **Excluded**	It has been determined that the conditions required to lead to in-package criticality are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.6). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.25.0A	No	**Non-ITBC:** Criticality Characteristics Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Package Materials, Properties, and Configuration Drip Shield Materials, Properties, and Configuration Infiltration and Seepage Properties Radionuclide Inventory and Source-Term Properties	**Non-ITBC:** As-emplaced Waste Package-Drip Shield Configuration Loading of Waste Forms Repository Layout Waste Package and TAD Canister Excluded Materials Waste Package Moisture Removal and Inerting Waste Package Spacing

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	2.2.08.12.0B Chemistry of Water Flowing into the Waste Package **Included**	The chemistry of the water that comes into contact with the waste form and waste package internals is altered by reaction with the exposed metallic and waste form surfaces inside the waste package. Results of analyses indicate that the chemistry is more affected by the rate and amount of water interacting with the waste package internals than the chemistry of this water (SNL 2007 [DIRS 180506], Section 6.3.1.3.3). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.12.0B	No	**Non-ITBC:** In-Package Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Package Thermal Environment Radionuclide Inventory and Source-Term Properties Corrosion Products Properties Seepage Water Properties	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Form and Waste Package Internals	3.1.01.01.0A Radioactive Decay and Ingrowth **Included**	Decay and ingrowth of radionuclides occurs in the waste form and along transport paths of any radionuclides released from the waste form. Some radionuclides have sufficiently short half-lives (e.g., ^{90}Sr and ^{137}Cs) that they decay to insignificant levels in the waste package. Other radionuclides have moderate half-lives and decay to products that may be released from the waste (e.g., ^{241}Am decays to ^{237}Np (SNL 2007 [DIRS 180472], Section 6.1; SNL 2007 [DIRS 184748], Section D.2; SNL 2008 [DIRS 183750], Section 6.7.2). Decay and ingrowth have been included in the TSPA. Within the waste package, radioactive decay and ingrowth contribute to the waste inventory, which defines the amount of different radionuclides present in different waste forms (SNL 2007 [DIRS 180472]). The ITBC evaluations of parameter characteristic associated with radioactive decay is much like that of inventory; since both are well characterized given the controls on inventory used in the analyzed basis. Any change to inventory will be managed by the change evaluation process (SNL 2007 [DIRS 180472] Section 6.1.10). The decay and ingrowth processes are not considered ITBC for the waste form and waste package internals because the residence time through the waste form is shorter than the half-lives of major dose contributors. Additionally, in the evaluation of barrier capability, transport of radionuclides from the waste inventory, are evaluated separately in transport-related FEPs. **FEP Source:** SNL 2008 [DIRS 183041] – 3.1.01.01.0A	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration Characterization of Fault Displacement	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package Pallet	1.2.02.03.0A Fault Displacement Damages EBS Components **Included**	The subsurface layout maintains a 60 meter standoff distance between the repository and the Solitario Canyon and Ghost Dance faults. This standoff ensures that EBS components are not damaged by displacement on these faults, so these faults do not influence the release of radionuclides from the Yucca Mountain repository to the accessible environment. Within the repository block, waste packages and emplacement pallets will be emplaced on known secondary faults (Sundance fault, Drill Hole Wash fault, Sever Wash fault, Pagany Wash fault, and the western splay of the Ghost Dance fault) and on hypothetical small faults with a cumulative offset of 2 meters. The potential damage to waste packages and drip shields from displacement on these faults is included in the TSPA Model (SNL 2007 [DIRS 176828], Section 6.11.5). However, it is not expected that damage to the emplacement pallet from fault displacement will significantly affect dose because waste package failures from fault displacement occur for exceedance frequencies less than 2.5×10^{-7} per year and because of the limited number of locations in the emplacement drift that might be affected by secondary faults. Additionally, this degradation process is much less significant than the more likely seismically-induced ground motion effects (SNL 2007 [DIRS 176828], Section 6.7). The response of the pallet to fault displacement is therefore not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.03.0A	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration Characterization of Fault Displacement	**Non-ITBC:** Repository Standoff from Quaternary Fault Emplacement Drift Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package Pallet	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to damage the emplacement pallets from waste package-to-pallet impacts that may occur during a seismic event. These impacts may deform or even crush the emplacement pallets once general corrosion of Alloy 22 reduces the thickness of the cradles that support the waste package. The impact loads may also fail the stainless steel connector rods in the pallet, allowing the two cradles to move independently during a seismic event. While the cradles remain intact and can support the waste package above the invert, the presence of the pallet can delay diffusive releases of radionuclides from the waste package to the invert, thereby providing a significant barrier to the release of radionuclides. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0A	Yes	**ITBC:** Emplacement Pallet Materials, Properties, and Configuration Properties of the Host Rock Unit Characterization of Seismic Events	**ITBC:** As-emplaced Waste Package-Drip Shield Configuration Emplacement Pallet Fabrication and Corrosion Allowance Emplacement Pallet Design Emplacement Pallet Function EBS Drip Shield / Emplacement Drift Invert Materials Interactions Materials Contacting the Waste Package
Waste Package Pallet	2.1.06.05.0A Mechanical Degradation of Emplacement Pallet **Excluded**	The waste package emplacement pallet provides mechanical stability for the waste package given ground motions associated with a potential seismic event. The potential mechanical degradation of the waste package emplacement pallet has been evaluated and determined to not significantly affect the ability of the pallet to maintain its function of keeping the waste package stable and above the invert. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.05.0A	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration	**Non-ITBC:** Emplacement Pallet Design Emplacement Pallet Function Emplacement Pallet Fabrication and Corrosion Allowance Waste Package and Emplacement Pallet Static Stresses EBS Drip Shield / Emplacement Drift Invert Materials Interactions EBS Materials Interactions - Pallet

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Waste Package Pallet	2.1.06.05.0C Chemical Degradation of Emplacement Pallet **Included**	The waste package emplacement pallet provides chemical stability for the waste package and a uniform chemical boundary condition for evaluation of waste package degradation, in that the waste package does not come into direct contact with the invert. The potential chemical degradation of the waste package emplacement pallet has been evaluated and determined to not significantly affect the ability of the pallet to maintain its function of keeping the waste package stable and above the invert. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.05.0C	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Emplacement Pallet Design Emplacement Pallet Function Emplacement Pallet Fabrication and Corrosion Allowance EBS In-drift Materials Interactions As-emplaced Waste Package-Drip Shield Configuration Waste Package Outer Barrier Material Specifications
Waste Package Pallet	2.1.06.07.0A Chemical Effects at EBS Component Interface **Excluded**	Solid-to-solid interactions at the interfaces between the various features of the EBS have been considered in the design and analysis of the in-drift chemical environment such that galvanic coupling and other chemical interactions are insignificant to postclosure performance assessment. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0A	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** EBS Materials Interactions – Copper EBS Drip Shield / Emplacement Drift Invert Materials Interactions EBS Materials Interactions - Pallet
Waste Package Pallet	2.1.06.07.0B Mechanical Effects at EBS Component Interfaces **Excluded**	Administrative controls for the repository construction and operations will be developed to assure that waste packages and drip shields are placed in accordance with the repository design. Physical effects of steady-state contact (static loading) that occur at the interfaces between materials in the drift may affect the performance of the system. The mechanical effects of static loading that occur at interfaces between materials in the emplacement drift are not significant to the postclosure performance of the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0B	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Emplacement Pallet Design Emplacement Pallet Function Emplacement Pallet Fabrication and Corrosion Allowance Waste Package and Emplacement Pallet Static Stresses As-Emplaced Waste Configuration./ Waste Package Outer Barrier Material Specifications

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Waste Package Pallet	2.1.11.07.0A Thermal Expansion/ Stress of In-drift EBS Components **Excluded**	Although thermal expansion of EBS features occurs, no significant stress differentials exist between the different features. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.07.0A	No	**Non-ITBC:** In-Drift Thermal Environment Waste Package Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Temperature Limit Waste Decay Heat Waste Package Thermal Limits Invert and EBS Components in Situ Stress and Thermal Response Waste Package Longitudinal Gap Waste Package Radial Gap
Invert	1.2.02.03.0A Fault Displacement Damages EBS Components **Included**	The subsurface layout maintains a 60 meter standoff distance between the repository and the Solitario Canyon and Ghost Dance faults. This standoff ensures that EBS components are not damaged by displacement on these faults, so these faults do not influence the release of radionuclides from the Yucca Mountain repository to the accessible environment. Within the repository block, EBS components will be emplaced on known secondary faults (Sundance fault, Drill Hole Wash fault, Sever Wash fault, Pagany Wash fault, and the western splay of the Ghost Dance fault) and on hypothetical small faults with a 2-meter offset (SNL 2007 [DIRS 176828], Section 6.11.2). It is not expected that damage to the invert from fault displacement will significantly affect dose because damage to waste packages and drip shields occurs for annual exceedance frequencies of less than 2.5×10^{-7} and because the invert is affected by fault displacement at a limited number of locations in the emplacement drifts (SNL 2007 [DIRS 176828], Section 6.11.5). This degradation process is much less significant than the more likely seismic-induced ground motion effects (SNL 2007 [DIRS 176828], Section 6.7). The response of invert to fault displacement is therefore not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.03.0A	No	**Non-ITBC:** Characterization of Fault Displacement	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness Repository Standoff from Quaternary Fault Emplacement Drift Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	1.2.03.02.0A Seismic Ground Motion Damages EBS Components **Included**	Vibratory ground motion has the potential to damage the steel framework and ballast in the invert. The framework in the invert is carbon steel that is expected to corrode quickly in the moist, in-drift environment. The response of the steel framework is therefore not ITBC, with or without seismic events. The ballast in the invert is an engineered material that will be produced from crushed tuff generated during mining operations. This crushed tuff is a highly porous material that may settle or compact during a seismic event, but is not considered to provide a significant barrier capability in comparison to the intact tuff in the unsaturated zone surrounding the emplacement drifts. The response of invert to vibratory ground motion is therefore not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.03.02.0A	No	**Non-ITBC:** Invert Materials, Properties, and Configuration Properties of the Host Rock Unit Characterization of Igneous Events	**Non-ITBC:** Invert Materials Emplacement Drift Invert Configuration Emplacement Drift Invert Function Verification of Design Rock Properties Repository Geographic and Geologic Location Repository Elevation - Overburden Thickness
Invert	2.1.06.05.0B Mechanical Degradation of Invert **Excluded**	Mechanical degradation of the invert does not significantly affect the capability of the other EBS features, nor would such changes affect the radionuclide migration rate through the invert to the edge of the EBS, because changes in invert ballast porosity do not significantly affect the radionuclide transport characteristics. Seismically induced changes to the invert, and the effect from dead loading due to drift collapse, are considered separately (see FEP 1.2.03.02.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.05.0B	No	**Non-ITBC:** Invert Materials, Properties, and Configuration	**Non-ITBC:** As-emplaced Waste Package-Drip Shield Configuration Invert and EBS Components in Situ Stress and Thermal Response Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials
Invert	2.1.06.05.0D Chemical Degradation of Invert **Excluded**	The crushed tuff invert ballast material is not subject to dissolution or weathering processes that could significantly change its hydrological, mechanical, or radionuclide transport characteristics. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.05.0D	No	**Non-ITBC:** Invert Materials, Properties, and Configuration	**Non-ITBC:** EBS Drip Shield / Emplacement Drift Invert Materials Interactions Invert Materials Emplacement Drift Invert Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.08.05.0A Flow Through Invert **Included**	Advective flow through the invert as a result of seepage or condensation in the drifts, or imbibition from the host rock into the invert, is included in the TSPA. Only seepage and drift-wall condensation represent potentially significant advective flow. Partitioning of released radionuclides from the EBS to the LNB is sensitive to advective flow, but is relatively insensitive to hydrologic properties of the invert (SNL 2007 [DIRS 177407], Section 6.5.2.6). The invert thickness provides only limited delay or retardation of radionuclides; hence flow through the invert is not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.05.0A	No	**Non-ITBC:** Invert Materials, Properties, and Configuration Infiltration and Seepage Properties	**None**
Invert	2.1.06.07.0B Mechanical Effects at EBS Component Interfaces **Excluded**	Administrative controls for the repository construction and operations will be developed to assure that waste packages and drip shields are placed in accordance with the repository design. Physical effects of steady-state contact (static loading) that occur at the interfaces between materials in the drift may affect the performance of the system. The mechanical effects of static loading that occur at interfaces between materials in the emplacement drift are not significant to the postclosure performance of the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.06.07.0B	No	**Non-ITBC:** Emplacement Pallet Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration	**Non-ITBC:** Emplacement Pallet Design Emplacement Pallet Function EBS Materials Interactions – Pallet Emplacement Pallet Fabrication and Corrosion Allowance Waste Package and Emplacement Pallet Static Stresses As-Emplaced Waste Configuration. Waste Package Outer Barrier Material Specifications
Invert	2.1.08.06.0A Capillary Effects (wicking) in EBS **Included**	The effects of wicking in the invert of the EBS have been included in the Multiscale Thermal-Hydrologic Model. The effect of this wicking (without seepage) is to very slightly increase the advective flux through the invert (SNL 2007 [DIRS 184433], Section 6.3.3). The magnitude of the flux predicted is so small that the effect is not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.06.0A	No	**Non-ITBC:** Invert Materials, Properties, and Configuration In-Drift Thermal Environment Convection, Condensation, and Evaporation	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.08.07.0A Unsaturated Flow in the EBS **Included**	Unsaturated flow occurs through the invert as a result of seepage or drift-wall condensation, imbibition from the host rock, or capillary condensation, and affects the release of radionuclides from the EBS to the LNB features (SNL 2007 [DIRS 177407], Section 6.5.2.6 and Table 6.4-1). While the presence of moisture in the invert is required for radionuclide release from the engineered barrier, and advective flow enhances the potential release rate, the invert transport path is short, and has a minor effect on barrier performance compared to the LNB. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.07.0A	No	**Non-ITBC:** Invert Materials, Properties, and Configuration In-Drift Thermal Environment Convection, Condensation, and Evaporation	**None**
Invert	2.1.08.12.0A Induced Hydrologic Changes in Invert **Excluded**	The permeability of the invert ballast materials and the fractured rocks beneath the emplacement drifts is sufficiently large to preclude any significant effects from plugging or other changes in hydrologic properties. In addition, the repository drifts are designed to promote free drainage and prevent accumulation of water. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.08.12.0A	No	**Non-ITBC:** Invert Materials, Properties, and Configuration Properties of the Host Rock Unit Unsaturated Zone Properties	**Non-ITBC:** Emplacement Drift Gradient Non-Emplacement Opening Gradient Repository Elevation – Standoff from the Water Table Invert Materials Emplacement Drift Invert Configuration
Invert	2.1.09.01.0A Chemical Characteristics of Water in Drifts **Included**	Chemical characteristics of water in the invert will be affected by the incoming water chemistry (i.e., seepage, drift-wall condensation, or imbibition from the host rock). When inflow occurs, such waters will have already interacted with the host rock, so changes within the invert are not expected to be significant. Invert waters will be similar to other waters in the environment and will therefore, not contribute significantly to barrier capability (SNL 2007 [DIRS 177412], Section 6.13.4). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.01.0A	No	**Non-ITBC:** Seepage Water Properties In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Invert Materials Properties, and Configuration	**Non-ITBC:** Invert Materials Emplacement Drift Invert Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.04.0A Radionuclide Solubility, Solubility Limits, and Speciation in the Waste form and EBS **Included**	Solubility limited transport in the invert is included in the performance assessment, and could delay releases to the LNB if precipitates accumulate. However, this is not a significant process because waters in the invert will tend to dilute radionuclides released from the waste package, considering all possible sources of invert water. Hence, while this process is included in TSPA, it is not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.04.0A	No	**Non-ITBC:** In-Drift Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration	**Non-ITBC:** Invert Materials
Invert	2.1.09.05.0A Sorption of Dissolved Radionuclides in EBS **Included**	Sorption in the invert is included in the performance assessment, and could delay releases to the LNB if precipitates accumulate. However, this is not a significant process because waters in the invert-transport pathway is short, and its effect on EBS performance is limited. Hence, while this process is included in TSPA, it is not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.05.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Invert Materials Emplacement Drift Invert Configuration

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.06.0B Reduction-oxidation Potential in Drifts **Included**	Although the redox potential in the invert could affect radionuclide solubility, oxidizing conditions are conservatively used to represent both the invert and the in-package environment. Thus, this process has no effect on radionuclide releases (SNL 2007 [DIRS 177412], Sections 6.14 and 6.8.4) and is not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.06.0B	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Unsaturated Zone Properties Properties of the Host Rock Unit	**Non-ITBC:** Repository Layout Design of Ground Support System
Invert	2.1.09.07.0B Reaction Kinetics in Drift **Included**	Reaction kinetics control the composition of water, particularly in the waste package where waste forms degrade at limited rates. Reaction kinetics are included in the performance assessment, but have limited effect in the invert on releases from the invert because of the inverts limited extent and the formation of precipitates such as schoepite, which causes the source condition for transport to be solubility limited, while highly soluble fission products are readily released from grain-boundaries in spent fuel. Accordingly, rates of waste form degradation are not considered to be ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.07.0B	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.08.0A Diffusion of Dissolved Radionuclides in EBS **Included**	Radionuclide diffusion in the waste package and in the invert is slow, and limits radionuclide releases when this is the only operant transport mechanism. Release rates from the engineered barrier tend to be dominated by advection, with limited influence from slow diffusive transport (SNL 2007 [DIRS 177407], Sections 6.3.1.1 and 6.3.1.2). Thus, while diffusive transport in the invert is slow, it has limited impact on barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.08.0A	No	**Non-ITBC:** Invert Materials Properties, and Configuration Unsaturated Zone Properties Properties of the Host Rock Unit Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Emplacement Drift Invert Configuration Invert Materials
Invert	2.1.09.08.0B Advection of Dissolved Radionuclides in EBS **Included**	Radionuclide releases from the engineered barrier are dominated by advection. Advective releases from the waste package can occur only when both the drip shield and waste package are breached to the extent that such transport can occur. Even if the drip shield and waste package are not breached, advective releases are more significant than diffusive from a system performance perspective because advective releases to the LNB occur into the fractures of the unsaturated zone, while diffusive releases are partitioned to the matrix (SNL 2007 [DIRS 177407], Sections 6.3.1.1 and 6.3.1.2). Hence the factors that control advective transport within the EBS, and partitioning to the LNB below, are important to capability of the engineered barrier. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.08.0B	No	**Non-ITBC:** Infiltration and Seepage Properties Invert Materials Properties, and Configuration Unsaturated Zone Properties Properties of the Host Rock Unit Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Invert	2.1.09.13.0A Complexation in EBS **Excluded**	Chemical and biological conditions that could contribute to complexation of radionuclides in the invert will not occur or will be present to such limited extent as to not enhance the rates of transport of radionuclides released from the waste package. Therefore, complexation effects in the invert are negligible from a barrier capability perspective. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.13.0A	No	**Non-ITBC:** In-drift Chemical Environment Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Invert Materials Properties, and Configuration Radionuclide Inventory and Source-Term Properties	**Non-ITBC:** Waste Package and TAD Canister Excluded Materials Committed Materials
Invert	2.1.09.19.0A Sorption of Colloids in EBS **Excluded**	Although colloids could potentially sorb on invert ballast materials, thus reducing the rate of radionuclide release, this sorption is small and, because the travel path through the invert is short compared with that through the unsaturated zone below the repository, is relatively insignificant. For pseudo-colloids to which radionuclides are reversibly sorbed, sorption of the carrier particles has limited effect on radionuclide transport. Because of the limited affect on barrier performance, colloid sorption is excluded from the TSPA (SNL 2008 [DIRS 183041] – 2.1.09.19.0A) and the process is not ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.19.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Form Degradation Corrosion Products Properties Waste Form/Package Internals Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert (Continued)	2.1.09.19.0A Sorption of Colloids in EBS **Excluded** (Continued)			Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	
Invert	2.1.09.19.0B Advection of Colloids in EBS **Included**	Colloidal releases from the engineered barrier are dominated by advection. Advective releases from the waste package can occur only when both the drip shield and waste package are breached to the extent that such transport can occur. Even if the drip shield and waste package are not breached, advective transport of colloids through the invert is more significant than diffusive (SNL 2007 [DIRS 177407], Section 6.3.4.4). However, the advection of colloids is a small contributor to release compared to that of dissolve radionuclide species and its impact on barrier capability is not considered ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.19.0B	No	**Non-ITBC:** Invert Materials Properties, and Configuration Unsaturated Zone Properties Properties of the Host Rock Unit Radionuclide Inventory and Source-Term Properties Drip Shield Materials, Properties, and Configuration Waste Package Materials, Properties, and Configuration Waste Form Degradation Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Form/Package Internals Materials, Properties, and Configuration	**Non-ITBC:** Emplacement Drift Invert Configuration Emplacement Drift Invert Function

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.20.0A Filtration of Colloids in EBS **Excluded**	Although colloid filtration could potentially occur during transport through the invert ballast materials, thus reducing the rate of radionuclide release, this process has been conservatively not included in the performance assessment, and is considered not to be ITBC because of the limited extent of the travel path length through the invert. (SNL 2008 [DIRS 183041] – 2.1.09.20.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.20.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Form Degradation Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Form/Package Internals Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.21.0A Transport of Particles Larger than Colloids in EBS **Excluded**	Particles larger than colloids that are released from the waste form are an insignificant fraction of the total particles. Radionuclides reversibly or irreversibly sorbed onto colloid-sized particles have a much more significant effect on the rate of release of radionuclides from the engineered barrier, through the invert ballast and, are therefore, considered not to be ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.21.0A	No	**Non-ITBC:** Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Corrosion Products Properties Waste Form/Package Internals Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**None**
Invert	2.1.09.22.0A Sorption of Colloids at air–Water Interface **Excluded**	Although the potential for sorption of colloids at the air-water interface is possible, thus reducing the release rate of colloidal particles from the invert ballast, this process has been conservatively not included in the performance assessment, and is considered not to be ITBC because of the limited extent of the travel path length through the invert. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.22.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.23.0A Stability of Colloids in EBS **Included**	Colloid stability in the invert is a function of the aqueous chemical conditions (SNL 2007 [DIRS 177423], Section 6.6.8), and a colloid stability model is included as a process in the TSPA (SNL 2008 [DIRS 183041] – 2.1.09.23.0A). If environmental conditions favor stability, then the associated radionuclides are transported colloidally. If conditions are not favorable, the colloids and associated radionuclides are immobilized, and true colloids may dissolve becoming subject to aqueous transport (SNL 2007 [DIRS 177407], Section 6.3.1.2). Colloidal transport is most important for radioelements such as Pu which are relatively insoluble, and tend to be strongly sorbed. Thus, regardless of whether colloids are stable, transport of the associated radionuclides is likely to be attenuated by sorption onto immobile solids. For this reason and the small transport path represented by the invert, colloid stability is considered not to be ITBC. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.23.0A	No	**Non-ITBC:** In-Drift Chemical Environment Invert Materials Properties, and Configuration Radionuclide Inventory and Source-Term Properties Waste Form Degradation Waste Form/Package Internals Materials, Properties, and Configuration Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Invert Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.24.0A Diffusion of Colloids in EBS **Included**	Diffusion of colloids is not a significant mode of release. Only the smallest of colloidal particles, together with any associated radionuclides, may be transported significantly by diffusion in the EBS. Advection is a more significant method of transport in the invert (SNL 2007 [DIRS 177407], Sections 6.1.1 and Table 6.3-2). While colloidal diffusion is included in the TSPA, the process is considered not to be ITBC because it is less significant than that, which is associated with dissolved radionuclides. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.24.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Form Degradation Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Form/Package Internals Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.26.0A Gravitational Settling of Colloids in EBS **Excluded**	Settling of colloids has no effect on the transport of colloids through the invert because of the limited extent of the travel path length through the invert and is, therefore, excluded from the performance assessment, and is considered not to be ITBC (SNL 2008 [DIRS 183041] – 2.1.09.26.0A). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.26.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Form Degradation Corrosion Products Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Waste Form/Package Internals Materials, Properties, and Configuration	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.09.27.0A Coupled Effects on Radionuclide Transport in EBS **Excluded**	Thermal-chemical effects are included insofar as the evaporative evolution of invert porewater, and the resulting pH and ionic strength effects on colloid stability, are included in the TSPA (see FEP 2.1.09.23.0A). However, other cross-couplings among thermal, hydrological, chemical, and mechanical processes produce no known, significant effects on the release and transport of radionuclides in the EBS. Accordingly, such processes are considered not to be important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.27.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Invert Materials Properties, and Configuration	**None**
Invert	2.1.11.07.0A Thermal Expansion/ Stress of In-drift EBS Components **Excluded**	Although thermal expansion of EBS features occurs, no significant stress differentials exist between the different features. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.07.0A	No	**Non-ITBC:** In-Drift Thermal Environment Waste Package Materials, Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Waste Package Temperature Limit Waste Decay Heat Waste Package Thermal Limits Invert and EBS Components in Situ Stress and Thermal Response Waste Package Longitudinal Gap Waste Package Radial Gap

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.11.10.0A Thermal Effects on Transport in EBS **Excluded**	The Soret effect and thermal effects on sorption reactions, respectively are considered as insignificant and as conservative. Accordingly, these effects are considered not to be ITBC. Thermal effects on diffusion (FEPs 2.1.09.08.0A and 2.1.09.24.0A), porewater chemistry (FEP 2.1.09.01.0A), and flow processes (FEP 2.1.09.04.0A) are addressed separately. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.11.10.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**None**
Invert	2.1.12.06.0A Gas Transport in EBS **Excluded**	Transport of gas in the EBS is shown to be inconsequential to repository performance. The gas phase in the emplacement drifts will be well mixed. Gases present in the drifts will freely advect and diffuse into the host rock where dilution, dispersion, and reaction with moisture will occur. No plausible change in host rock characteristics will alter this behavior, because these effects will not specifically impact radionuclide release or transport. Note that thermal Convection (FEP 2.1.11.09.0C) and gas-phase transport of radionuclides (FEP 2.1.12.07.0A) are addressed separately. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.06.0A	No	**Non-ITBC:** Invert Materials Properties, and Configuration Properties of the Host Rock Unit Unsaturated Zone Properties	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.12.07.0A Effects of Radioactive Gases in EBS **Excluded**	The effects of radioactive gases in the EBS were analyzed and were found to be inconsequential to repository performance. Doses from the aqueous phase transport of $^{14}CO_2$ and ^{222}Rn were found to bound the doses from the gas-phase transport. Therefore, this process is considered not to be important to barrier capability **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.12.07.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**None**
Invert	2.1.14.17.0A Near-Field Criticality **Excluded**	It has been determined that the conditions required to lead to near-field criticality are not likely to occur, and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.3). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.17.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.14.20.0A Near-field Criticality Resulting from a Seismic Event **Excluded**	It has been determined that the conditions required to lead to near-field criticality are not likely to occur, and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.4). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.20.0A	No	**Non-ITBC:** In-Drift Chemical Environment In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat Invert Materials Properties, and Configuration	**Non-ITBC:** Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials
Invert	2.1.14.23.0A Near-field Criticality Resulting from Rockfall **Excluded**	It has been determined that the conditions required to lead to near-field criticality are not likely to occur, and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature (SNL 2007 [DIRS 173869], Section 6.5). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.23.0A	No	**Non-ITBC:** In-Drift Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration	**Non-ITBC:** Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.1.14.26.0A Near-field Criticality Resulting from an Igneous Event **Excluded**	It has been determined that the conditions required to lead to near-field criticality are not likely to occur, and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature(SNL 2007 [DIRS 173869], Section 6.6). **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.14.26.0A	No	**Non-ITBC:** In-Drift Chemical Environment Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat In-Drift Thermal Environment Convection, Condensation, and Evaporation Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration	**Non-ITBC:** Emplacement Drift Invert Configuration Emplacement Drift Invert Function Invert Materials
Invert	2.2.07.06.0A Episodic or Pulse Release from Repository **Excluded**	Release pulses caused by bathtub behavior of the waste package have been analyzed (SNL 2007 [DIRS 177407], Sections 6.4.1 and 6.6.1) and found to be reasonably bounded or represented by the continuous release mode used in the TSPA. Episodic release is therefore, considered to not be important to barrier capability. Note that time varying releases from the repository are possible given changes in invert chemistry (FEPs 2.1.09.04.0A and 2.1.09.23.0A), and are included in the TSPA models. The potential for episodic inflow to the EBS (FEP 2.2.07.05.0A) is addressed separately. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.06.0A	No	**Non-ITBC:** In-Drift Chemical Environment Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Unsaturated Zone Properties Infiltration and Seepage Properties	**Non-ITBC:** Repository Standoff From Paintbrush Nonwelded Hydrogeologic Unit Repository Elevation - Overburden Thickness Repository Geographic and Geologic Location

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	2.2.07.06.0B Long-term release of radionuclides from the repository **Included**	The release of radionuclides from the repository may occur over a long period of time, as a result of the timing and magnitude of the waste packages and drip shield failures, waste form degradation, and radionuclide transport through the invert. Releases from the waste package and engineered barrier system serve as a time dependent boundary condition to the mountain scale radionuclide transport model as discussed in Particle Tracking Model and Abstraction of Transport Processes (SNL 2007 [DIRS 184748], Section 6.4.7). This allows for a general time dependent radionuclide source term that accounts for long term releases. Releases from the waste package and engineered barrier system serve as a time-dependent boundary condition to the mountain-scale radionuclide transport model, regardless of when the release occurs, thus allowing for a general time-dependent radionuclide source term that accounts for long-term releases (SNL 2007 [DIRS 184748], Sections 6.4.6, and 6.4.7). As such, this FEP is not considered ITBC because the delay in the invert during the 10,000 year period for non-retarded radionuclides is not significant. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.06.0B	No	**Non-ITBC:** In-Drift Chemical Environment Radionuclide Inventory and Source-Term Properties Invert Materials Properties, and Configuration Unsaturated Zone Properties	**None**

Table A-2. ITBC Analyses of Engineered Barrier System FEPs (Continued)

Feature	FEP Number, Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Invert	3.1.01.01.0A Radioactive Decay and Ingrowth **Included**	The process of decay and ingrowth of radionuclides is included in the TSPA (SNL 2007 [DIRS 180472], Section 6.3; SNL 2007 [DIRS 184748], Section 6.8.2.2; and SNL 2007 [DIRS 177407], Section 6.3.1.2). However, because the transport pathway through the invert is short, and residence times are consequently limited relative to the LNB, the contribution to barrier performance from this process occurring in the invert is insignificant. Accordingly the decay and ingrowth in the invert is considered not to be important to barrier capability. Also, radioactive decay and ingrowth effects depend directly on inventory, which is well characterized, and will be managed through the change evaluation process (see Section 6.1.8). **FEP Source:** SNL 2008 [DIRS 183041] – 3.1.01.01.0A	No	**Non-ITBC:** Radionuclide Inventory and Source-Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**None**

[1] A FEP relates to a Parameter Characteristic if it directly influences or is directly influenced by the parameter characteristic. The Parameter is determined to be ITBC if for a particular Barrier and Barrier Feature, that Parameter Characteristic substantially affects the rate of movement of water and the release or release rate of radionuclides from the Yucca Mountain repository to the accessible environment.

[2] Entries in this column identify areas which support the analyzed basis and are not amenable to direct control or identified as a Control Parameter Characteristic.

[3] Control Parameter Characteristics identify the areas where controls for operations and design are required to support the analyzed basis. Any changes to the controls or the design will be evaluated through an established change control process, which will include an evaluation of the impacts of change on FEPs, ITBC, analysis and/or model reports, models, and assumptions that support the LA.

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	1.2.02.01.0A Fractures **Included**	Fractures below the repository still conduct the majority of the percolation flux through the unsaturated zone, although the low-matrix-permeability zeolitic rocks of the CHn, cause increased lateral diversion toward the faults, and the vitric CHn is dominated by matrix flow. In addition, the fractures have a significant effect on the rate of radionuclide transport through the unsaturated zone through their influence on transport properties. Important fracture-related transport processes/properties include fracture permeability, porosity, frequency, active fracture model, matrix diffusion coefficient, sorption, and colloid filtration (SNL 2007 [DIRS 184614], Section 6.1.2); SNL 2007 [DIRS 177396], Sections 6.1.1 and 6.1.2). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.01.0A	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	1.2.02.02.0A Faults **Included**	A significant fraction of percolation flux below the repository occurs through faults (on average over 30% at the water table location). In addition, faults are important to unsaturated zone transport because they provide fast pathways for radionuclide transport to the water table (SNL 2007 [DIRS 177396], Section 6.7.5). The Drill Hole Wash fault and the Pagany Wash fault act as the main transport conduits, from the repository horizon to the water table (SNL 2007 [DIRS 177396], Section 6.8.1.2). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.02.0A	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location Repository Standoff from Quaternary Fault

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	1.2.04.02.0A Igneous Activity Changes Rock Properties **Excluded**	Studies of natural analogue sites show that the effect of unlikely intrusive igneous events is generally to alter the properties in the immediate vicinity (a few meters) from the intrusive sill or dike. These changes (which may be increases or decreases in permeability and porosity) are of such limited spatial extent. In addition, because dikes would be nearly vertical, the formation of a significant perched water zone associated with a dike is not expected. Furthermore, although lateral diversion and formation of perched water occurs where the TSw contacts the zeolitic CHn, transport sensitivity analyses indicate that most of the delay in radionuclide movement to the water table occurs within the TSw and above the zone of strong lateral diversion. Hence, any changes in potential lateral diversion resulting from dikes would have negligible effects on radionuclide transport times. Other unsaturated zone flow and transport sensitivity analyses provide additional support that radionuclide transport between the repository and the water table is insensitive to changes in fault properties. Therefore, igneous activity-induced rock property changes do not significantly affect the capabilities of the unsaturated zone below the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.02.0A	No	**Non-ITBC:** Characterization of Igneous Events Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	1.2.04.05.0A Magma or Pyroclastic Base Surge Transports Waste **Excluded**	The transport of waste through the UZ by magma or pyroclastic base surge following an unlikely eruptive igneous event is insignificant compared to areal transport of the waste resulting from ash and tephra eruption that is included in performance assessment. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.05.0A	No	**Non-ITBC:** Characterization of Igneous Events	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	1.2.04.06.0A Eruptive Conduit to Surface Intersects Repository **Included**	Even though the possibility of an eruptive conduit intersecting the repository and extending to the surface has been included in the performance assessment, the number of waste packages potentially intersected by such an event (SNL 2007 [DIRS 177432], Section 7.2) is considered an insignificant contributor to the dose to the reasonably maximally exposed individual (RMEI). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.06.0A	No	**Non-ITBC:** Characterization of Igneous Events	**Non-ITBC:** Repository Geographic and Geologic Location Emplacement Drift Orientation Emplacement Drift Spacing

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	1.2.06.00.0A Hydrothermal Activity **Excluded**	Hydrothermal activity resulting from a non-magmatic heat source is not expected in the Yucca Mountain area. Any other possible hydrothermal activity requires a predecessor igneous event. There is no clear evidence of extensive hydrothermal activity resulting from previous igneous events at or near Yucca Mountain. In the unlikely event of an igneous intrusion or eruption, the possible effects of hydrothermal activity are inconsequential to repository performance (see discussion of FEP 1.2.04.02.0A, Igneous Activity Changes Rock Properties). This is because of the limited scale of effects from basaltic dikes on hydrothermal alteration of unsaturated zone flow (i.e., flow pathways and velocities). **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.06.00.0A	No	**Non-ITBC:** Characterization of Igneous Events	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	1.2.10.01.0A Hydrologic Response to Seismic Activity **Excluded**	Seismic activity may alter the rock, fracture, and fault characteristics, which may affect the hydrogeology of the unsaturated zone in the vicinity of the repository. Investigations focusing on the potentiometric hydrologic response, given changes in rock properties adjacent to a fault, demonstrate that the changes in water table elevation are not expected to exceed 50 m and are transient and local in nature. Because the emplacement drifts are located at least 120 m above the current water table, such transient perturbations will not have any significant long-term effect to the flowpaths or velocities in the unsaturated zone below the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.10.01.0A	No	**Non-ITBC:** Characterization of Igneous Events Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	1.2.10.02.0A Hydrologic Response to Igneous Activity **Excluded**	Igneous intrusions that might occur in the time frame of 10,000 years after closure would affect a relatively small volume of the host rock and are expected to be oriented subparallel to existing flow directions. Consequently, future intrusions would not have a significant effect on groundwater flow patterns or rates. Given the limited area of any thermal or geochemical alteration, and the consequent change of rock properties around an intrusion, any geochemical effects would be minimal. The potential development of a hydrothermal system from igneous activity is not expected, based on analogue studies and would be of low consequence due to its limited size relative to the repository footprint. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.10.02.0A	No	**Non-ITBC:** Characterization of Igneous Events Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	1.3.01.00.0A Climate Change **Included**	Climate change significantly affects the amount and distribution of water that infiltrates into the surficial soils and underlying bedrock. Future climate analyses indicate that the climate at Yucca Mountain will evolve to a warmer and wetter monsoon climate followed by a cooler, wetter glacial-transition climate within the first 10,000 years after closure and then by a even wetter full glacial climate within the period of geologic stability as proposed by 40 CFR 197 [DIRS 177357]. The effects of climate change on groundwater flow in the unsaturated zone below the repository are incorporated into the TSPA using time-dependent infiltration rates as a boundary condition to the Site-Scale UZ Flow Model for the first 10,000 years and for the post-10,000-year period, using the deep percolation rate as specified in the proposed rule 40 CFR 197 [DIRS 177357]. The effects are then incorporated into the unsaturated zone transport assessment through the use of the flow fields. The climate change effects control the percolation flux and the radionuclide transport rate. **FEP Source:** SNL 2008 [DIRS 183041] – 1.3.01.00.0A	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone Flow Extent of Unsaturated Zone	**ITBC**: Repository Elevation above the Water Table **Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	1.3.07.02.0B Water Table Rise Affects UZ **Included**	A water table rise is expected following a change in climate. Although, uncertainty exists in the amount of rise, the TSPA models conservatively considered the rise to be 120 m. The water table rise has little impact on the unsaturated zone flow because the flow field is predominantly vertical and is controlled by the infiltration rate and hydraulic conductivity; therefore, the effect of water table rise on unsaturated zone flow is realized by truncating the flow field at the new water table elevation. The water table rise also reduces the transport length in the unsaturated zone and reduces the capability of the unsaturated zone below the repository to limit the rate of radionuclide movement (SNL 2007 [DIRS 184748], Sections 6.4.8.4 and 6.6.2.1.6). However, this reduction is not significant for TSPA, particularly when compared to the 18 km of saturated zone transport path length. **FEP Source:** SNL 2008 [DIRS 183041] – 1.3.07.02.0B	No	**Non-ITBC:** Extent of Unsaturated Zone	**Non-ITBC:** Repository Elevation above the Water Table

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	1.4.01.01.0A Climate Modification Increases Recharge **Included**	The ability of the unsaturated zone to prevent or substantially reduce the rate of movement of radionuclides is dependent on the percolation flux of water through the unsaturated zone, and the distribution of that flux within the fractured rock mass. This flux is directly dependent on the net infiltration which, in turn, is affected by surficial processes and climate change. Future climate change significantly affects percolation in the unsaturated zone below the repository. The net effect of climate change after repository closure is to increase the amount of water that can infiltrate and percolate through the unsaturated zone as recharge to the water table. The climate effect on the unsaturated zone flow below the repository has been directly included in the Site-Scale UZ Flow Model by using variable infiltration rates for each of three climates for the first 10,000 years following repository closure: present-day, monsoon, and glacial-transition. After that and through the period of geological stability as proposed by 40 CFR 197 [DIRS 177357], the effect of climate modification on percolation and recharge is incorporated into the Site-Scale UZ Flow Model using the distribution of deep percolation rate as specified in the proposed rule 40 CFR 197 [DIRS 177357]. The effect of climate change on radionuclide transport in the unsaturated zone is realized by (1) using the predicted future unsaturated zone flow fields (with increased percolation rates), and (2) incorporating the rise in the water table due to recharge and the associated reduction in the unsaturated zone thickness. The increase in percolation flux associated with future climate states significantly reduces the capability of the unsaturated zone feature to reduce the rate of radionuclide movement. **FEP Source:** SNL 2008 [DIRS 183041] – 1.4.01.01.0A	Yes	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Extent of Unsaturated Zone	**ITBC:** Repository Elevation above the Water Table **Non-ITBC** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.1.09.12.0A Rind (chemically altered zone) Forms in the Near Field **Excluded**	Thermal-hydrologic-chemical effects in the vicinity of the emplacement drifts induced by the evolution of the pore waters due to coupled thermal processes were found to produce changes in fracture permeability on the order of the natural variation, with most substantial changes above and to the side of the drift within about a drift diameter. While these changes would tend to reduce permeability in the affected regions and lead to a reduction in transport, they are considered insignificant because they are localized and within the natural variation. No changes are expected in the LNB; therefore no effect on flow and transport from the repository is expected. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.12.0A	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties In-Drift Chemical Environment In-Drift Thermal Environment, Convection, Condensation, and Evaporation	**Non-ITBC** Committed Materials
Unsaturated Zone Below the Repository	2.1.09.21.0C Transport of Particles Larger than Colloids in the UZ **Excluded**	Particles larger than colloids are not expected to be released from the Engineered Barrier System (EBS) (see FEP 2.1.09.21.0A). In the unlikely event of a release, such particles in the unsaturated zone have a negligible effect on radionuclide transport in the unsaturated zone because: (1) the highly variable orientation and roughness of the fracture surfaces along unsaturated zone transport pathways will promote both settling and filtration of particles larger than colloids (regardless of whether the fractures are water filled or air filled), and (2) processes such as attachment to immobile air-water interfaces and matrix imbibition will promote additional immobilization of particles in the unsaturated zone. In comparison, radionuclides reversibly or irreversibly sorbed onto colloidal-sized particles have a much more significant effect on the rate of movement of radionuclides. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.21.0C	No	**Non-ITBC:** Radionuclide Inventory and Source Term Properties Unsaturated Zone Transport Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Corrosion Products Properties	**None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.01.03.0A Changes in Fluid Saturations in the Excavation Disturbed Zone **Excluded**	Fluid saturation changes in the excavation-disturbed zone beneath the emplacement drifts could occur as a result of preclosure dryout, flow diversion around the emplacement drift, and/or postclosure thermal processes. These reductions in fluid saturations could decrease the percolation around the excavation and the transport of radionuclides below the opening by decreasing diffusion and increasing matrix imbibition and matrix diffusion. This process does not substantially impact the flow of water or the release of radionuclides because of the relatively short dryout period compared with the performance period and because of its localized effect. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.03.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Properties of the Host Rock Unit Properties of Unsaturated Zone Unsaturated Zone Flow Unsaturated Zone Transport Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing Duration of Ventilation Period
Unsaturated Zone Below the Repository	2.2.01.04.0A Radionuclide Solubility in the Excavation Disturbed Zone **Excluded**	Radionuclide solubility limits depend on the solution chemistry (including pH and Eh) and temperature. In the excavation disturbed zone (EDZ), the pH range is narrower and the solution is more dilute than in the in-drift environment; therefore, changes in radionuclide solubility from the EBS to the EDZ are insignificant to result in mineral precipitation and thus will not affect aqueous transport. In addition, although radionuclide solubility limits could affect the formation of certain kinds of true colloids, such as polymeric forms of plutonium oxide, these colloids are not found in significant quantities and are known to transform into pseudocolloids, whose formation is not affected by solubility limits. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.04.0A	No	**Non-ITBC:** In-Drift Chemical Environment Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Committed Materials

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.01.05.0A Radionuclide Transport in the Excavation Disturbed Zone **Excluded**	Investigations on the effects of stress relief on fracture permeability in the EDZ have found that the vertical permeability beneath the drift is changed by a factor of two or more over only a very narrow zone, on the order of one to two meters does not substantially impact the unsaturated zone radionuclide transport based on sensitivity analyses. Also, the potential changes in fracture aperture in the EDZ are found to be within the range of uncertainty already considered by the current UZ Radionuclide Transport Model. The transport characteristics in the EDZ, are considered to be insignificantly different from the repository horizon unsaturated zone strata. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.01.05.0A	No	**Non-ITBC:** In-Drift Chemical Environment Radionuclide Inventory and Source Term Properties Unsaturated Zone Properties Unsaturated Zone transport Unsaturated Zone Flow Properties of the Host Rock Unit Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Committed Materials Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.03.01.0A Stratigraphy **Included**	Stratigraphy and associated heterogeneity in hydrologic properties has a significant effect on unsaturated zone flow processes due to the contribution of faults in conducting flow below the repository and due to the different flow characteristics of the TSw, zeolitic and vitric CHn and CFu units. The zeolitic CHn have low matrix permeability that promotes the development of perched water zones through which lateral diversion can lead water toward the faults. Stratigraphy also affects the transport. The zeolitic rocks tend to have higher sorption capacities that reduces transport rates. In addition, mass transfer between fractures and the tuff matrix plays an important role in transport within the unsaturated zone. Because flow velocity in the matrix is much slower than in fractures, transfer of radionuclides from the fractures to the matrix can significantly retard the overall transport of radionuclides from the repository to the water table. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.03.01.0A	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone transport Unsaturated Zone Flow Properties of the Host Rock Unit	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.03.02.0A Rock Properties of Host Rock and Other Units **Included**	Rock properties, such as fracture permeability and sorption coefficient, significantly affect the distribution of percolation flux and radionuclide transport rate in the unsaturated zone. The properties and their associated variabilities have been incorporated into the Site-Scale UZ Flow Model and the UZ Radionuclide Transport Model. The unsaturated zone flow model uses layer-specific hydrologic properties and fault properties to represent the large-scale heterogeneity, because smaller-scale heterogeneity within a hydrogeologic unit has an insignificant effect on site-scale flow processes. Permeability differences at stratigraphic interfaces contributed to some lateral diversion of percolation flux in the stratigraphic units above the repository. In addition, the UZ Radionuclide Transport Model uses stochastic parameter distributions (e.g., for sorption coefficient, matrix diffusion coefficient, active fracture model , and fracture porosity) to capture additional effects for transport processes. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.03.02.0A	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone transport Unsaturated Zone Flow Properties of the Host Rock Unit	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.06.01.0A Seismic Activity Changes Porosity and Permeability of Rock **Excluded**	Although seismic activity may alter the porosity and permeability of the rock matrix in the unsaturated zone below the repository, the effects of changes to the rock matrix porosity and permeability caused by changes in rock stress are negligible compared with changes to the fracture porosity and permeability. Damage of the rock matrix material due to seismic loading would manifest itself in the form of inter-lithophysal tensile fractures that coalesce to form observable shear fractures with offset. The exposed lithophysal rocks in the Exploratory Studies Facility and the Enhanced Characterization of the Repository Block Cross-Drift show no fracturing of this type. Observed fracturing is consistent with typical cooling-fracture related history (BSC 2005 [DIRS 170137], Section 6.3.1). These findings indicate that the matrix material is largely unaffected by redistribution of strain introduced by seismic activity. The fractures are, therefore, more sensitive to mechanical strain; when a volume of fractured rock is subjected to a stress, most of the resulting strain occurs in the fractures. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.01.0A	No	**Non-ITBC** Characterization of Igneous Events Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC^1	Core Parameter Characteristic^2	Control Parameter Characteristic^3
Unsaturated Zone Below the Repository	2.2.06.02.0A Seismic Activity Changes Porosity and Permeability of Faults **Excluded**	It is inferred from the probabilistic seismic hazard analysis (PSHA) expert elicitation, that formation of significant new faults are unlikely in the Yucca Mountain vicinity within the next 10,000 years. In addition, although seismic events may reactivate existing faults, the resulting fault displacements are limited to a few meters with insignificant changes in hydrologic properties of faults. Furthermore, sensitivity analyses indicate that radionuclide transport in the unsaturated zone is not significantly affected by changes in fracture aperture or permeability in the fault zones. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.02.0A	No	**Non-ITBC** Characterization of Igneous Events Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.06.02.0B Seismic Activity Changes Porosity and Permeability of Fractures **Excluded**	The recent PSHA expert elicitation supports the interpretation that formation of significant new fractures is unlikely in the Yucca Mountain vicinity within the next 10,000 years. In addition, sensitivity analyses indicate only virtually no effect of fracture aperture changes on radionuclide transport in the unsaturated zone, and only a small effect of fracture permeability changes relative to other uncertainties associated with e.g., the infiltration rate. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.02.0B	No	**Non-ITBC:** Characterization of Igneous Events Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.06.03.0A Seismic Activity Alters Perched Water Zones **Excluded**	Perched water has only been found at Yucca Mountain near the TSw-CHn interface. In particular, the presence of perched water appears to be correlated with the presence of zeolitically altered minerals within the Calico Hills nonwelded (CHn). Zeolities at Yucca Mountain were formed during alteration of volcanic glass some 13-11.5 Ma, therefore, any effects of tectonic or seismic processes on the lithologic units, should have already occurred. The fact that the perched water occurrence is strongly correlated with the zeolitic lithology indicates that the effects of seismic and tectonic processes do not play a significant role in the formation and persistence of perched water. Any changes in flow due to seismically induced drainage from perched water are expected to be within the range of uncertainty in percolation fluxes included in the TSPA. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.03.0A	No	**Non-ITBC** Characterization of Igneous Events Unsaturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.07.02.0A Unsaturated Groundwater Flow in the Geosphere **Included**	Groundwater flow in the unsaturated zone defines the distribution of percolation flux and is the driving force for radionuclide transport below the repository. Variations in percolation rate and fracture hydrologic properties are two most important factors that affect transport times through the unsaturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.02.0A	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.07.03.0A Capillary Rise in the UZ **Included**	The capillary rise or capillary wicking, affects the distribution of percolation flux above the water table, and therefore is included in the models of unsaturated zone flow and transport. However, it has a small effect on the site-scale flow and transport processes. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.03.0A	No	**Non-ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.07.07.0A Perched Water Develops **Included**	Perched water zones exist near the TSw/CHn interface below the repository, as a result of the zeolitization process. These zones lead to lateral diversion of flow in the CHn towards the faults, which act as main pathways for fast flow and transport in the unsaturated zone. Transport analysis shows that transport time to the water table is substantially shorter in regions of the repository underlain by perched water (SNL 2007 [DIRS 184748], Figure 6.6.2-1). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.07.0A	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.07.08.0A Fracture Flow in the UZ **Included**	The unsaturated zone beneath the repository is generally composed of fractured volcanic tuff. The rate of movement of radionuclides in the unsaturated zone is dependent on the flux of water through the fractured rock mass. This flux is distributed between faults, fractures, and the matrix of the host rock and other units in the unsaturated zone. The rate of movement of radionuclides is dependent on the degree of fracture flow, which is variable across the hydrostratigraphic units of the unsaturated zone below the repository. In the absence of significant matrix diffusion, transport is mainly by advection through fractures. The absence of facture flow in the vitric portions of the Calico Hills substantially reduces the advective transport velocity, delaying movement of radionuclides in the unsaturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.08.0A	Yes	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.07.09.0A Matrix Imbibition in the UZ **Included**	Water and (dissolved and colloidal) radionuclides may be imbibed into the matrix between the flowing fractures. Matrix imbibition affects the distribution of flow between fractures and the matrix in the fractured unsaturated zone. Matrix imbibition is dominant in the Calico Hills nonwelded vitric rock, which substantially slows radionuclide transport. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.09.0A	Yes	**ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.07.15.0B Advection and Dispersion in the UZ **Included**	Advection processes dominate the transport time of dissolved and colloidal radionuclides in the UZ Transport Abstraction Model. Additionally, it is noted that dispersive processes tend to be ineffective in the unsaturated zone in spreading short-term transient releases from the EBS (BSC 2004 [DIRS 170035], Section 6.2.5; 6.3.6.3). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.15.0B	Yes	**ITBC**: Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.07.21.0A Drift Shadow Forms Below Repository **Excluded**	The presence of a drift shadow (i.e., relatively dry unsaturated rock beneath the EBS caused by the diversion of percolating water around the drift) could reduce advective transport of radionuclides through this zone. However, the drift shadow effect has been found to have only a second-order effect on radionuclide transport through the unsaturated zone, because a dryout zone forms primarily in the fracture while the matrix continuum is less affected by the drift shadow, and because radionuclides are mostly released from the drift invert into the matrix continuum. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.21.0A	No	**Non-ITBC:** Unsaturated Zone Properties Unsaturated Zone Flow Unsaturated Zone Transport Infiltration and Seepage Properties Properties of the Host Rock Unit	**Non-ITBC:** Repository Geographic and Geologic Location Emplacement Drift Configuration

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.08.01.0B Chemical Characteristics of Groundwater in the UZ **Included**	Chemical characteristics of groundwater, including temperature, pH, Eh, ionic strength, and major ionic concentrations, have been incorporated into the UZ Transport Abstraction Model through sorption coefficients (K_ds). Probability distributions of the K_ds were developed for each radioelement of interest among the three major rock types. The K_d distributions were developed through laboratory experiments under various conditions (time, element concentration, atmospheric composition, particle size, and temperature) with correlations based on consideration of such variables as pH, Eh, water chemistry, rock composition, rock surface area, and radionuclide concentration. The K_d distributions are then sampled in the TSPA to account for the effects of natural variations in pore-water chemistry and mineral surfaces. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.01.0B	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.08.03.0B Geochemical Interactions and Evolution in the UZ **Excluded**	Thermo-chemical interaction studies using the THC seepage model indicate that changes in fracture permeabilities resulting from mineral precipitation or dissolution will be within the natural variation in these properties. After rewetting, pore-water chemistries return to the unperturbed conditions in 10,000 to 30,000 years. In addition, colloids entrainment is not expected due to reduced colloids stability under elevated temperatures. Furthermore, use of introduced materials, such as cementitious materials, will not significantly affect radionuclide transport in the unsaturated zone because they are not used in emplacement drifts and because flow is mainly vertical in the unsaturated zone, limiting lateral migration of these materials. In summary, geochemical interactions are not expected to significantly modify the transport characteristics of the unsaturated zone below the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.03.0B	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.08.05.0A Diffusion in the UZ **Excluded**	Unlike matrix diffusion which is described in the included FEP 2.2.08.08.0B, molecular diffusion in faults and fractures is insignificant in comparison to advection-related hydrodynamic dispersion in the unsaturated zone. For the lower-bound groundwater flow velocity under the present-day climate, the minimum dispersion coefficient is estimated to be at least 10 times of the diffusion coefficient. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.05.0A	No	**Non-ITBC:** Seepage Water Properties Unsaturated Zone Properties Unsaturated Zone Transport Unsaturated Zone Flow	**Non-ITBC:** Repository Geographic and Geologic Location
Unsaturated Zone Below the Repository	2.2.08.06.0B Complexation in the UZ **Included**	The presence of potential complexation has been included in the development of the sorption properties of the radionuclides in the unsaturated zone. Complexation has been implicitly included in the sorption properties, which also include chemical characteristics of the groundwater, radionuclide concentrations, variations in rock surface properties, and using a range of representative ligands (see description of included FEP 2.2.08.01.0B Geochemical interactions and evolution in the unsaturated zone). This process is determined non-ITBC because its direct effects on sorption are included in other FEPs which are important to performance of the unsaturated zone below the repository. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.06.0B	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties	**Non-ITBC:** **None**
Unsaturated Zone Below the Repository	2.2.08.07.0B Radionuclide Solubility Limits in the UZ **Excluded**	Radionuclide solubility limits depend on the solution chemistry (including pH and Eh) and temperature. In the unsaturated zone, the pH range is narrower and the solution is more dilute than in the in-drift environment; therefore, changes in radionuclide solubility from the EBS to the unsaturated zone are insignificant to result in mineral precipitation and thus will not affect aqueous transport. In addition, although radionuclide solubility limits could affect the formation of certain kinds of true colloids, such as polymeric forms of plutonium oxide, these colloids are not found in significant quantities and are known to transform into pseudocolloids, whose formation is not affected by solubility limits. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.07.0B	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.08.08.0B Matrix Diffusion in the UZ **Included**	Matrix diffusion, results in the diffusion of dissolved radionuclides from fractures into the matrix of the fractured rock. Because the advective transport is significantly slower in the matrix, matrix diffusion can be a very efficient retarding mechanism, especially for moderately to strongly sorbed radionuclides, due to the increase in rock surface accessible to sorption. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.08.0B	Yes	**ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties	**Non-ITBC:** **None**
Unsaturated Zone Below the Repository	2.2.08.09.0B Sorption in the UZ **Included**	Sorption plays an important role in delaying the movement of most radionuclides through the unsaturated zone. Several radionuclides that are the dominant contributors to the total inventory are significantly retarded in the unsaturated zone when subject to significant matrix diffusion or matrix dominated flow in the vitric Calico Hills. These include ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am. Other radionuclides, such as ^{237}Np, are slightly sorbed. Therefore, sorption is included in the UZ Transport Abstraction Model using a linear equilibrium sorption ($\underline{K}_d$) model. The K_d distributions were developed through laboratory experiments under various conditions (time, element concentration, atmospheric composition, particle size, and temperature) with correlations based on consideration of such variables as pH, Eh, water chemistry, rock composition, rock surface area, and radionuclide concentration. The K_d distributions were sampled in the TSPA to account for the effects of natural variations in pore-water chemistry and mineral surfaces in the UZ. Although it could potentially further delay radionuclide movement through the unsaturated zone, sorption of dissolved or colloidal radionuclides onto fracture surfaces is not considered in the UZ Transport Abstraction Model due to insufficient data. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.09.0B	Yes	**ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.08.10.0B Colloidal transport in the UZ **Included**	Several radionuclides can be transported irreversibly or reversibly attached to colloids (notably ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am). These colloidally transported radionuclides can be retarded as they are transported through the fractured rock, due to colloid filtration. This retardation provides a significant delay in the movement of radionuclides to the saturated zone and subsequently to the accessible environment. A small fraction of the colloids are conservatively modeled to be unretarded in the unsaturated zone (SNL 2007 [DIRS 184748], Sections 6.5.1.2, 6.5.1.3 and 6.6.2). Sorption of colloidal transport of radionuclides is included in the UZ Transport Abstraction Model (SNL 2007 [DIRS 184748], Sections 6.5.1.2, 6.5.1.3 and 6.6.2). Although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.10.0B	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**
Unsaturated Zone Below the Repository	2.2.09.01.0B Microbial Activity in the UZ **Excluded**	The concentrations of complexing agents that may be released from microorganisms are expected to be small. In addition, in the assumed oxidizing environment, reductive biotransformation reactions would only decrease the solubility, and increase the sorption of key redox-sensitive radionuclides; hence their potential effect would benefit performance. Even if microbial cells can transport through fractures in the unsaturated zone, their impact on radionuclide transport is still expected to be small compared to that of inorganic groundwater colloids. Furthermore, similar to the reasons described in FEP 2.2.09.01.0A (Microbial activity in the saturated zone), heterotrophic microbial activity, which uses organic carbon as the sole energy source, is expected to be limited; and even in the event that organic carbon is converted to HCO3-, the resulting perturbation to the pH and carbonate water chemistry would be negligible in the unsaturated zone. Therefore, potential microbial effects on radionuclide movement in the unsaturated zone are not expected to be significant and have been excluded from the performance assessment; FEP Source: SNL 2008 [DIRS 183041] – 2.2.09.01.0B	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.10.04.0A Thermo-mechanical Stresses Alter Characteristics of Fractures Near Repository **Excluded**	Thermo-mechanical effects, induced by the response to heating of emplaced waste, do not significantly affect the hydrologic characteristics of the fractured rock mass below the repository, in particular the fracture permeability, capillarity, porosity, or percolation flux. Therefore, these processes are not expected to affect significantly, transport characteristics such as matrix diffusion, which is correlated to permeability and porosity in the unsaturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.04.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Unsaturated Zone Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing
Unsaturated Zone Below the Repository	2.2.10.04.0B Thermo-mechanical Stresses Alter Characteristics of Faults Near Repository **Excluded**	The thermo-mechanical induced stresses have no long term effect on fracture properties that would affect long term unsaturated zone flow and transport as noted in FEP 2.2.10.04.0A, thus, the thermo-mechanical stresses will have less of an impact on the block-bounding faults, which will be further away from the heat source. A fault's response to the same thermo-mechanical induced stresses imposed on fractures will be mitigated due to its size and distance from the heat source. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.04.0B	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Unsaturated Zone Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.10.05.0A Thermo-mechanical Stresses Alter Characteristics of Rocks Above And Below The Repository **Excluded**	Thermal-mechanical effects, induced by the response to heating by emplacement waste, do not significantly affect the hydrologic characteristics of the fractured rock mass. Changes in fracture permeability by elastic closure or opening of pre-existing fractures are estimated to be within a factor of 0.3 to 5, whereas capillary pressure changes within a factor of 0.7 to 1.2. The changes stated here are for the LNB. The LNB has a smaller range of predicted change. These thermally induced stress changes do not significantly impact the water percolation flux near and below the repository. In addition, screening analysis of FEP 2.2.06.02.0B shows that the effects of changes to fracture aperture or spacing on radionuclide transport in the unsaturated zone are expected to be negligible over a wide range of permeability variation. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.05.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Unsaturated Zone Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing
Unsaturated Zone Below the Repository	2.2.10.06.0A Thermo-chemical Alteration in the UZ (solubility, speciation, phase changes, precipitation/ dissolution) **Excluded**	Analyses show that potential thermal-chemical processes have insignificant effects on chemical compositions in the unsaturated zone. Sorption coefficients are either unaffected by temperature or increase slightly with temperature; therefore, the temperature dependency of K_ds is not incorporated. Fracture permeabilities are slightly reduced as a result of mineral precipitation of silica and calcite; however, the effects are on the order of the natural variation in these properties. Compositions of most aqueous species vary most during the relatively short thermal period, and return to unperturbed conditions within their ranges of variability in or around 10,000 years. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.06.0A	No	**Non-ITBC:** Unsaturated Zone Chemical Environment In-Drift Thermal Environment, Convection, Condensation, and Evaporation Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.10.07.0A Thermo-chemical Alteration of the Calico Hills Unit **Excluded**	Thermo-chemical alteration of the Calico Hills unit could affect unsaturated zone flow and transport by: (1) mineral dissolution and precipitation, which would change the fracture porosity and permeability of the fracture network; (2) changing the fracture-matrix interaction through the Active Fracture Model ; or (3) changing the sorption coefficient (K_d) through mineral dissolution and precipitation on the fracture wall surfaces. However, sensitivity analyses indicate that: (a) changes to fracture permeability of the CHn have a much less effect than variations in infiltration rates; and (b) changes in γ or K_d values of the CHn do not significantly affect radionuclide breakthrough, as transport in the unsaturated zone is controlled by the overlying TSw unit. Models show that elevation of the repository above the CHn ensures that the CHn will not be heated to temperature ranges that would cause significant dewatering of zeolites (see description of FEP 2.2.10.14.0A, Mineralogic Dehydration Reactions). **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.07.0A	No	**Non-ITBC:** Unsaturated Zone Chemical Environment In-Drift Thermal Environment, Convection, Condensation, and Evaporation Unsaturated Zone Properties Unsaturated Zone Transport Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing Standoff from the CHn Unit
Unsaturated Zone Below the Repository	2.2.10.09.0A Thermo-chemical Alteration of the Topopah Spring Basal Vitrophyre **Excluded**	Fluid inclusion data and thermal history analysis show that the current degree of alteration in TSw basal vitrophere resulted from exposure to temperatures of up to 80-95ºC for a long period of time (a million years). In comparison, the postclosure thermal pulse will be very brief relative to the extended thermal history of the mountain, and drift wall temperatures drop below 50ºC in less than 20,000 years, and will have little effect on the abundance of secondary minerals in the TSw basal vitrophyre. Therefore, thermally-induced alteration of this unit will be limited and will not significantly affect the sorptive or hydrologic properties of the units. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.09.0A	No	**Non-ITBC:** Unsaturated Zone Chemical Environment In-Drift Thermal Environment, Convection, Condensation, and Evaporation Unsaturated Zone Properties Unsaturated Zone Transport Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.10.14.0A Mineralogic Dehydration Reactions **Excluded**	Bounding calculations showed that the volume reduction of initially saturated zeolitic tuff heated in air at 95°C was 0.76 vol%. Mountain-scale thermal-hydrologic modeling indicates that matrix liquid saturation in zeolitic tuff at the base of the TSw will remain between about 0.94 and 1 throughout the thermal period, and peak temperatures at the base of TSw where the tuffs are zeolitized will remain below 75ºC. Therefore, mineral dehydration of the basal TSw and the upper CHn units are not expected to have any significant effect on unsaturated groundwater flow and, hence, radionuclide transport. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.14.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Unsaturated Zone Properties Unsaturated Zone Transport Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing
Unsaturated Zone Below the Repository	2.2.11.03.0A Gas Transport in Geosphere **Excluded**	The only radionuclides that would have a potential for significant gas transport are ^{14}C and ^{222}Rn. Although ^{129}I can exist in the gaseous phase, it is highly soluble and, therefore, would be more likely to be dissolved in groundwater rather than exist as a gas. Other gas phase isotopes have been eliminated in a screening analysis. For ^{14}C, the annual dose from the gas-phase release pathways is insignificant compared to the annual dose from the aqueous-phase pathways. Gas flow studies also show that ^{222}Rn released from the repository in the gas phase is expected to radioactively decay before reaching the ground surface. Therefore, all radionuclides released from the EBS are considered to be transported in the aqueous phase in the geosphere, which maximizes the potential dose consequences associated with radionuclides, such as ^{14}C, and is therefore conservative. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.11.03.0A	No	**Non-ITBC:** Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.12.00.0A Undetected Features in the UZ **Excluded**	Discrete features such as faults have been included in the Site-Scale UZ Flow Model and the UZ Transport Abstraction Model. Model results show within the repository footprint existing major fault features carry only less than 1.5% of flow at the repository horizon and less than 38% at the water table. The existence of a large undetected feature such as a seismogenic fault is not expected, given the extensive site investigation. Therefore, undetected features would not be expected to significantly alter the fraction of flow through features within the repository footprint, and therefore will have only limited effect on unsaturated zone transport. In addition, the effects of fault properties are found to be less important to transport than the presence of perched water, while models with various conceptualizations of perched water predict similar breakthroughs. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.12.00.0A	No	**Non-ITBC:** Unsaturated Zone Properties Unsaturated Zone Transport Unsaturated Zone Flow	**Non-ITBC:** **None**
Unsaturated Zone Below the Repository	2.2.14.09.0A Far-field Criticality **Excluded**	It has been determined that the conditions required to lead to a far field critical event are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides, or impact the barrier capability of this feature. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.14.09.0A	No	**Non-ITBC:** Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.14.10.0A Far-field Criticality Resulting from a Seismic Event **Excluded**	It has been determined that the conditions required to lead to a far-field critical event are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.14.10.0A	No	**Non-ITBC:** Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Characterization of Igneous Events Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**
Unsaturated Zone Below the Repository	2.2.14.11.0A Far-field Criticality Resulting from Rockfall **Excluded**	It has been determined that the conditions required to lead to a far field critical event are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.14.11.0A	No	**Non-ITBC:** Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Unsaturated Zone Below the Repository	2.2.14.12.0A Far-field Criticality Resulting from an Igneous Event **Excluded**	It has been determined that the conditions required to lead to a far-field critical event are not likely to occur and the parameter characteristics associated with this process and feature do not substantially effect the release of radionuclides or impact the barrier capability of this feature. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.14.12.0A	No	**Non-ITBC:** Unsaturated Zone Properties Unsaturated Zone Transport Radionuclide Inventory and Source Term Properties Characterization of Igneous Events Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**
Unsaturated Zone Below the Repository	3.1.01.01.0A Radioactive Decay and Ingrowth **Included**	For radionuclides that are highly sorbed, sufficient radioactive decay can occur after closure to reduce their rate of movement to the saturated zone. For other radionuclides (notably ^{241}Am to ^{237}Np), ingrowth can increase the effective amount of radionuclides being transported. These processes are included in the UZ Transport Abstraction Model (SNL 2007 [DIRS 184748], Section 8.2.2 [a]). Radioactive decay and ingrowth are much like inventory; it is well characterized, given the fixed inventory that is used in the analyzed basis. Any change to inventory will be managed by the change evaluation process. The decay and ingrowth processes are not considered ITBC for the unsaturated zone below the repository because the groundwater residence time through the unsaturated zone is much shorter than the half-lives of major dose contributors. **FEP Source:** SNL 2008 [DIRS 183041] – 3.1.01.01.0A	No	**Non-ITBC:** Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	1.2.02.01.0A Fractures **Included**	Fracture characteristics are important to the barrier capability for the saturated zone, because groundwater flow occurs primarily within the fracture network of the volcanic tuff units. The fracture networks in the saturated zone at Yucca Mountain appear to be well-connected over large distances at the scales of interest (hundreds of meters to kilometers). These fracture networks, in turn, control the movement of the dissolved and colloidal radionuclides below the water table. Fracture characteristics (e.g., fracture porosity, flowing interval porosity, and flowing interval spacing) are included in the SZ Flow and Transport Abstraction Model using a dual porosity effective continuum approach. Their associated uncertainties are represented through the parameter distributions, which were sampled when generating the breakthrough curves for the TSPA. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.01.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	1.2.02.02.0A Faults **Included**	Faults affect the groundwater flow paths, influence the horizontal anisotropy in permeability, and can enhance dispersion by increasing permeability heterogeneities along the saturated zone flow paths. Therefore, faults are incorporated into the SZ Flow and Transport Abstraction Model through the use of rock properties, and uncertainties in fault-related parameters such as horizontal anisotropy, are also probabilistically included in the model. Faults are considered ITBC for the saturated zone because they may act as preferred conduits or barriers to flow. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.02.02.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location Repository Standoff from Quaternary Fault

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	1.2.04.02.0A Igneous Activity Changes Rock Properties **Excluded**	Studies of natural analogue sites show that the effect of unlikely intrusive igneous events is generally to alter the properties in the immediate vicinity (a few meters) from the intrusive sill or dike. These changes (which may increase or decrease permeability and porosity) are of limited spatial extent. In addition, future dikes are expected to be parallel to subparallel orientation relative to the direction of maximum principal transmissivity, and to have small widths relative to the width of the areally extensive saturated zone flow and transport domain and the widths of the predominant flow paths. Therefore, igneous activity-induced small-scale rock property changes do not significantly affect the capabilities of the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.02.0A	No	**Non-ITBC:** Characterization of Igneous Events Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	1.2.04.07.0B Ash Redistribution in groundwater **Excluded**	The consequences associated with leaching of radionuclides from an ashfall into groundwater are small compared to the consequences of directly exposing the same inventory of radionuclides to seepage following igneous intrusion. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.04.07.0B	No	**Non-ITBC:** Characterization of Igneous Events Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	1.2.06.00.0A Hydrothermal Activity **Excluded**	Any possible hydrothermal activity in the vicinity of Yucca Mountain generally requires a predecessor igneous event. However, there is no clear evidence of extensive hydrothermal activity resulting from previous igneous events at or near Yucca Mountain. Even in the event of an igneous intrusion or eruption, the possible effects of hydrothermal activity are inconsequential to repository performance (see discussion of FEP 1.2.04.02.0A, Igneous Activity Changes Rock Properties) because the widths of igneous intrusions that would intersect the saturated zone flow domain and the contact zone where the in situ rock's mineralogy would be thermally altered are small. Therefore, any associated hydrothermal activity produced from future igneous activity would be localized and of low consequence to saturated zone flow paths. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.06.00.0A	No	**Non-ITBC:** Characterization of Igneous Events	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	1.2.09.02.0A Large-scale Dissolution **Excluded**	Dissolution processes are not expected to affect the rate of radionuclide migration in the saturated zone because volcanic rocks are not readily soluble in water and their solubility is low enough, that large-scale dissolution does not occur. Even in the more soluble carbonate aquifers, significant dissolution and radionuclide movement would not occur because of a lack of observed extensive carbonate cavities at such depth and because of the large distance of the carbonate aquifers to the water table and the upward vertical hydraulic gradient in these units. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.09.02.0A	No	**Non-ITBC:** Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	1.2.10.01.0A Hydrologic Response to Seismic Activity **Excluded**	Seismic activity may alter the rock, fracture, and fault characteristics, which may affect the hydrogeology of the saturated zone in the vicinity of the repository. However, investigations focusing on the potentiometric hydrologic response, given changes in rock properties adjacent to faults, demonstrate that the changes in water-table elevations are not expected to exceed 50 m and are transient and local in nature. Even if water table rises by up to 120 m under future wetter climates, seismic events are still unlikely to affect hydrologic conditions at the repository horizon. Furthermore, seismic activity will have an insignificant effect on the location of the large hydraulic gradient or on groundwater chemistry in the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.10.01.0A	No	**Non-ITBC:** Characterization of Igneous Events Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	1.2.10.02.0A Hydrologic Response to Igneous Activity **Excluded**	Igneous intrusions that might occur in the time frame of 10,000 years after closure would affect a relatively small volume of the host rock and are expected to be oriented subparallel to existing flow directions. Consequently, future intrusions would not have a significant effect on groundwater flow patterns or rates in the saturated zone. Given the limited area of any thermal or geochemical alteration, and the consequent change of rock properties around an intrusion, any geochemical effects would be minimal. The potential development of a hydrothermal system from igneous activity is not expected based on analogue studies and would be of low consequence due to its limited size relative to the saturated zone model domain. **FEP Source:** SNL 2008 [DIRS 183041] – 1.2.10.02.0A	No	**Non-ITBC:** Characterization of Igneous Events Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	1.3.01.00.0A Climate Change **Included**	Climate change alters the flux through the saturated zone by increasing the regional recharge and causing the water table to rise (SNL 2007 [DIRS 177391], Section 6.6.4.1). The effect on regional recharge will lead to an increase in the saturated zone groundwater flux between the repository and the accessible environment, which in turn tends to decrease the advective transport time from the repository to the accessible environment for both sorbing and nonsorbing radionuclides that may be released from the unsaturated zone below the repository. This increased flux and potential changes to the groundwater flow paths are conservatively approximated in the SZ Flow and Transport Abstraction Model by increasing the specific discharge. This increase causes a significant increase in the movement of radionuclides, which degrades the capability of the saturated zone feature of the Lower Natural Barrier. **FEP Source:** SNL 2008 [DIRS 183041] – 1.3.01.00.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Flow Extent of Saturated Zone	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation above the Water Table
Saturated Zone	1.3.07.01.0A Water Table Decline **Excluded**	Significant lowering of the water table by other than anthropogenic processes under future wetter climates is not expected except for short-term, anomalously dry conditions that are not expected to lower the water table elevation by more than a few meters. Such small decreases to the water table elevation are well within the uncertainties included in the unsaturated and saturated zone models and are therefore of low consequence. **FEP Source:** SNL 2008 [DIRS 183041] – 1.3.07.01.0A	No	**Non-ITBC:** Saturated Zone Properties Saturated Zone Flow Extent of Saturated Zone	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	1.3.07.02.0A Water Table Rise Affects SZ **Included**	Following a change in climate and the resultant increase in recharge both in the vicinity of the site and in the region around the site, the water table is expected to rise. Although uncertainty exists in the amount of rise, the TSPA models conservatively considered the rise to be up to 120 m. The water table rise increases the transport length in the saturated zone by less than 120 m. However, this reduction is not significant when compared to the 18 km of saturated zone transport path length. Furthermore, this effect is diminished over the period of geologic stability. **FEP Source:** SNL 2008 [DIRS 183041] – 1.3.07.02.0A	No	**Non-ITBC:** Extent of Saturated Zone	**Non-ITBC:** Repository Elevation above the Water Table

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	1.4.01.01.0A Climate Modification Increases Recharge **Included**	The increase in recharge associated with future climate states significantly increases the groundwater flux through the tuff and alluvial water-conducting features, which reduces the effectiveness of the barrier capability of this feature. This effect is incorporated into the saturated zone flow and transport model, and is determined to be ITBC because of its significant contribution to the barrier capability of the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 1.4.01.01.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Flow Extent of Saturated Zone	**Non-ITBC:** Repository Geographic and Geologic Location Repository Elevation above the Water Table
Saturated Zone	1.4.07.02.0A Wells **Included**	The effect of pumping wells on saturated zone groundwater flow has been incorporated into the Site-Scale SZ Flow Model via the configuration of the water table used as an upper boundary and the flow rates across the model boundaries as provided by the Death Valley regional model. The regional model specifically incorporated the irrigation wells located south of Yucca Mountain in Amargosa Valley. In addition, measured water levels from these existing wells are used in the calibration of the Site-Scale SZ Flow Model. Furthermore, the effects of wells on the dose to the RMEI are included into the TSPA by assuming all of the radionuclide mass that reaches the 18-km accessible environment, is contained in the representative volume of groundwater from which the RMEI obtains all required water. The effects of wells are not ITBC for the saturated zone because wells drilled for domestic or agricultural use are not anticipated to significantly affect groundwater flow or radionuclide movement due to the their large distances away from the predominant flow paths. **FEP Source:** SNL 2008 [DIRS 183041] – 1.4.07.02.0A	No	Saturated Zone properties Saturated Zone Flow	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.1.09.21.0B Transport of Particles Larger than Colloids in the SZ **Excluded**	Very few radionuclide-bearing particles larger than colloids are expected to be introduced into the saturated zone from the unsaturated zone (see FEPs 2.1.09.21.0A and 2.1.09.21.0C). In addition, the highly variable orientation and roughness of the fracture and alluvium surfaces along saturated zone transport pathways promote both settling and filtration of particles larger than colloids. Furthermore, vertical velocity components in the saturated zone are not expected to be large enough to keep particles larger than 1μm in diameter suspended indefinitely. **FEP Source:** SNL 2008 [DIRS 183041] – 2.1.09.21.0B	No	**Non-ITBC:** Radionuclide Inventory and Source Term Properties Saturated Zone Transport Waste Form/Package Internals Materials, Properties, and Configuration Waste Form Degradation Corrosion Products Properties Waste Form/Package Internals Materials, Properties, and Configuration	**None**
Saturated Zone	2.2.03.01.0A Stratigraphy **Included**	Stratigraphic controls affect groundwater flow paths and rates in the saturated zone. Various parameters significant to the transport of radionuclides through the saturated zone (e.g., effective diffusion, matrix porosity, and bulk density) are dependent on the stratigraphy and heterogeneity of hydrogeologic units. Stratigraphy is included in the performance assessment through the hydrogeologic framework model for saturated zone flow and transport. 27 hydrostratigraphic units and 10 discrete geologic features representing major faults and fractures are represented with specific hydrologic and transport parameters. Stratigraphy is ITBC because of its importance to the determination of groundwater flowpaths and rates of radionuclide movements in the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.03.01.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Transport Saturated Zone Flow	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.03.02.0A Rock Properties of Host Rock and Other Units **Included**	Rock properties for 27 hydrostratigraphic units and 10 discrete geologic features related to faults and factures are explicitly included in the SZ Flow and Transport Abstraction Model. Rock properties are considered ITBC because they have a significant effect on the groundwater flowpaths and the rate of radionuclide movement. Some of the important properties include the flowing interval spacing, matrix diffusion, fracture porosity, and matrix porosity of the alluvium, and retardation properties matrix porosity of the volcanic units, and effective porosity of the alluvium. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.03.02.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Transport Saturated Zone Flow	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	2.2.06.01.0A Seismic Activity Changes Porosity and Permeability of Rock **Excluded**	Existing rock hydrologic properties reflect the cumulative response to cumulative displacements of a dynamic seismic past. Because the Yucca Mountain region is now experiencing lower extension rates and is tectonically less active than 5 million years ago, future fault displacements are minor and will alter rock properties minimally compared to intact host rock alterations due to the cumulative fault displacements of an active tectonic past. Therefore, future seismic activity will not result in any significant new faults and fractures in the intact host rock, nor will it alter the hydrologic properties in the existing “zone of alteration” within that region that would affect saturated zone flow path origins. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.01.0A	No	**Non-ITBC:** Characterization of Igneous Events Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.06.02.0A Seismic Activity Changes Porosity and Permeability of Faults **Excluded**	Current fault porosities and permeabilities reflect the effects of a seismically active past within the Yucca Mountain region. The PSHA expert elicitation indicates that future seismic events are expected to rupture existing faults, rather than develop new faults in the Yucca Mountain vicinity within the next 10,000 years. In addition, although seismic events may reactivate existing faults, the resulting fault displacements are limited to a few meters with insignificant changes in hydrologic properties of faults. Furthermore, the uncertainty in the effective hydrologic properties incorporated in the SZ Flow and Transport Model, coupled with uncertainty in specific discharge, exceeds the changes that would be caused by small movements along existing faults. Therefore, seismic activity-induced changes, to fault porosity and permeability, are not considered in the SZ Flow and Transport Abstraction Model and are not ITBC for the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.02.0A	No	**Non-ITBC:** Characterization of Igneous Events Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	2.2.06.02.0B Seismic Activity Changes Porosity and Permeability of Fractures **Excluded**	The main result of seismic activity is expected to be the reactivation of existing fractures rather than the opening of new fractures such that any new fractures formed would have a negligible effect on hydrologic or transport properties. In addition, existing regional stresses imposed on fracture hydrologic properties reflect the crustal extension stresses in effect today, and regional fracture hydrologic properties are not expected to be significantly altered from current conditions by future seismic activity. Furthermore, the uncertainty in hydrologic properties incorporated in the SZ Flow and Transport Model exceeds any changes in fracture hydrologic properties resulting from seismic activity. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.06.02.0B	No	**Non-ITBC:** Characterization of Igneous Events Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	2.2.07.12.0A Saturated Groundwater Flow in the Geosphere **Included**	Groundwater flow in the saturated zone defines the distribution of flowpaths and flow rates and is the driving force for radionuclide transport from the water table to the accessible environment. Variations in flowpaths and rates along the volcanic tuff and alluvium aquifers units are important factors that affect transport times through the SZ. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.12.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.07.13.0A Water-Conducting Features in the SZ **Included**	Water flow in the saturated zone occurs within the fractured tuff units and the alluvium. The groundwater flow rates, radionuclide transport velocities, and radionuclide retardation characteristics of these different water-conducting features are significantly different. In addition to the differences in flow and transport characteristics of the 27 different hydrogeologic units in the saturated zone, the presence of 10 discrete flowing features in the fractured tuff units control the advective velocities and, therefore, transport times from the base of the unsaturated zone to the alluvium. Depending upon their physical properties, these discrete features act as either barriers or conduits to groundwater flow in the saturated zone. In the southern part of the saturated zone model domain near Amargosa Valley, the flow in the alluvium provides a significant reduction in the movement of radionuclides to the accessible environment. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.13.0A	Yes	**ITBC**: Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	2.2.07.14.0A Chemically Induced density Effects on Groundwater Flow **Excluded**	Water entering the saturated zone from the unsaturated zone will tend to have higher density because of evaporative concentration. Density-driven flow will not occur under ambient flow conditions because of insufficient density gradient between. During the thermal period, higher density seepage water will carry a small flux and will be localized and transient, and will by diluted by porewater in the unsaturated zone prior to reaching the water table. This small percolation flux from the repository will be further diluted by the base flow in the saturated zone once reaching the water table. The potential effect of chemically induced density effects is expected to be minor compared to the uncertainties in groundwater specific discharge and flowing interval porosity that are included in the SZ Flow and Transport Abstraction Model. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.14.0A	No	**Non-ITBC:** Saturated Zone Properties Saturated Zone Flow	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.07.15.0A Advection and Dispersion in the SZ **Included**	Advection is the principal transport mechanism for both dissolved and colloidal radionuclides in the saturated zone. The advective flux is dependent on the hydrogeologic characteristics of the hydrostratigraphic units and discrete water-conducting features in the saturated zone, as well as the hydraulic gradient through these units and features. Dispersive processes tend to spread transient radionuclide pulses that may be released to the saturated zone (e.g., following the breach of a waste package or the water table rise associated with climate changes). These processes have been included in the saturated zone transport. Advection through the fractures is ITBC because of its importance for determining flow paths and rates of radionuclide movement in the SZ. Dispersion, however, is not ITBC because it has insignificant contributions to radionuclide transport in the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.15.0A	Yes	**ITBC:** Saturated Zone Properties Saturated Zone Flow Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	2.2.07.16.0A Dilution of Radionuclides in Groundwater **Included**	Dilution of radionuclides as a result of groundwater transport is included in the TSPA in two ways: dispersion in flowing groundwater and dilution in the representative volume of groundwater. Dispersion is insignificant in affecting the rate of radionuclide movement (see description of FEP 2.2.07.15.0A, Advection and Dispersion in the SZ). In addition, the method for calculating the concentration of radionuclides in the annual water demand of the RMEI as implemented in the TSPA model is prescribed by the regulation. Therefore, dilution of radionuclides is not ITBC for the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.16.0A	No	**Non-ITBC:** Radionuclide Inventory and Source Term Properties Saturated Zone Properties Saturated Zone transport Saturated Zone Flow Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.07.17.0A Diffusion in the SZ **Included**	Unlike matrix diffusion which is described in the included FEP 2.2.08.08.0A, molecular diffusion in the fractured volcanic tuffs and alluvium is insignificant in comparison to fractured-dominated advection and hydrodynamic dispersion in the saturated zone. Estimated upper limit of effective diffusion coefficient is about two orders of magnitude lower than the minimum dispersion coefficients for volcanic units. Therefore, although included in the SZ Flow and Transport Abstraction Model for the performance assessment, this process is not ITBC for the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.07.17.0A	No	**Non-ITBC:** Unsaturated Zone Chemical Environment Unsaturated Zone Properties Unsaturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	2.2.08.01.0A Chemical Characteristics of Groundwater in the SZ **Included**	Chemical characteristics of groundwater, including temperature, pH, Eh, ionic strength, and major ionic concentrations, significantly affect sorption, which is an important factor that contributes to radionuclide transport in the SZ, and has been incorporated into the SZ flow and transport abstraction model through sorption coefficients (K_ds). Probability distributions of the K_ds were developed for each radioelement of interest among the three major rock types. The K_d distributions were developed through laboratory experiments under various conditions (time, element concentration, atmospheric composition, particle size, and temperature) with correlations based on consideration of such variables as pH, Eh, water chemistry, rock composition, rock surface area, and radionuclide concentration. The K_d distributions were sampled in the TSPA to account for the effects of natural variations in pore-water chemistry and mineral surfaces. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.01.0A	No	**Non-ITBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.08.03.0A Geochemical Interactions and Evolution in the SZ **Excluded**	The saturated zone is predominately in an oxidizing environment, which generally facilitates transport of radionuclides more than a reducing environment. Reducing zones have been observed directly east of Yucca Mountain in wells H-3, H-4, WT-17, b#1, WT-10, WT-12 and WT-14. It is not expected that these local reduction zones will be oxidized during the 10,000 years after repository closure, or that they will increase in size. The presence of reducing conditions along the flow path would tend to increase transport time, because reducing conditions could lead to increased sorption and precipitation of redox-sensitive radionuclides. Reducing oxidizing conditions would result in dissolution and desorption and a return to the radionuclide concentrations similar to those prior to encountering the localized reducing condition. Therefore, oxidizing conditions along the entire flow path is conservatively assumed in the development of radionuclide K_d distributions in the saturated zone. In addition, mixing of paleowaters and recharged waters under current climatic conditions would not result in major changes in the bulk water chemistry. Furthermore, temporal changes in water geochemistry exert little effects on geochemical interaction in the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.03.0A	No	**Non-ITBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport	**Non-ITBC:** Repository Geographic and Geologic Location
Saturated Zone	2.2.08.06.0A Complexation in the SZ **Included**	The presence of potential complexation agents has been included in the development of the sorption properties of the radionuclides in the saturated zone. Complexation has been implicitly included in the sorption properties, which also include chemical characteristics of the groundwater, radionuclide concentrations, and variations in rock surface properties (see description of included FEP 2.2.08.01.0A, Chemical characteristics of groundwater in the SZ).). This process is determined non-ITBC because its direct effects on sorption are included in other FEPs which are important to performance of the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.06.0A	No	**Non-TBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.08.07.0A Radionuclide Solubility Limits in the SZ **Excluded**	Radionuclide solubility limits depend on the solution chemistry (including pH and Eh) and temperature. Radionuclide concentrations entering the saturated from the unsaturated zone are not expected to exceed solubility limits because of the effects of dilution, dispersion, matrix diffusion, and sorption in the unsaturated zone (see description of FEP 2.2.08.07.0B Radionuclide solubility limits in the UZ). They will be further reduced in the saturated zone by the same processes. Therefore, changes in radionuclide solubility from the unsaturated to the saturated zone have been excluded from the SZ Flow and Transport Model. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.07.0A	No	**Non-ITBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**
Saturated Zone	2.2.08.08.0A Matrix Diffusion in the SZ **Included**	Field scale in situ tracer tests at the C-wells validated matrix diffusion as an important transport mechanism in fractured volcanic formations in the saturated zone. This process can be an effective retarding mechanism and is ITBC for the saturated zone. Although field-test data from the Alluvial Testing Complex and the Nye County Early Warning Drilling Program Site 22 also indicate some degree of heterogeneity in the alluvium, no credit is taken for matrix diffusion in the alluvial units based on consideration for conservatism. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.08.0A	Yes	**ITBC**: Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.08.09.0A Sorption in the SZ **Included**	Sorption plays an important role in delaying the movement of most radionuclides through the saturated zone. Several radionuclides, including those that contribute the most significant fraction of the inventory (for example, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am), are moderately to highly sorbed in the saturated zone. Therefore, sorption is included in the SZ Flow and Transport Abstraction Model using a linear equilibrium sorption (K_d) model. The K_d distributions were developed through laboratory experiments under various conditions (time, element concentration, atmospheric composition, particle size, and temperature) with correlations based on consideration of such variables as pH, Eh, water chemistry, rock composition, rock-surface area, and radionuclide concentration. The K_d distributions were sampled in the TSPA to account for the effects of natural variations in pore-water chemistry and mineral surfaces. Although it could potentially further delay radionuclide movement through the saturated zone, sorption of dissolved or colloidal radionuclides onto fracture surfaces is not considered in the SZ Flow and Transport Abstraction Model due to insufficient data. Sorption is determined to be ITBC for the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.09.0A	Yes	**ITBC**: Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.08.10.0A Colloidal Transport in the SZ **Included**	Several radionuclides can be transported irreversibly or reversibly attached to colloids (notably ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{243}Am). These colloids can be filtered and retarded as they are transported through the fractured rock mass and porous alluvium such that their movement is prevented or the rate of movement is substantially reduced. Colloidal transport is affected by the type of colloid and the characteristics of the water-conducting features. Colloidal transport effects, including retardation of colloids in the saturated zone, are included in the SZ Flow and Transport Abstraction Model. Based on considerations for conservatism, a small fraction of the colloids is modeled as unretarded in the saturated zone, and colloid matrix diffusion is not included in the model because its effect on saturated zone transport is expected to be small. Although considered and accounted for in the postclosure analyzed basis, the contribution of colloid transport processes is less significant than that associated with the transport of dissolved radionuclides and parameter characteristics associated with the transport of colloids are not considered important to barrier capability. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.08.10.0A	No	**Non-ITBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**
Saturated Zone	2.2.09.01.0A Microbial Activity in the SZ **Excluded**	Heterotrophic microbial activity, which uses organic carbon as the sole energy source, is expected to be limited because groundwater samples taken indicate little to no organic carbon in groundwater. Additionally, any potential autotrophic microbial reaction will not generate CO_2. Even in the events that organic carbon is converted to CO_2, the resulting perturbation to the pH and carbonate water chemistry would be negligible. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.09.01.0A	No	**Non-ITBC:** Saturated Zone Chemical Environment Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.10.02.0A Thermal Convection Cell Develops in SZ **Excluded**	Thermal-hydrologic modeling indicates that the water-table temperature will peak approximately 6,000 years after closure, at less than about 30°C above the current ambient temperature. An analysis using the Rayleigh number indicates that the peak temperature is below the critical value for the onset of convection in the saturated zone. Additionally, the peak temperature is estimated to result in a water-table mounding of 5.05 m and a 21% increase in the hydraulic gradient, which are small variations compared to the uncertainty of groundwater specific discharge already captured in the SZ Flow and Transport Abstraction Model. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.02.0A	No	**Non-ITBC:** In-Drift Thermal Environment, Convection, Condensation, and Evaporation Saturated Zone Properties Saturated Zone Flow Extent of Saturated Zone Geothermal Gradient Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing
Saturated Zone	2.2.10.03.0A Natural Geothermal Effects on Flow in the SZ **Included**	Natural geothermal effects, as they influence fluid properties, are implicitly included in the SZ Site-Scale Flow Model, which serves as the basis for the SZ Flow and Transport Abstraction Model. Studies of two-phase fluid inclusions in the unsaturated zone show that significant or widespread alteration of the natural geothermal gradient has not occurred in the unsaturated zone, which implies that significant change to the geothermal gradient has likewise been absent from the saturated zone. Therefore, this process, although included in the models of saturated zone flow, does not significantly affect the groundwater flowpaths or rate of movement of radionuclides. Therefore, the effect is considered non-ITBC for the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.03.0A	No	**Non-ITBC:** Saturated Zone Properties Saturated Zone Flow Extent of Saturated Zone Geothermal Gradient	**Non-ITBC:** Repository Geographic and Geologic Location

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.10.08.0A Thermo-chemical Alteration in the SZ (solubility, speciation, phase changes, precipitation/dissolution) **Excluded**	Analyses show that potential thermal-chemical processes have insignificant effects on chemical compositions in the unsaturated zone (see FEP 2.2.10.06.0A Thermo-chemical alteration in the unsaturated zone). Similarly for the saturated zone, thermal-hydrologic modeling indicate that the water-table temperature will peak approximately 6,000 years after closure, at less than about 30°C above the current ambient temperature; such temperature increases will be insufficient to alter the zeolites (clinoptilolite) and will have no effect on sorption coefficients (K_ds) since the K_ds are either unaffected by temperature or increase slightly with temperature. Fracture permeabilities may be slightly reduced as a result of mineral precipitation of silica and calcite, however, the effects are inconsequential to site-scale flow and transport in the saturated zone. Finally, any thermally-induced changes in unsaturated zone water chemistry would be further diluted, given the relatively small volume of unsaturated zone water that contributes to the total water flow in the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.08.0A	No	**Non-ITBC:** Saturated Zone Chemical Environment In-Drift Thermal Environment, Convection, Condensation, and Evaporation Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing Repository Elevation above the Water Table

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.10.13.0A Repository-Induced Thermal Effects on Flow in the SZ **Excluded**	Thermal-hydrologic modeling indicates that the water-table temperature will peak approximately 6,000 years after closure, at less than about 30°C above the current ambient temperature. Such temperature increases will not cause the groundwater specific discharge to approach the upper limit of the uncertainty range considered in the SZ Flow and Transport Abstraction Model. In addition, although increased temperatures can cause some changes in groundwater chemistry, the variability introduced by such changes will be much less than is already included in the range of distribution coefficients used to model sorption. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.10.13.0A	No	**Non-ITBC:** Saturated Zone Chemical Environment In-Drift Thermal Environment, Convection, Condensation, and Evaporation Saturated Zone Properties Saturated Zone Transport Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** Drift Wall Temperature Waste Package Spacing Repository Elevation above the Water Table
Saturated Zone	2.2.11.01.0A Gas Effects in the SZ **Excluded**	There is no evidence of large-scale gas build-up in the saturated zone, or significant volumes of oil or gas in the Yucca Mountain vicinity. Additionally, there is no potential for clathrates or for microbial degradation of organic components as potential hydrocarbon or gas sources at Yucca Mountain. Furthermore, degradation of repository components that would potentially produce gas is not expected to affect flow and transport in the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.11.01.0A	No	**Non-ITBC:** Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	2.2.12.00.0B Undetected Features in the SZ **Included**	Potential impacts on groundwater flow from undetected features in the saturated zone, such as fracture zones, inhomogeneities, faults, gravel lenses, and channels in the alluvium are implicitly incorporated in the SZ flow and Transport Abstraction Model and the SZ 1-D Transport Model through stochastic parameter distributions. The Site-Scale SZ Flow Model is based on observed and inferred flow paths and flow properties, and uncertainty in the models implicitly includes the effects of these discrete features, whether detected or undetected. Groundwater specific discharge in the saturated zone may be enhanced due to the presence of undetected features. In the alluvium, undetected features could be gravel lenses and channels, and in the volcanic units undetected features could be faults and fractures or fracture clusters. Uncertainties in parameters related to these features are applied to the hydrogeologic units when generating saturated zone breakthrough curves for the TSPA. This modeling approach, coupled with adequate characterization of the saturated zone, ensures that groundwater flow rates and flow paths are not significantly affected by any undetected features. Therefore, this effect is non-ITBC for the saturated zone. **FEP Source:** SNL 2008 [DIRS 183041] – 2.2.12.00.0B	No	**Non-ITBC:** Saturated Zone Properties Saturated Zone Flow	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	**FEP Number Name, and Screening Decision**	**Discussion of Effect on Barrier Capability**	**Relates to ITBC**[1]	**Core Parameter Characteristic**[2]	**Control Parameter Characteristic**[3]
Saturated Zone	3.1.01.01.0A Radioactive Decay and Ingrowth **Included**	Radionuclides that have low advective velocity and are highly sorbed in the saturated zone can have sufficient radioactive decay along their travel path after closure to significantly reduce the rate of movement to the accessible environment. The degree of decay is a function of the half-life of the radionuclide in comparison to the transport time along the expected travel paths between the repository and the accessible environment. For other radionuclides (notably ^{241}Am to ^{237}Np), ingrowth can increase the effective rate of radionuclide movement. Both of these processes are included for both dissolved and colloidal radionuclide transport in the saturated zone transport (SNL 2007 [DIRS 183750], Section 7.4.2 [b]; 6.7.4.2 [b]). Decay is considered in the SZ Flow and Transport Abstraction Model, and additionally, ingrowth in the SZ 1-D Transport Model. Radioactive decay and ingrowth are much like inventory, which is well characterized given the fixed inventory that is used in the analyzed basis. Any change to inventory will be managed by the change evaluation process (see Section 6.1.8). The decay and ingrowth processes are not considered ITBC for the saturated zone because the average groundwater residence time through the saturated zone is much shorter than the half-lives of major dose contributors. **FEP Source:** SNL 2008 [DIRS 183041] – 3.1.01.01.0A	No	**Non-ITBC:** Radionuclide Inventory and Source Term Properties Waste Package Source Term, Inventory, Inventory Decay, and Decay Heat	**Non-ITBC:** **None**

Table A-3. ITBC Analysis of Lower Natural Barrier FEPs (Continued)

Feature / Component	FEP Number Name, and Screening Decision	Discussion of Effect on Barrier Capability	Relates to ITBC[1]	Core Parameter Characteristic[2]	Control Parameter Characteristic[3]
Saturated Zone	3.2.07.01.0A Isotopic Dilution **Excluded**	In general, for radionuclides that are rare in the natural environment, such as isotopes of technetium, plutonium, and americium, isotopic dilution of radionuclides of repository origin, by natural sources, would not occur. For other naturally occurring isotopes of elements such as strontium, uranium, and carbon present in the saturated zone, isotopic dilution could only dilute their concentrations and thus reduce the radiological consequences. The effect is non-ITBC because it is expected to be insignificant. **FEP Source:** SNL 2008 [DIRS 183041] – 3.2.07.01.0A	No	**Non-ITBC:** Saturated Zone Properties	**Non-ITBC:** Repository Geographic and Geologic Location

[1] A FEP relates to a Parameter Characteristic if it directly influences or is directly influenced by the parameter characteristic. The Parameter is determined to be ITBC if for a particular Barrier and Barrier Feature, that Parameter Characteristic substantially affects the rate of movement of water and the release or release rate of radionuclides from the Yucca Mountain repository to the accessible environment.

[2] Entries in this column identify areas which support the analyzed basis and are not amenable to direct control or identified as a Control Parameter Characteristic.

[3] Control Parameter Characteristics identify the areas where controls for operations and design are required to support the analyzed basis. Any changes to the controls or the design will be evaluated through an established change control process, which will include an evaluation of the impacts of change on FEPs, ITBC, analysis and/or model reports, models, and assumptions that support the LA.

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