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Scientific Analysis/Calculation Administrative Change Notice

Complete only applicable items.

QA: QA
Page 1 of 2

1. Document Number:	ANL-WIS-MD-000027	**2. Revision:**	00	**3. ACN:**	01
4. Title:	Features, Events, and Processes for the Total System Performance Assessment: Analyses				
5. No. of Pages Attached:	48				

6. Approvals:

Preparer:	Russell Jarek Print Name and Sign	4/1/08 Date
Checker:	Charles Bryan Charles R. Bryan Print name and sign	4/2/08 Date
QCS/Lead Lab QA Reviewer:	Charles Beach Charles P. Beach Print name and sign	4-1-08 Date
Responsible Manager:	Stephanie Kuzio Print name and sign	4-3-08 Date

7. Affected Pages	8. Description of Change:
ix	FEP 1.2.07.02.0A location corrected to page number 6-186 in Listing of FEPs.
xx	Listing for Figure J-1 added to list of Figures.
xxi and xxii	Note added to the list of Tables describing the intentional absence of direct and indirect input tables that are common to all FEPs. This change carries over to next page and there is a format adjustment to a page number on page xxii.
xxviii	Technical acronym for SSC (silver-silver chloride electrode) added to list of Acronyms and Abbreviations.
6-62	Replaced incorrect text to properly indicate that FEP 1.1.08.00.0A is excluded on the basis of low consequence.
6-67	FEP cross-references corrected to indicate proper "included" or "excluded" status; corrected spelling.
6-120	Clarified the description regarding included effect of seismic activity on seepage.
6-166	FEP description clarified by replacing word "aeolian" with the proper term "eolian".
6-215	Clarified the expected length of time for the monsoon climate state.
6-226, 6-244, 6-248, 6-280	Added clarification for the "proposed" rule prior to 70 FR 53313 callouts.
6-241	Clarified the specification of "proposed" rule citation and fixed spelling of "impactss".
6-302	Corrected text to reflect that there are five waste package types, not three, in the referenced table.
6-335, 6-339, 6-340, 6-453, 6-455, 6-457, 6-463, 6-465, 6-477, 6-480, 6-482, 6-483, 6-520, 6-521, 6-524, 6-526 through 6-533, 6-583, 6-586 through 6-598, 6-609, 6-611, 6-613, 6-614, 6-618, 6-619 through 6-622, 6-629, 6-630, 6-633, 6-638, 6-639, 6-645	Reference to SNL 2008 [DIRS 177407] should be to SNL 2007 [DIRS 177407]. Note that the affected pages are listed but they are not included as page changes.
6-347, 6-351, 6-353, 6-357, 6-359, 6-361, 6-363, 6-365, 6-367, 6-369, 6-371, 6-373, 6-378, 6-380, 6-624	Direct input tables on the identified pages incorrectly describe the cladding status as "breached on receipt at the repository" when in fact it should reflect the text and is considered to be "breached on emplacement." Note that the affected pages are listed but they are not included as page changes.

Scientific Analysis/Calculation Administrative Change Notice

QA: QA
Page 2 of 2

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1. Document Number:	ANL-WIS-MD-000027	**2. Revision**:	00	**3. ACN**:	01

4. Title: Features, Events, and Processes for the Total System Performance Assessment: Analyses

6-348, 6-549	Cladding is clarified to be breached upon “emplacement”.
6-370	Second paragraph of TSPA Disposition corrected to cite Section 6.2.1.2[a], not 6.1.2.2[a]. Spelling error corrected.
6-405	Screening Decision is corrected to “Excluded – low consequence”.
6-641	Corrected the oxygen consumption information to utilize more general repository-relevant information and adjusted the text to agree.
6-803	Clarified the discussion of the criticality potential of configurations.
6-827	Corrected table number cross-references.
6-834, 6-846, 6-859, 6-1117, 6-1120, 6-1128, 6-1130	Clarified sentence regarding probability of external criticality event.
6-835, 6-861, 6-1121, 6-1122, 6-1133	Deleted a sentence regarding navy fuel evaluation, and replaced “nine” with “the” in same paragraph.
6-837, 6-862, 6-1123, 6-1134	Revised the paragraph that follows the table and begins “DOE fuel groups in…” to read “Naval SNF and DOE fuel groups in…”. Note that the affected pages are listed but they are not included as page changes.
8-41	Updated referencing information for NEA 2006 [DIRS 185174].
8-55	Updated referencing information for SNL 2008 [DIRS 183478].
8-76, C-4, E-2, E-9	Direct input usages of DTN: MO0703PASEISDA.002 [DIRS 183156] are corrected to the information actually utilized from a revised version in DTN: MO0703PASEISDA.002 [DIRS 185278] (CR 11873).
A-2	Table A-1, Control Parameter 01-03, is clarified by noting that FEP 1.1.01.01.0A is excluded.
A-14	Control Parameter 07-03 has been removed as it is no longer in use.
C-3, C-5, C-6, C-16, C-18	Indirect input DTN: MO0703PASEISDA.002 [DIRS 183156] updated to the revised version this DTN: MO0703PASEISDA.002 [DIRS 185278] (CR 11873). These page changes are not included as they only affect the DIRS number presented for this source.
E-8	Source information was included for the variable f_b.
I-11	Figure I-3a is replaced by original source figure, which is more consistent with figure caption and its comparison Figure I-3b.

LISTING OF FEPS

FIGURES (Continued)

TABLES

Note: The following list does not include direct and/or indirect input tables for the individual FEPs. Direct and/or indirect input tables, along with their respective caption labels (“Direct Inputs” or “Indirect Inputs”), are common to all FEPs and therefore need not be listed here.

TABLES (Continued)

Page

ACRONYMS AND ABBREVIATIONS (Continued)

s	second
SAR	Safety Analysis Report
SAW	simulated acidified water
SCC	stress corrosion cracking
SCW	simulated concentrated water
SDW	simulated dilute water
SEM	scanning electron microscopy
SNF	spent nuclear fuel
SSC	silver–silver chloride electrode
SR	Site Recommendation
SZ	saturated zone
TAD	transportation, aging, and disposal (canister)
TBD	to be determined
TBV	to be verified
TFM	tracers, fluids, and materials
TH	thermal-hydrologic
THC	thermal-hydrologic chemical
THM	thermal-hydrologic-mechanical
TMI	Three-Mile Island
TPSA	total system performance assessment
TSPA-LA	total system performance assessment for the license application
TWP	technical work plan
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
UZ	unsaturated zone
V	volt
vol %	volume percent
WIPP	Waste Isolation Pilot Plant
WPOB	waste package outer barrier
WRIP	water–rock interaction parameter
wt %	weight percent
YMP	Yucca Mountain Project
yr	year

FEP: 1.1.09.00.0A

FEP NAME:

Schedule and Planning

FEP DESCRIPTION:

This FEP addresses the sequences of events and activities occurring during construction, operation, and closure of the repository. Deviations from the design construction or waste emplacement schedule may affect the long-term performance of the disposal system.

SCREENING DECISION:

Included

TSPA DISPOSITION:

Scheduling and planning are components of the process implemented to achieve the expected repository postclosure conditions. The subsurface facilities are planned to be constructed in phases and the development of the subsurface facilities will proceed while emplacement operations are conducted in the completed drifts. The schedule for waste emplacement and planned subsurface ventilation will affect the radionuclide inventories and thermal-hydrological conditions at the time of repository closure. In particular, conditions at closure will depend on the implementation of design requirements for subsurface facilities and their ventilation, sealing, and closure (SNL 2007 [DIRS 179466]), and for waste emplacement (SNL 2007 [DIRS 179354]).

Modifications and deviations from the design for construction, operation, and closure of the repository are subject to regulatory requirements and review that address deliberate changes and modifications. The manner in which the DOE must address changes, and by which the NRC is informed of the changes, is codified in 10 CFR 63.44 [DIRS 180319]. After the NRC authorizes construction of the repository, changes to the repository design or procedures as described in the SAR will be subject to the requirements of 10 CFR 63.44 [DIRS 180319], “Changes, tests, and experiments,” as well as any specific license conditions imposed in accordance with 10 CFR 63.32, “Conditions of construction authorization,” 10 CFR 63.42 [DIRS 180319], “Conditions of license,” or 10 CFR 63.43 [DIRS 180319], “License specification.” Deviations from design as a result of inadequate quality control during repository construction, operation, and closure is addressed in excluded FEP 1.1.08.00.0A (Inadequate Quality Control and Deviations from Design), which is excluded from the TSPA on the basis of low consequence.

Phased construction and operation provides an opportunity for orderly implementation of lessons learned and incorporation of new information that would improve the safety of construction and operations. The repository will implement a management system that includes the evaluation of changes, tests and experiments. Lessons learned and new information will be evaluated against the criteria in 10 CFR 63.44 [DIRS 180319], and the lessons learned or new information will be implemented following construction authorization or license amendment if any of the criteria are met; otherwise, the proposed changes will be implemented and documented in updates to the performance confirmation program for a repository at Yucca Mountain is described in *Performance Confirmation Plan* (BSC 2004 [DIRS 172452]). Appropriate planning of repository activities and the effective implementation of quality control procedures will ensure that monitoring activities have an insignificant effect on long-term repository performance as described in *Performance Confirmation Plan* (BSC 2004 [DIRS 172452], Section 3.3; note that the procedure governing the evaluation of site activities has been superseded by SCI-PRO-007, *Determination of Importance and Site Performance Protection Evaluations*). These topics are discussed further in included FEP 1.1.09.00.0A (Schedule and Planning) and excluded FEP 1.1.08.00.0A (Inadequate Quality Control and Deviations from Design), although not with specific reference to monitoring.

The strategy for collection, evaluation, and presentation of monitoring data throughout site characterization, construction, and operation is an integral component of the performance confirmation plan. Preclosure monitoring activities will be diverse and will be modified as appropriate to current and ongoing repository activities. The performance confirmation activities that could have the greatest impact on repository performance are those that are, in some way, intrusive to the repository, through the use of boreholes, wells, drilling, construction of monitoring alcoves, or equipment emplacement in the drifts. These activities include seepage monitoring, subsurface water and rock testing, unsaturated zone testing, saturated zone monitoring, saturated zone alluvium testing, construction effects monitoring, seal testing, monitoring in or near thermally accelerated drifts, and saturated zone fault hydrology testing (BSC 2004 [DIRS 172452], Section 3.3).

Planned monitoring activities in the unsaturated zone, including seepage monitoring, rock and water sampling, and testing of transport properties and field sorptive properties of the host rock, are described in *Performance Confirmation Plan* (BSC 2004 [DIRS 172452], Sections 3.3.1.2, 3.3.1.3, and 3.3.1.4). Seepage monitoring is expected to have low impact because the amount of seepage that could be sampled is insignificant so as to not impact water reaching the drifts. In thermally accelerated drifts, the monitoring and testing period will be followed by closure of the test bed, which may include removing waste packages and instrumentation and sealing, as appropriate (BSC 2004 [DIRS 172452], Sections 3.3.1.2 and 3.3.1.9). Rock and water sampling is expected to have low impact because the drilling to obtain samples is very limited and occurs in a very small portion of the drift and main cross section. Since the amount of rock that may be sampled is an insignificant amount, impact to the pathway of water reaching the drifts is negligible, especially during the periods after closure (BSC 2004 [DIRS 172452], Section 3.3.1.3). Testing of transport properties and field sorptive properties of the host rock are expected to have low impact because the alcoves and drilling to obtain samples is very limited and occurs in a very small portion of the repository. The amount of rock anticipated to contain residual concentrations of tracers is negligible with respect to performance (BSC 2004 [DIRS 172452], Section 3.3.1.4). In general, further evaluations of waste isolation, test-to-test interference, and operations will be conducted during the detailed test planning. Any boreholes or alcoves used may be sealed prior to closure if modeling results indicated that they would increase seepage potential or alter the chemistry of potential water leaving the drifts. Any monitoring boreholes that unexpectedly intercept waste emplacement drifts have addtional sealing requirements (SNL 2007 [DIRS 179466], Table 4-1, Parameter Number 09-03).

drift results for temperature and relative humidity, representing the differences between the open-drift and the rubble-filled cases (SNL 2008 [DIRS 184433], Section 6.3.17[a]). Without seepage, the rubble will dry out, then gradually rewet after hundreds to thousands of years, due to capillary condensation, with essentially zero percolation flux (SNL 2007 [DIRS 181244], Section 6.5.3). With seepage, the surface of the drip shield under collapse-rubble remains dry until the waste package surface has cooled to approximately 100°C (SNL 2008 [DIRS 184433], Sections 6.3.7.3 and Table 6.3-44). Uncertainty in the effects of drift collapse on the in-drift environment is propagated to performance assessment through use of two sets of "deltas" for the low- and high-thermal conductivity rubble, respectively, which are sampled epistemically for each realization.

Effects on Seepage—Changes in seepage behavior caused by seismically induced rockfall and drift collapse are also included in performance assessment calculations for the lithophysal host rock only. A seepage abstraction is used to represent the range from intact (uncollapsed) to fully collapsed openings (SNL 2007 [DIRS 181244], Section 6.2.2[a]). The approach uses rockfall volume as modeled in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Section 6.7.1) to define the extent of drift degradation; in the case of multiple seismic events, the cumulative rockfall volume is used. Drifts are considered intact if the cumulative rockfall volume is less than 5 m^3 per meter drift length, are considered fully collapsed if the cumulative rockfall volume is larger than 60 m^3 per m drift length, and are considered partially collapsed otherwise. In cases of partial collapse, the abstraction approach is to interpolate seepage linearly between the uncollapsed and collapsed seepage results using the cumulative rockfall volume as the interpolation parameter. *Abstraction of Drift Seepage* (SNL 2007 [DIRS 181244], Section 6.4.2.4.2) and *Seepage Model for PA Including Drift Collapse* (BSC 2004 [DIRS 167652], Section 6.6.3) represent the fully collapsed opening as a circular profile with twice the intact diameter, filled with rubble. Capillary properties for the rubble are different from the host rock, forming a capillary barrier to seepage. Seepage into collapsed drifts can occur at any temperature (not constrained to temperatures less than 100°C as for intact drifts) because no "vaporization barrier effect" at the boundary of the intact rock was observed in simulations (SNL 2007 [DIRS 181244], Section 6.5.3). The "vaporization barrier effect" involves evaporation of water in the host rock above the drift opening, and condensation elsewhere, with the effect of diverting liquid flow around the drift. It acts in concert with capillary diversion of liquid flux. With doubled diameter in the collapsed-drift simulations, the intact rock was much cooler at the crown and sides of the degraded opening. In other respects, the collapsed drift abstraction is similar to that for intact drifts.

Seepage simulations conducted to evaluate parametric sensitivity for the collapsed-drift case showed that the effects from local rockfall in nonlithophysal units are small (SNL 2007 [DIRS 181244], Section 6.4.2.4.2). Therefore, no explicit change is made in the seepage abstraction to represent rockfall in nonlithophysal units as long as the number of local breakouts is relatively small. The seepage abstraction for intact drifts is already increased by 20% to account for the possibility of irregular opening geometry associated with minor drift degradation (SNL 2007 [DIRS 181244], Section 6.7.1.2). If, on the other hand, seismic events cause significant degradation with local breakouts at several locations so that multiple topographic lows form at the roof, the seepage predictions for intact drifts are not applicable (SNL 2007 [DIRS 181244], Section 6.2.3[a]). In this case, the seepage rates are set equal to an upper-bound value given by the local percolation flux. A cumulative rockfall volume larger than 0.5 m^3 per meter drift length indicates that significant degradation has occurred and the seepage abstraction needs to be changed accordingly.

Temperature Limit for Seepage Contact with Waste Packages in Rubble—A temperature constraint is applied to the flow conditions within the drift after drift collapse. Seepage can enter the drift and be diverted through the rubble to the invert beneath the waste package, but cannot contact the waste package surface until the waste package surface temperature drops below 100°C. This threshold temperature of 100°C is based on sensitivity studies (SNL 2008 [DIRS 184433], Section 6.3.7.3 and Table 6.3-44; SNL 2007 [DIRS 181244], Section 6.5.3) of conditions required for seepage to penetrate the rubble in a collapsed drift and contact the drip shield. The value of 100°C is a reasonable upper bound from the sensitivity studies, and

FEP: 1.2.04.07.0C

FEP NAME:

Ash Redistribution via Soil and Sediment Transport

FEP DESCRIPTION:

Following deposition of contaminated ash on the surface, ash deposits may be redistributed on the surface via eolian and fluvial processes.

SCREENING DECISION:

Included

TSPA DISPOSITION:

Ashfall is included in the performance assessment to demonstrate compliance with the individual protection standard after permanent closure (proposed 10 CFR 63.311 (70 FR 53313 [DIRS 178394])) and is addressed through the modeling of an eruption that includes airborne transport of waste-contaminated tephra (ash) and subsequent deposition of the tephra on the land surface. (The preferred term "tephra" refers to pyroclasts resulting from a volcanic eruption, regardless of size, in contrast to the term "ash" which technically refers only to pyroclasts less than 2 mm in diameter. Both terms are used in the discussion of this FEP.) Ashfall and associated aerial dispersal of contaminated tephra is addressed in included FEP 1.2.04.07.0A (Ashfall), and ashfall characteristics are discussed in detail in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (SNL 2007 [DIRS 177431]). In addition to the initial ashfall, the performance assessment also includes consideration of exposure from contaminated tephra that could be redistributed to the RMEI location from other locations by sediment transport processes.

As discussed in included FEP 1.2.04.03.0A (Igneous Intrusion into Repository), disruptive igneous events are not included in performance assessments to demonstrate compliance with the groundwater protection standards (10 CFR 63.331 [DIRS 180319]) and the individual protection standard for human intrusion (proposed 10 CFR 63.321 (70 FR 53313 [DIRS 178394])) because they are unlikely events. The exclusion of this FEP from the groundwater protection and human intrusion performance assessments is consistent with the requirements of proposed 10 CFR 63.342(b) and (c)(1) (70 FR 53313 [DIRS 178394]).

The technical basis for inclusion of FEP 1.2.04.07.0C (Ash Redistribution via Soil and Sediment Transport) in the performance assessment relies on analysis results presented in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Table 7-1). The volcanic hazard is the annual frequency of intersection of the repository by a volcanic dike. The annual frequency of an igneous event ranges from approximately 7.4×10^{-10} to 5.5×10^{-8} for the 5th and 95th percentiles, respectively, with a mean annual frequency of 1.7×10^{-8} (BSC 2004 [DIRS 169989], Table 7-1). Since the mean annual frequency of intersection is greater than the screening criterion value (1 in 10,000 in 10,000 years; proposed 10 CFR 63.342(a) (70 FR 53313 [DIRS 178394])) an igneous event must be included in the

FEP: 1.3.01.00.0A

FEP NAME:

Climate Change

FEP DESCRIPTION:

Climate change may affect the long-term performance of the repository. This includes the effects of long-term change in global climate (e.g., glacial/interglacial cycles) and shorter-term change in regional and local climate. Climate is typically characterized by temporal variations in precipitation and temperature.

SCREENING DECISION:

Included

TSPA DISPOSITION:

Global climate change is addressed in TSPA, using a climate analysis based on paleoclimate information. That is, the record of climate changes in the past is used to predict the expected changes in climate for the future. Future climates are described in terms of discrete climate states that are used to approximate continuous variations in climate. The discussion in this FEP is limited to natural processes. The effects of human activity on climate change are addressed in excluded FEP 1.4.01.00.0A (Human Influences on Climate).

Future climate forecasts (BSC 2004 [DIRS 170002]) indicate that the climate at Yucca Mountain is predicted to evolve to the cooler, wetter conditions of a glacial-transition climate within the first 10,000 years after disposal. Within that period of time, the present-day climate is predicted to last for 400 to 600 years after present; a monsoon climate is predicted to last 900 to 1,400 years following the present-day climate; and a glacial-transition (intermediate) climate state is predicted to last for the remainder of the 10,000-year period (BSC 2004 [DIRS 170002], Table 6-1). A fourth climate state is based on regulation (proposed 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394) and continues from 10,000 years to 1,000,000 years postclosure. To simplify how the climate change is implemented in the TSPA model for the first 10,000 years postclosure, only the maximum durations were used (i.e., 600 years for the present-day climate, 1,400 years for the monsoon climate, and 8,000 years for the glacial-transition climate) (SNL 2008 [DIRS 183478], Section 6.3.1.2). Proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394]) requires that the DOE vary factors related to climate based on cautious but reasonable assumptions. At the same time, changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology should not be projected (10 CFR 63.305(b) [DIRS 180319]). The climate change FEP was evaluated and addressed from the perspective of natural processes and from the perspective of the factors that are related to human activity. In accordance with the proposed rule (70 FR 53313 [DIRS 178394], pp. 53315 and 53316), the effects of climate change after 10,000 years, but within the period of geologic stability, are assumed to be limited to the results of increased percolation of water through the repository, with percolation rates reflecting climate conditions that are wetter and cooler than present-day conditions.

FEP: 1.3.07.01.0A

FEP NAME:

Water Table Decline

FEP DESCRIPTION:

Climate change could produce decreased infiltration (e.g., an extended drought), leading to a decline in the water table in the saturated zone, which would affect the release and exposure pathways from the repository.

SCREENING DECISION:

Excluded – low consequence

SCREENING JUSTIFICATION:

The Yucca Mountain region is a desert environment and future climate predictions indicate only increased precipitation (BSC 2004 [DIRS 170002], Sections 6.6 and 7.1; DTNs: GS000308315121.003 [DIRS 151139] and UN0201SPA021SS.007 [DIRS 161588]). Moreover, paleoclimate records indicate that arid conditions are short compared to wetter conditions while climatic conditions during the past two million years were wetter than current conditions 70% to 80% of the time (Forester et al. 1996 [DIRS 100148], p. 52). Analysis of Searles Lake deposits indicate that extremely dry conditions (resulting in lake desiccation) have occurred only twice within the past 600,000 years: once about 290,000 years ago and again in the past 10,000 years (Jannik et al. 1991 [DIRS 109434], p. 1,146 and Figure 10). This FEP examines the effects of a climate change over the next 10,000 years that lead to much drier conditions resulting in desertification of the surface environment, decreased infiltration, and declining water table elevation. It should be noted that the water table has been modeled to be higher for the post-10,000-year period because of the higher rate of deep infiltration required in proposed 10 CFR 63.342(c) (70 FR 53313 [DIRS 178394]).

Present groundwater elevations in the Basin and Range province (which includes the Yucca Mountain region) reflect the current arid climatic conditions and the decrease in infiltration (i.e., decreased recharge) over the course of the present-day climate. The present-day climate extends for 600 years beyond the present in the TSPA. After the present-day climate, warmer and wetter monsoonal climatic conditions extend an additional 1,400 years. A cooler and wetter glacial-transition climatic condition will follow the brief monsoonal period and will persist for the remainder of the 10,000 years after repository closure (BSC 2004 [DIRS 170002], Section 7). *Future Climate Analysis* (BSC 2004 [DIRS 170002]) only predicts the average expected climate; however, this FEP addresses variability of future climates that could yield short-term, arid conditions that cause the current water table elevation to fall. However, these anomalously dry conditions are not expected to lower the water table elevation by more than a few meters (Luckey et al. 1996 [DIRS 100465], p. 29; Ervin et al. 1994 [DIRS 100633], pp. 11 to 13). Such small decreases to the water table elevation are well within the uncertainties included in both the unsaturated and saturated zone models and are therefore of low consequence.

FEP: 1.4.01.02.0A

FEP NAME:

Greenhouse Gas Effects

FEP DESCRIPTION:

The Greenhouse Effect is the result of so-called ‘greenhouse gases’ allowing incoming solar radiation to pass through the Earth's atmosphere, but preventing much of the outgoing infrared radiation from the surface and lower atmosphere from escaping into outer space. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), ozone (O_3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs). Many of these gases are generated through various natural and physical processes, and have been responsible for maintaining habitable conditions on the planet. Human activities, such as burning fossil fuels, clearing forests (thereby increasing the oxidation of soil organic matter with the concurrent release of CO_2 as a decay product), most motorized transport and industrial processes have the potential to increase the levels of greenhouse gases, which could lead to changes in climate.

SCREENING DECISION:

Excluded – by regulation

SCREENING JUSTIFICATION:

The description of the present-day climate, as discussed in included FEP 1.3.01.00.0A (Climate Change), is based on climate records that implicitly include effects of modern society over the duration of the historical record as well as the greenhouse gas effects. Future changes in human influences on the concentrations of atmospheric gases are excluded from postclosure assessment on the basis of the requirements contained in 10 CFR 63.305(b) [DIRS 180319] and in proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394]), which provide as follows: “DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology. In all analyses done to demonstrate compliance with this part, DOE must assume that all of those factors remain constant as they are at the time of submission of the license application” (10 CFR 63.305(b) [DIRS 180319]); and “DOE must vary factors related to the geology, hydrology, and climate based upon cautious, but reasonable assumptions consistent with present knowledge of factors that could affect the Yucca Mountain disposal system during the period of geologic stability and consistent with the requirements for performance assessment specified at § 63.342” (proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394])).

The supplementary information portion of the preamble to 10 CFR Part 63 (66 FR 55732 [DIRS 156671]) provides a rationale for the requirements in 10 CFR 63.305(b) [DIRS 180319] and in proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394]), and indicates that natural evolution of the geosphere and biosphere is to be included in the performance assessment but any impacts caused by future changes in human behaviors are not to be included. In response to comments made in the rulemaking proceeding associated with climate change (66 FR 55732

FEP: 1.4.01.03.0A

FEP NAME:

Acid Rain

FEP DESCRIPTION:

Acid rain refers to precipitation on a local to regional scale containing higher than normal amounts of nitric and sulfuric acids. This can result from man-made sources such as emissions produced from the burning of fossil fuels. Acid rain can detrimentally affect aquatic and terrestrial life by interfering with the growth, reproduction, and thus survival of affected organisms. It can influence the behavior and transport of contaminants in the biosphere, particularly by affecting surface water and soil chemistry and may also cause societal change due to contamination of water sources.

SCREENING DECISION:

Excluded – by regulation

SCREENING JUSTIFICATION:

The description of present-day climate, as discussed in included FEP 1.3.01.00.0A (Climate Change), includes the effects of acid rain and is based on climate records that implicitly include effects of modern society over the duration of the historical record. Future human influences on climate and other components of the reference biosphere are excluded on the basis of requirements contained in 10 CFR 63.305(b) [DIRS 180319] and proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394]), which provide as follows: “DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology. In all analyses done to demonstrate compliance with this part, DOE must assume that all of those factors remain constant as they are at the time of submission of the license application” (10 CFR 63.305(b) [DIRS 180319]); and “DOE must vary factors related to the geology, hydrology, and climate based upon cautious, but reasonable assumptions consistent with present knowledge of factors that could affect the Yucca Mountain disposal system during the period of geologic stability and consistent with the requirements for performance assessments specified at § 63.342” (proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394])).

The supplementary information portion of the preamble to 10 CFR Part 63 (66 FR 55732 [DIRS 156671]) provides rationale for the requirements in 10 CFR 63.305(b) [DIRS 180319] and in proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394]), and indicates that only natural evolution of the geosphere and biosphere is to be included in the performance assessment but any impacts caused by the future changes in human behaviors are not to be included. In 67 FR 62628 [DIRS 162317], the NRC states, “DOE’s performance assessments are required to consider the naturally occurring features, events and processes that could affect the performance of a geologic repository” (67 FR 62628 [DIRS 162317], p. 62629). In response to comments made in the rulemaking proceeding, the NRC stated that considering future economic growth trends and human behaviors would add inappropriate speculation into the requirements and would lead to problems

FEP: 1.4.01.04.0A

FEP NAME:

Ozone Layer Failure

FEP DESCRIPTION:

Human actions (i.e., the use of certain industrial chemicals) may lead to destruction or damage to the earth's ozone layer. This may lead to significant changes to the climate locally and globally, affecting properties of the geosphere such as groundwater flow patterns.

SCREENING DECISION:

Excluded – by regulation

SCREENING JUSTIFICATION:

The description of present-day climate, as discussed in included FEP 1.3.01.00.0A (Climate Change), is based on climate records that implicitly include effects of modern society over the duration of the historical record. Future changes in human influences on climate are excluded from postclosure assessment on the basis of requirements contained in 10 CFR 63.305(b) [DIRS 180319] and proposed 10 CFR 63.305 (c) (70 FR 53313 [DIRS 178394]), which provide as follows: "DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology. In all analyses done to demonstrate compliance with this part, DOE must assume that all of those factors remain constant as they are at the time of submission of the license application" (10 CFR 63.305(b) [DIRS 180319]); and "DOE must vary factors related to the geology, hydrology, and climate based upon cautious, but reasonable assumptions consistent with present knowledge of factors that could affect the Yucca Mountain disposal system during the period of geologic stability and consistent with the requirements for performance assessment specified at § 63.342" (proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394])).

The supplementary information portion of the preamble to 10 CFR Part 63 (66 FR 55732 [DIRS 156671]) provides rationale for the requirements in 10 CFR 63.305(b) [DIRS 180319] and in proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394]), and indicates that only natural evolution of the geosphere and biosphere is to be included in the performance assessment but any impacts caused by future changes in human behaviors are not to be included. In response to comments made in the rulemaking proceeding associated with climate change (66 FR 55732 [DIRS 156671], p. 55,757), the NRC emphasized the importance of including "climate change in both the geosphere and the biosphere performance assessment calculations to ensure that the conceptual model of the environment is consistent with our scientific understanding of reasonably anticipated natural events." Similarly, in 67 FR 62628 [DIRS 162317] the NRC states, "DOE's performance assessments are required to consider the naturally occurring features, events and processes that could affect the performance of a geologic repository…" (67 FR 62628 [DIRS 162317], p. 62629). In further response to comments, the NRC stated that considering future economic growth trends and human behaviors would add inappropriate speculation into

FEP: 1.4.07.03.0A

FEP NAME:

Recycling of Accumulated Radionuclides from Soils to Groundwater

FEP DESCRIPTION:

Radionuclides that have accumulated in soils (e.g., from deposition of contaminated irrigation water) may leach out of the soil and be recycled back into the groundwater as a result of recharge (either from natural or agriculturally induced infiltration). The recycled radionuclides may lead to enhanced radionuclide exposure at the receptor.

SCREENING DECISION:

Excluded – low consequence

SCREENING JUSTIFICATION:

The estimated increase in the mean dose to the RMEI as a consequence of radionuclide recycling, averaged over the period of simulation, is calculated to be less than 11%, which is not significant compared with the range of uncertainty simulated by the TSPA model. Recycling of radionuclides accumulated in soils encompasses two pathways, irrigation recycling and capture of deep percolation from septic systems. The irrigation recycling pathway includes the leaching of radionuclides from agricultural soil irrigated with contaminated water, transport of the radionuclides by deep percolation to the water table, and recapture of the radionuclides by the water supply well. The potential recapture of deep percolation from septic systems is also included as a pathway to recycle radionuclides to the water where they are recaptured by the water supply well. The hypothetical community in which the RMEI resides is located in the accessible environment above the highest concentration of radionuclides in the plume of contamination, which is approximately 18 km from the repository. Such a community is assumed to practice irrigated agriculture, consistent with the regulatory construct that a rural community could be located at such a location; that the members of this community could grow some food using well water; and that other gardening, farming, and raising of domestic animals could occur (66 FR 32093 [DIRS 155216], p. 32093). Radionuclide recycling is a phenomenon that could reasonably result from irrigated farming, as inferred from observations of deep percolation beneath irrigated fields in Amargosa Valley (Stonestrom et al. 2003 [DIRS 165862]).

To consider the consequence of radionuclide recycling, an analysis was conducted based on a stylized agricultural and residential water use scenario for calculating the potential impact on dose to the RMEI as a result of radionuclide recycling at the location of the hypothetical community of which the RMEI is part. The analysis of the radionuclide recycling process consists of a quantitative process model that considers radionuclide recycling as a process that is coupled to the stylized biosphere model as applied in TSPA. The recycling model is developed in accordance with current and proposed regulatory requirements governing the RMEI (10 CFR 63.312 [DIRS 180319]) and the reference biosphere (10 CFR 63.305 [DIRS 180319] and proposed 10 CFR 63.305(c) (70 FR 53313 [DIRS 178394])). The output of the recycling model, when coupled with the biosphere model in the TSPA, is the mean annual dose to the RMEI.

FEP: 2.1.01.01.0A

FEP NAME:

Waste Inventory

FEP DESCRIPTION:

The waste inventory includes all potential sources of radio toxicity and chemical toxicity. It consists of the radionuclide inventory (typically in units of curies), by specific isotope, and the non-radionuclide inventory (typically in units of density or concentration), including chemical waste constituents. The radionuclide composition of the waste will vary due to initial enrichment, burn-up, the number of fuel assemblies per waste package, and the decay time subsequent to discharge of the fuel from the reactor.

SCREENING DECISION:

Included

TSPA DISPOSITION:

Modeling the waste inventory in the TSPA can be divided into two tasks. The first is to select those radionuclides important to dose calculations. The second is to determine which radionuclides are present in each type of waste and in what quantity.

The radionuclides of importance to dose calculations were assessed in *Radionuclide Screening* (SNL 2007 [DIRS 177424]). This information was incorporated in *Initial Radionuclide Inventories* (SNL 2007 [DIRS 180472]) and is reproduced in Table 6-1[a] of that report. Waste package quantities are also described in *Total System Performance Assessment Data Input Package for Requirements Analysis for DOE SNF/HLW and Navy SNF Waste Package Overpack Physical Attributes Basis for Performance Assessment* (SNL 2007 [DIRS 179567], Table 4-1, Parameter Number 03-02; SNL 2007 [DIRS 179394], Table 4-1, Parameter Number 03-02). Nonradioactive chemically toxic waste is not included in the repository disposal inventory; nonradiological toxicity is discussed further in excluded FEP 3.3.07.00.0A (Non-Radiological Toxicity and Effects).

Nominal average waste package inventories of the important radionuclides for each type of waste are documented in *Initial Radionuclide Inventories* (SNL 2007 [DIRS 180472]). Weighted average grams per package for the 32 important radionuclides and five waste types (commercial SNF, DOE SNF, HLW, MOX, and lanthanum borosilicate) are listed in Table 7-1[a] of *Initial Radionuclide Inventories* (SNL 2007 [DIRS 180472]).

The weighted average waste inventory values (grams per package for each radionuclide for each waste type) (SNL 2007 [DIRS 180472], Table 7-1[a]), along with the uncertainty multipliers from Table 7-2 of *Initial Radionuclide Inventories* (SNL 2007 [DIRS 180472]), are input to GoldSim for use in the TSPA model. The uncertainty multipliers address uncertainties in the average waste package inventories due to factors such as uncertainties in the isotopic concentrations in spent fuel, uncertainties in the commercial SNF delivery forecasts,

FEP: 2.1.02.12.0A

FEP NAME:

Degradation of Cladding Prior to Disposal

FEP DESCRIPTION:

Certain aspects of cladding degradation may occur before the spent fuel arrives at Yucca Mountain. Possible mechanisms include rod cladding degradation during reactor operation, degradation during wet spent fuel pool storage, degradation during dry storage, and rod degradation during shipping (i.e., from creep and from vibration and impact) and fuel handling.

SCREENING DECISION:

Included

TSPA DISPOSITION:

Cladding degradation prior to receipt at the repository can occur during reactor operation, SNF pool storage, dry storage, transport, and handling. The condition of DOE SNF and commercial SNF cladding at the time of emplacement in the repository is discussed in the following paragraphs.

A significant but unquantified fraction of the N Reactor fuel, which constitutes about 85% of the MTHM of DOE SNF (BSC 2004 [DIRS 172453], Section 6.1.7), will have damaged cladding at the time of emplacement in disposal canisters (Abrefah et al. 1995 [DIRS 151125]). There has been insufficient characterization of the condition of the DSNF cladding to establish its initial condition and the effectiveness of the cladding as a barrier to radionuclide transport. For the purposes of TSPA it is considered that all DOE SNF cladding (with the exception of naval SNF cladding) is breached at the time of its emplacement in the repository and will neither inhibit groundwater contacting the DOE SNF matrix nor the release of radionuclides from the DOE SNF after groundwater contact. DOE SNF cladding itself is further discussed in excluded FEP 2.1.02.25.0A (DSNF Cladding). Naval SNF cladding is discussed in included FEP 2.1.02.25.0B (Naval SNF Cladding).

The amount of initial "out of reactor" commercial SNF cladding damage is expected to be low, as documented in *Cladding Degradation Summary for LA* (SNL 2007 [DIRS 180616]), which is based on utility data collected from multiple sources. However, a decision has been made not to take cladding credit for the TSPA (SNL 2007 [DIRS 180616], Section 6.2.1.2[a]). For the purposes of TSPA it is considered that all commercial SNF cladding is breached at the time of its emplacement in the repository and will neither inhibit groundwater contacting the commercial SNF fuel matrix nor the release of radionuclides from the commercial SNF after groundwater contact (SNL 2008 [DIRS 183478], Section 6.3.7.3).

FEP: 2.1.02.23.0A

FEP NAME:

Cladding Unzipping

FEP DESCRIPTION:

In either dry or wet oxidizing conditions and with perforated fuel cladding, the UO_2 fuel can oxidize. The volume increase of the fuel as it oxidizes can create stresses in the cladding that may cause gross rupture of the fuel cladding (unzipping).

SCREENING DECISION:

Included

TSPA DISPOSITION:

The axial splitting or "unzipping" of commercial SNF cladding is caused by the volume increase associated with the formation of fuel or cladding corrosion products (excluded FEP 2.1.09.03.0A (Volume Increase of Corrosion Products Impacts Cladding)). Unzipping of commercial SNF cladding is expected to occur after the fuel cladding is perforated, and it leaves fuel pellets exposed to the waste package internal environment.

For the TSPA, it is considered that all commercial SNF fuel cladding (stainless steel and Zircaloy) is breached on emplacement in the repository as discussed in included FEP 2.1.02.12.0A (Degradation of Cladding Prior to Disposal) and in *Cladding Degradation Summary for LA* (SNL 2007 [DIRS 180616], Section 6.2.1.2[a]).

Experiments carried out at Argonne National Laboratory involving two commercial SNF fuel rod segments with perforated cladding found that unzipping along the length of each fuel rod segment occurred in less than two years due to the fuel-side cladding corrosion (Cunnane et al. 2003 [DIRS 162406], Section 2a). Dry oxidation of the commercial SNF fuel (oxidation of UO_2 to U_3O_8) could also result in rapid cladding unzipping. Dry oxidation of the fuel in commercial SNF rods with breached cladding is expected to occur under the expected low humidity and high temperature conditions in the repository if the waste package fails soon after repository closure. Wet oxidation of the fuel in commercial SNF rods with breached cladding following waste package failure is also expected to result in rapid cladding unzipping.

Commercial SNF cladding unzipping is included in the TSPA model by assuming that the commercial SNF cladding is breached on emplacement in the repository and that cladding unzipping exposes bare fuel along the entire length of the fuel rod immediately following waste package failure. No credit is taken for the commercial SNF cladding playing any role in limiting exposure of the fuel to the repository environment or in limiting radionuclide release from the fuel.

DOE SNF and naval SNF cladding are discussed in excluded FEP 2.1.02.25.0A (DSNF Cladding) and in included FEP 2.1.02.25.0B (Naval SNF Cladding).

FEP: 2.1.03.03.0B

FEP NAME:

Localized Corrosion of Drip Shields

FEP DESCRIPTION:

Localized corrosion (pitting or crevice corrosion) could enhance degradation of the drip shields.

SCREENING DECISION:

Excluded – low consequence

SCREENING JUSTIFICATION:

Titanium and its alloys are resistant to general and localized corrosion due to the formation of a protective oxide layer on the metal surface in the presence of oxygen and moisture (Jones 1996 [DIRS 105076], p. 524). Both of these conditions are expected to be persistent within the repository. The drip shield plates are to be fabricated from Titanium Grade 7 (SNL 2007 [DIRS 179354], Table 4-2, Parameter Number 07-04), which is alloyed with 0.15% palladium for increased localized corrosion resistance. The drip shield structural support members are to be fabricated with Titanium Grade 29 (SNL 2007 [DIRS 179354], Table 4-2, Parameter Number 07-04), which is higher strength titanium containing approximately 6% aluminum, 4% vanadium, and 0.1% ruthenium, the latter of which is added to improve localized corrosion resistance, analogous to the impact that palladium has in Titanium Grade 7.

In *General Corrosion and Localized Corrosion of the Drip Shield* (SNL 2007 [DIRS 180778], Section 5.6), localized corrosion of the titanium drip shield is assumed to initiate when the corrosion potential (E_{corr}) equals or exceeds the threshold potential for breakdown of the passive film ($E_{critical}$). A correlation between exposure parameters (temperature, chloride ion concentration, and pH) and the difference between the critical potential ($E_{critical}$) and the corrosion potential (E_{corr}) (i.e., $\Delta E = E_{critical} - E_{corr}$) was developed to indicate when localized corrosion could be initiated. Localized corrosion initiates when ΔE is less than or equal to zero (i.e., when E_{corr} is greater than or equal to $E_{critical}$). The critical or threshold potential is defined as the potential where the current density in the forward portion of an anodic cyclic polarization scan rapidly increases, rather than the potential at which any specific value of the current density is achieved (SNL 2007 [DIRS 180778], Section 6.6.1). The results show, for Titanium Grade 7, that the mean ΔE is generally in excess of 1 V over all anticipated ranges of pH, chloride concentration, and temperature (SNL 2007 [DIRS 180778], Section 6.6.3) in the repository. Localized corrosion of Titanium Grade 7 is not expected to initiate in repository-relevant environments even at pH values as high as 14 (SNL 2007 [DIRS 180778], Section 8.4).

For the drip shield application in the repository, there is an early period of dry air exposure prior to aqueous exposure. During this time, the drip shield will be subjected to a long period of slow thermal oxidation resulting in the formation of a thick and relatively defect-free oxide coating on the Titanium Grades 7 and 29 components of the drip shield (SNL 2007 [DIRS 180778], Section 6.4.1). An increase in the oxide film thickness, coupled with a decrease in defect

The effects of high-energy blocks have been considered as part of the seismic rockfall analyses in excluded FEP 1.2.03.02.0B (Seismic-Induced Rockfall Damages EBS Components), and have been found to be insignificant. These results provide an upper bound to the expected mechanical effects of rockfall during the nominal scenario.

Analyses related to multiple rockfalls were conducted in *Multiple Rock Fall on Drip Shield* (BSC 2004 [DIRS 171756]). Bounding characteristics of the credible multiple rockfalls for postclosure were used in the calculation. The structural response of the drip shield to two identical 2-metric ton rock block impacts onto the same location was analyzed. Along the highly deformed area at the point of impact, the average stress intensity through the drip shield plate thickness (along a line perpendicular to the plate surface) was determined for several locations. It was concluded that at the location of highest average stress intensity, the wall-averaged total stress intensity through the drip shield top plate, and the maximum bending surface principal stress in the longitudinal stiffeners do not exceed the respective true tensile strengths of these titanium drip shield components, as discussed in *Multiple Rock Fall on Drip Shield* (BSC 2004 [DIRS 171756], Section 6.1).

The effects of rockfall on crack initiation in the drip shield are discussed in *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007 [DIRS 181953], Section 8.1.6), excluded FEP 2.1.03.10.0B (Advection of Liquids and Solids Through Cracks in the Drip Shield), and excluded FEP 2.1.03.02.0B (Stress Corrosion Cracking (SCC) of Drip Shields). The tightness of stress corrosion cracks in passive alloys such as Titanium Grade 7 (i.e., small crack-opening displacement) and their tortuosity will lead to negligible water flow through these openings (SNL 2007 [DIRS 181953], Section 6.8.5.2). For the case of multiple rockfalls on the same drip shield location, the total damaged area from multiple block impacts during a ground motion is conservatively estimated as the sum of the damaged areas from the individual block impacts (SNL 2007 [DIRS 176828], Section 6.10.2.9). The consequence of stress corrosion cracking on drip shield water diversion performance is discussed in excluded FEP 2.1.03.10.0B (Advection of Liquids and Solids through Cracks in the Drip Shield).

Prior to closure (prior to the installation of the drip shield), waste packages that have come into contact with fallen rock will be inspected to ensure that any damage to the waste package outer corrosion barrier is within acceptable limits (SNL 2007 [DIRS 179354], Table 4-1, Parameter Number 03-24). Since the drip shield continues to function through rockfall events as described above, the waste package and cladding will be protected from rockfall during the postclosure period, for as long as the drip shield remains intact, and rockfall will therefore be of low consequence while this is the case.

TSPA considers all fuel cladding (with the exception of naval SNF cladding) to be breached at the time of its emplacement in the repository, as discussed in included FEP 2.1.02.12.0A (Degradation of Cladding Prior to Disposal) and in *Cladding Degradation Summary for LA* (SNL 2007 [DIRS 180616], Table 7-2[a]). Furthermore, following waste package failure, clad unzipping is considered to result in the immediate exposure of bare fuel to the waste package environment along the entire length of the fuel rod (included FEP 2.1.02.23.0A (Cladding Unzipping)). Therefore, the impact of rockfall on cladding integrity is of low consequence.

FEP: 2.1.09.06.0B

FEP NAME:

Reduction-Oxidation Potential in Drifts

FEP DESCRIPTION:

The redox potential in the EBS influences the oxidation of the in-drift materials and the in-drift solubility of radionuclide species. Local variations in the in-drift redox potential can occur.

SCREENING DECISION:

Included

TSPA DISPOSITION:

Engineered Barrier System: Physical and Chemical Environment (SNL 2007 [DIRS 177412], Section 6.7) evaluates the reduction-oxidation (redox) potential in the EBS drifts as part of the modeled chemical processes. The report accounts for redox potential in its oxygen mass balance analysis (SNL 2007 [DIRS 177412], Section 6.7). Specifically, in-drift gas composition calculations evaluated oxygen composition due to corrosion of ground support materials and other committed materials. The estimate of oxygen flux begins with calculating the gas flux across the drift wall and into the drift (SNL 2007 [DIRS 177412], Section 6.7.1). Oxygen fugacities may drop to as low as 10^{-9} bar for a brief period of time, but they recover rapidly exceeding 10^{-2} bars after approximately 3,000 years and approach ambient values before 10,000 years (SNL 2007 [DIRS 177412], Figure 6.7-5 (upper)). When the analysis considered the retardation of oxygen consumption by the formation of a higher surface area corrosion layer, the fO_2 values do not fall below approximately 10^{-7} bar and return to ambient before 3,000 years (SNL 2007 [DIRS 177412], Figure 6.7-5 (lower) and Section 6.7.1.7). The analysis concludes that oxidizing conditions, relative to important redox couples such as goethite/magnetite and nitrate/nitrite (SNL 2007 [DIRS 177412], Section 6.7.1.6) will persist in the in-drift environment. Thus, the effects of redox reactions are included in the inputs provided to the TSPA.

The lower fO_2 conditions produced by the corrosion of materials in the EBS would be confined to a limited time during the thermal pulse (i.e., for a few thousand years) as shown in the P&CE report (SNL 2007 [DIRS 177412], Section 6.7.1.5 and Figure 6.7-5), which presents the fO_2 time histories. The potential for reducing conditions to occur in the drift is also examined and dismissed in *In-Drift Precipitates/Salts Model* (IDPS) (SNL 2007 [DIRS 177411], Section 4.1.2). The IDPS model is only validated for oxidizing conditions and all evaporation simulations are set for atmospheric conditions (SNL 2007 [DIRS 177411], Section 6.6.2). Oxidizing conditions prevail, with respect to the examined redox couples, for equilibrium fugacity of oxygen of 10^{-9} bars (SNL 2007 [DIRS 177411], Section 4.1.2). The IDPS model lookup table output includes boundary values, abstraction output, and supplemental calculations (SNL 2007 [DIRS 177411], Section 6.6.3.5). Boundary values include temperature, the fugacities of carbon dioxide and oxygen, and the reaction progress.

Evaluation of the neutron absorber material misload failure mechanism is an important consideration for the determination of the criticality potential of configurations. The probability that proper neutron absorber material is not used in the waste package (or waste form if integrally connected) or becomes separated from the fissile material must then be evaluated for configurations where absorber material is necessary for criticality control. Misloading of the waste forms is also an important consideration for the determination of the criticality potential of configurations of commercial SNF that require loading restrictions (i.e., specified loading curves). The probability that such waste forms are not loaded as required must then be evaluated.

The neutron absorber misload event represents the absence and/or loss of efficacy of the neutron absorber plates due to fabrication-related errors (e.g., incorrect material installed during fabrication, absorber content of plates outside specified range). These types of events can only occur during fabrication and/or loading of a canister due to process or procedural errors and are similar to waste package and drip shield early failure mechanisms (SNL 2007 [DIRS 178765], Section 6.2). Errors in fabrication and operational processes are primarily due to human factors that are common to the various processes. Surrogate fabrication and operational processes with associated human factor errors have been evaluated in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007 [DIRS 178765]) and results are used for such initiating events for the waste package and drip shield early failure mechanisms. The surrogate processes are:

1. Improper performance of the neutron absorber plates represented as a material selection error in the waste package component fabrication processes (SNL 2007 [DIRS 178765], Section 6.3.2)

2. Failure of the waste package and canister drying/inerting process represented as an operational process error (SNL 2007 [DIRS 178765], Section 6.3.5)

3. Drip shield misplacement allowing the possibility of advective seepage flow directly on a waste package OCB (SNL 2007 [DIRS 178765], Section 6.4.4)

4. Fabrication flaws allowing increased susceptibility to SCCs (SNL 2007 [DIRS 178765], Section 6.3).

Waste package fabrication and operational process error probabilities have been obtained from DTNs: MO0701PASHIELD.000 [DIRS 180508] and MO0705EARLYEND.000 [DIRS 180946]. The probability values assigned to absorber plate misloads due to material selection errors, waste package and canister operational process failures, waste package SCC mitigation process failures, and the occurrence of OCB closure lid weld flaws for this analysis are listed in Table 2.1.14.15.0A-1. The operational process failures include the drying and inerting process and OCB outer lid weld stress mitigation process. These processes are conceptually similar since each requires operator actions and the human error failure rate from the OCB outer lid weld stress mitigation process is assigned to each one in Table 2.1.14.15.0A-1.

Table 2.1.14.19.0A-8. Cumulative Number of Failed Codisposal Waste Packages Expected versus Annual Exceedance Frequency

Exceedance Frequency Range (1/yr)	Expected Number of Failures Codisposal Short	Expected Number of Failures Codisposal Long	Exceedance Frequency Range (1/yr)	Expected Number of Failures Codisposal MCO
$> 1.2 \times 10^{-7}$	0	0	$> 6.3 \times 10^{-8}$	0
1.1×10^{-7} to 1.2×10^{-7}	2.6	3.5	5.4×10^{-8} to 6.3×10^{-8}	0.5
4.1×10^{-8} to 1.1×10^{-7}	3.7	4.9	2.1×10^{-8} to 5.4×10^{-8}	0.7
1.3×10^{-8} to 4.1×10^{-8}	4.3	5.7	1.0×10^{-8} to 2.1×10^{-8}	0.8
1.0×10^{-8} to 1.3×10^{-8}	21.6	28.5		

Source: DTN: MO0705CRITPROB.000 [DIRS 184958], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows 189 to 198.

For seismic events with an annual exceedance frequency greater than 1.2×10^{-7} per year (i.e., less severe earthquakes), no waste package damage is expected to occur due to faulting as shown in Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8. For seismic events with an annual exceedance frequency less than 1.2×10^{-7} per year (i.e., more severe earthquakes), waste package failure from seismically induced faulting is initiated. The number of failed waste packages increases with increasing seismic energy (decreasing annual exceedance frequency) to a maximum number that depends on waste package variant as shown in Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8. The annual exceedance frequency range for the commercial SNF TAD canister and codisposal waste packages is subdivided into three or four ranges for this analysis, depending on the waste package variant as shown in the column labeled "Exceedance Frequency Range" in Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8 for each waste package variant. The probabilities of these basic events are determined with Equation 2.1.14.19.0A-1 and the information provided in Table 2.1.14.19.0A-9.

Table 2.1.14.19.0A-9. Probabilities of Seismic Faulting Events with Waste Package Failure Capability

Commercial SNF TAD Waste Package Variant					
PGV Value (m/s)	λ_1 (events/year)	λ_2 (events/year)	t_1 (years)	t_2 (years)	Probability
4.07 to 3.77	1.0×10^{-8}	2.7×10^{-8}	10,000	0	1.7×10^{-4}
3.77 to 3.41	2.7×10^{-8}	7.0×10^{-8}	10,000	0	4.3×10^{-4}
3.41 to 3.34	7.0×10^{-8}	8.2×10^{-8}	10,000	0	1.2×10^{-4}
Codisposal Waste Package Variant					
4.07 to 4.00	1.0×10^{-8}	1.3×10^{-8}	10,000	0	3.0×10^{-5}
4.00 to 3.62	1.3×10^{-8}	4.1×10^{-8}	10,000	0	2.8×10^{-4}
3.62 to 3.21	4.1×10^{-8}	1.1×10^{-7}	10,000	0	6.9×10^{-4}
3.21 to 3.18	1.1×10^{-7}	1.2×10^{-7}	10,000	0	1.0×10^{-4}

Source: DTN: MO0705CRITPROB.000 [DIRS 184958], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows 203 to 209.

Near-field criticality cannot occur unless the waste package and waste form are degraded. Water infiltration is required to degrade the waste package internals and waste form and transport them to the near-field location. Criticality cannot occur unless at least the minimum critical mass of a waste form can be accumulated. The probability of an external criticality event is expected to be lower than the probability of an in-package criticality event. This is because, in addition to the events evaluated to calculate the probability of water infiltrating a breached waste package, the probability of the following events or processes must also be considered for external criticality:

- Separation of the fissile materials from the degraded waste form
- Sufficient seepage water to transport fissile materials from the waste package
- Accumulating sufficient fissile material into a potentially critical configuration in the near-field environment.

If a waste package is breached, water and solutes might enter and leave the waste package by several mechanisms, including diffusion, condensation of vapor, and advection of liquid water. Leakage through a crack-damaged drip shield is an insignificant source for liquid water penetration through cracks in the underlying waste package especially when compared to the threshold flow rate (0.1 kg/yr) used in TSPA to define whether seepage occurs (excluded FEP 2.1.03.10.0 (Advection of Liquids and Solids through Cracks in the Waste Package)). Therefore, the predominant mechanism for water inflow and outflow through a breached waste package is through diffusive transport unless the drip shield has failed. *Geochemistry Model Validation Report: Material Degradation and Release Model* (SNL 2007 [DIRS 181165], Section 6.2) indicated that the quantity of material released by diffusion would be small due to the tortuosity of the path, and therefore the diffusion-only scenario is not considered a viable method for material transport. Thus, advective flow of water is necessary for transporting fissile materials from the waste package to the near-field in any appreciable quantities to be considered for criticality.

Vibratory ground motion (included FEP 1.2.03.02.0A (Seismic Ground Motion Damages EBS Components)), faulting (included FEP 1.2.02.03.0A (Fault Displacement Damages EBS Components)), seismic induced drift collapse in the lithophysal units (included FEP 1.2.03.02.0C (Seismic-Induced Drift Collapse Damages EBS Components)), and seismic induced rockfall (excluded FEP 1.2.03.02.0B (Seismic Induced Rockfall Damages EBS Components)) are potential initiating events that are capable of creating advective flow paths into the waste package. Such failures may allow the influx of water (either advective or diffusive) into the waste package, which, in turn, has the potential to initiate processes leading to degradation and transport of the fissile material to the near-field location.

Note that excluded FEP 1.2.03.02.0B (Seismic-Induced Rockfall Damages EBS Components) has been screened from performance assessment on the basis of low consequence, which is not directly applicable to criticality potential evaluations. FEP 1.2.03.02.0B indicates that seismic-induced damage to the waste packages and its internals from rock block impacts in nonlithophysal units is screened out from the TSPA model on the basis of low probability. However, FEP 1.2.03.02.0B screens out tearing or rupture of the drip shield plates from large block impacts because of low consequence, which is not directly applicable to criticality potential evaluations. Drip shield failure could result in an advective flow path to the waste package OCB, creating an environment for subsequent localized corrosion processes (included FEP 2.1.03.03.0A (Localized Corrosion of Waste Packages)) that could breach the waste package OCB.

The probability of drip shield and waste package failure from a fault event varies with the magnitude of the earthquake but ranges from 1.2×10^{-4} to 4.3×10^{-4} for the commercial SNF waste packages and from 3.0×10^{-5} to 6.9×10^{-4} for the codisposal waste packages (SNL 2008 [DIRS 173869], Table 6.4-7).

There are several hundred distinct types of DOE SNF, and it is not practical to attempt to determine the impact of each individual type on repository performance. These fuels come from a wide range of reactor types, such as light- and heavy-water-moderated reactors, graphite-moderated reactors, and breeder reactors, with various cladding materials and enrichments, varying from depleted uranium to over 93% enriched ^{235}U. Many of these reactors, now decommissioned, had unique design features, such as core configuration, fuel element and assembly geometry, moderator and coolant materials, operational characteristics, and neutron spatial and spectral properties (DOE 2004 [DIRS 171271]).

Therefore, to facilitate DOE SNF waste form evaluations, the DOE SNF inventory was first reduced to 34 DOE SNF groups based on fuel matrix, cladding, cladding condition, and enrichment. These parameters are the fuel characteristics that were determined to have major impacts on the release of radionuclides from the DOE SNF and contributed to nuclear criticality scenarios (DOE 2000 [DIRS 118968], Section 5). Separate groups were further refined for the purposes of criticality, design basis events, and TSPA based on key parameters such as fuel matrix, cladding, and fuel condition, as well as fissile species and enrichment, and reactor and fuel design (DOE 2000 [DIRS 118968], Section 5.1). For criticality, nine DOE SNF criticality groups have been identified and are listed in *General Description of Database Information Version 5.0.1* (DOE 2007 [DIRS 182577], Table 6).

Within each of the nine DOE SNF criticality groups, a single fuel design was selected as being representative of the remaining fuel within each group. The term representative means that all fuels would perform similarly regarding chemical interactions within the waste package and basket, and that canister loading limits from the representative fuel (ranges of key parameters important to criticality such as linear fissile loading and total fissile mass) are established, which other fuels within the group can be shown to not exceed. Waste forms within a single criticality group that have configurations or key criticality parameters outside the range of applicability of the representative fuel will require supplemental analysis and/or additional reactivity control mechanisms.

A miscellaneous waste form category, which has a variety of fuel matrix properties originating from various post-irradiation examinations and other testing are not included in the criticality evaluations for the fuel groups as they will need to be evaluated on a case-by-case basis. Thus, the disposal criticality analysis methodology (YMP 2003 [DIRS 165505]) can be applied to the DOE SNF representative fuel groups for criticality evaluations.

Near-field criticality cannot occur unless the waste package and waste form are degraded. Water infiltration is required to degrade the waste package internals and waste form and transport them to the near-field location. Criticality cannot occur unless at least the minimum critical mass of a waste form can be accumulated in a favorable geometry. The probability of an external criticality event is expected to be lower than the probability of an in-package criticality event. This is because, in addition to the events evaluated to calculate the probability of water infiltrating a breached waste package, the probability of the following events or processes must also be considered for external criticality:

- Separation of the fissile materials from the degraded waste form
- Sufficient seepage water to transport fissile materials from the waste package
- Accumulating sufficient fissile material into a potentially critical configuration in the near-field environment.

Excluded FEP 2.1.07.01.0A (Rockfall) indicates that rockfall related to nonseismic processes such as drift degradation induced by in situ gravitational and excavation-induced stresses as well as thermally induced stresses don't generate rock block sizes sufficient to tear or rupture the drip shield plates. Drip shield damage from rockfall induced by thermal loading is found to be minor since the block sizes for such rockfall are small with a mean mass of less than 0.2 metric tons (BSC 2004 [DIRS 166107], p. 6-102). In addition, drift degradation (i.e., considering thermal and time-dependent effects on drift collapse, but excluding seismic effects) results in only partial collapse of the emplacement drifts at 20,000 years (see excluded FEP 2.1.07.02.0A (Drift Collapse)). The conclusion for the nominal scenario is that negligible drift degradation will occur over the initial 10,000-year postclosure period (BSC 2004 [DIRS 166107], Section 8.1 and Appendix S).

A waste package must be breached in order to transport fissile material out. If a waste package is breached, water and solutes might enter and leave the waste package by several mechanisms, including diffusion, condensation of vapor, and advection of liquid water. Therefore, rockfall does not result in waste package outer barrier breaching. Without a waste package breach, there is no potential for external criticality.

Summary - Since the drip shield continues to function through rockfall events as described above, there is no advective flow of water to the waste package for as long as the drip shield remains intact. Therefore, there is no means to transport fissile material to the near field by precluding the introduction of water to the waste package, which is necessary to degrade the internals and transport material into the near-field location. The probability of the occurrence of configurations with criticality potential for the near-field location resulting from rockfall is insignificant since no damage to the waste package OCBs is expected from the non-seismically initiated rockfall events. Accordingly, this FEP is excluded from the performance assessments conducted to demonstrate compliance with proposed 10 CFR 63.311 and 63.321 (70 FR 53313 [DIRS 178394]), and with 10 CFR 63.331 [DIRS 180319], on the basis of low probability. This result is applicable for all waste forms and waste package variants.

FEP: 2.1.14.26.0A

FEP NAME:

Near-Field Criticality Resulting from an Igneous Event

FEP DESCRIPTION:

Either during or as a result of an igneous disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505], Figure 3.3a).

SCREENING DECISION:

Excluded – low probability

SCREENING JUSTIFICATION:

This FEP justification accounts for external criticality for the near-field location for the igneous scenario, where *near-field* is defined as the region inside the drift external to the waste package. A prerequisite for any of the spent fuel waste forms to have potential for criticality is the introduction of water in liquid or vapor form to the inside of the TAD or DOE SNF canister. 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. Therefore, for a configuration to have potential for criticality, all of the following conditions must occur: (1) sufficient mechanical or corrosive damage to the waste package OCB 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 of fissionable material in a critical geometric configuration. The probability of developing a configuration with criticality potential is insignificant unless all four conditions are realized, and then is only representative of a conservative estimate since the probability values associated with the many other events required to generate a critical configuration that are less than one are not quantified, but rather are conservatively set to one.

Near-field criticality cannot occur unless the waste package and waste form are degraded. Water infiltration is required to degrade the waste package internals and waste form and transport them to the near-field location. Criticality cannot occur unless at least the minimum critical mass of a waste form can be accumulated in favorable geometry. The probability of an external criticality event is expected to be lower than the probability of an in-package criticality event. This is because, in addition to the events evaluated to calculate the probability of water infiltrating a breached waste package, the probability of the following events or processes must also be considered for external criticality:

- Separation of the fissile materials from the degraded waste form

Therefore, to facilitate DOE SNF waste form evaluations, the DOE SNF inventory was first reduced to 34 DOE SNF groups based on fuel matrix, cladding, cladding condition, and enrichment. These parameters are the fuel characteristics that were determined to have major impacts on the release of radionuclides from the DOE SNF and contributed to nuclear criticality scenarios (DOE 2000 [DIRS 118968], Section 5). Separate groups were further refined for the purposes of criticality, design basis events, and TSPA based on key parameters such as fuel matrix, cladding, and fuel condition, as well as fissile species and enrichment, and reactor and fuel design (DOE 2000 [DIRS 118968], Section 5.1). For criticality, nine DOE SNF criticality groups have been identified and are listed in *General Description of Database Information Version 5.0.1* (DOE 2007 [DIRS 182577], Table 6).

Within each of the nine DOE SNF criticality groups, a single fuel design was selected as being representative of the remaining fuel within each group. The term representative means that all fuels would perform similarly regarding chemical interactions within the waste package and basket, and that canister loading limits from the representative fuel (ranges of key parameters important to criticality such as linear fissile loading and total fissile mass) are established, which other fuels within the group can be shown to not exceed. Waste forms within a single criticality group that have configurations or key criticality parameters outside the range of applicability of the representative fuel will require supplemental analysis and/or additional reactivity control mechanisms.

A miscellaneous waste form category that has a variety of fuel matrix properties originating from various post-irradiation examinations and other testing is not included in the criticality evaluations for the fuel groups as they will need to be evaluated on a case-by-case basis. Thus, the disposal criticality analysis methodology (YMP 2003 [DIRS 165505]) can be applied to the DOE SNF representative fuel groups for criticality evaluations.

The minimum fissile mass necessary for criticality external to the waste packages is discussed in *Geochemistry Model Validation Report: External Accumulation Model* (SNL 2007 [DIRS 181395], Section 8.1.4[a]), where it was concluded that insufficient fissile material can collect over 10,000 years to achieve a critical mass for the igneous scenario, in which a critical mass is defined as one where k_{eff} (effective neutron multiplication factor) exceeds the critical limit for the material. The critical mass limits were evaluated for commercial SNF and DOE SNF waste forms using bounding parameters with regards to optimizing reactivity potential, so the actual masses that would be necessary to achieve criticality would need to be far greater than what was identified (SNL 2007 [DIRS 181395], Section 8.1.4[a]).

Model abstractions were performed for commercial SNF and three DOE SNF waste forms in *Geochemistry Model Validation Report: External Accumulation Model* (SNL 2007 [DIRS 181395]) (i.e., N Reactor (DOE3), TMI (DOE9), and FFTF (DOE1)) (SNL 2008 [DIRS 173869], Section 4.1.15), which make up a ~90% of the metric tons of heavy metal in the DOE SNF inventory expected to be stored in the repository. In addition to these waste forms making up ~90% of the inventory by mass, they were selected because they provide degradation and accumulation characteristics of uranium-metal (N Reactor), mixed-oxide (FFTF), and damaged uranium dioxide (TMI) waste forms which may be applicable to other representative DOE waste forms. Some of the other DOE SNF waste forms, such as Shippingport light-water

Far-field criticality cannot occur unless the waste package and waste form are degraded. Water infiltration is required to degrade the waste package internals and waste form and transport them to the far-field location. Criticality cannot occur unless at least the minimum critical mass of a waste form can be accumulated in a favorable geometry. The probability of an external criticality event is expected to be lower than the probability of an in-package criticality event. This is because, in addition to the events evaluated to calculate the probability of water infiltrating a breached waste package, the probability of the following events or processes must also be considered for external criticality:

- Separation of the fissile materials from the degraded waste form
- Sufficient seepage water to transport fissile materials from the waste package
- Accumulating sufficient fissile material into a potentially critical configuration in the far-field environment.

Because the quantity of material released by diffusion would be small due to the tortuousity of the path, advective flow of water is necessary for transporting fissile materials from the waste package to the near-field in any appreciable quantities to be considered for criticality (SNL 2007 [DIRS 181165], Section 6.2). An advective seepage flow path to a waste package for nominal repository conditions would occur due to misplacement of a drip shield leading to breaching of the waste package from localized corrosion. However, the probability of this type of event is very low (4.36×10^{-9} per drip shield; DTN: MO0705EARLYEND.000 [DIRS 180946], file: *Table 1.doc*, Table 1). Since this type of event occurs during the preclosure time period, it is independent of the postclosure time period. Using the total number of waste packages (11,162; MO0702PASTREAM.001 [DIRS 179925], file: *DTN-Inventory-Rev00.xls*, worksheet: "Unit Cell") as a conservative estimate for the number of drip shields (it is conservative because not all waste packages have sufficient quantities of fissile material to result in a criticality event) and multiplying by the probability of misplacing a drip shield results in an initiating event probability of 4.9×10^{-5}. This value is already below the regulatory screening criterion of 1 chance in 10,000 (10^{-4}) of occurrence within 10,000 years after disposal prior to consideration of probabilities (which would be less than 1.0) associated with the amount of degradation and accumulation into a favorable geometry for criticality that would only result in lowering the sequence probability.

As indicated in excluded FEP 2.1.14.12.0A (Far-Field Criticality Resulting from an Igneous Event) and excluded FEP 2.1.14.10.0A (Far-Field Criticality Resulting from a Seismic Event), the amount of fissile material accumulation in the far-field location is insufficient to pose a criticality concern. Note that the material degradation of the internals and subsequent accumulation in the far-field based on the seismic and igneous scenarios are bounding for nominal repository conditions because the seismic and igneous seepage fluxes are much higher. Therefore, under bounding seepage fluxes resulting from a sesimc or igneous initiating event, an insufficient amount of fissile material could accumulate in the far-field to pose a criticality concern, it can be concluded that under nominal reposity conditions, an insufficient amount of fissile material can accumulate in the far-field location to pose a criticality concern.

Far-field criticality cannot occur unless the waste package and waste form are degraded. Water infiltration is required to degrade the waste package internals and waste form and transport them to the near-field location. Criticality cannot occur unless at least the minimum critical mass of a waste form can be accumulated in a favorable geometry. The probability of an external criticality event is expected to be lower than the probability of an in-package criticality event. This is because, in addition to the events evaluated to calculate the probability of water infiltrating a breached waste package, the probability of the following events or processes must also be considered for external criticality:

- Separation of the fissile materials from the degraded waste form
- Sufficient seepage water to transport fissile materials from the waste package
- Accumulating sufficient fissile material into a potentially critical configuration in the near-field environment.

If a waste package is breached, water and solutes might enter and leave the waste package by several mechanisms, including diffusion, condensation of vapor, and advection of liquid water. Leakage through a crack-damaged drip shield is an insignificant source for liquid water penetration through cracks in the underlying waste package especially when compared to the threshold flow rate (0.1 kg/yr) used in TSPA to define whether seepage occurs (excluded FEP 2.1.03.10.0 (Advection of Liquids and Solids through Cracks in the Waste Package)). Therefore, the predominant mechanism for water inflow and outflow through a breached waste package is through diffusive transport unless the drip shield has failed. *Geochemistry Model Validation Report: Material Degradation and Release Model* (SNL 2007 [DIRS 181165], Section 6.2) indicated that the quantity of material released by diffusion would be small due to the tortuosity of the path, and therefore the diffusion-only scenario is not considered a viable method for material transport. Thus, advective flow of water is necessary for transporting fissile materials from the waste package to the far-field in any appreciable quantities to be considered for criticality.

Vibratory ground motion (included FEP 1.2.03.02.0A (Seismic Ground Motion Damages EBS Components)), faulting (included FEP 1.2.02.03.0A (Fault Displacement Damages EBS Components)), seismic-induced drift collapse in the lithophysal units (included FEP 1.2.03.02.0C (Seismic-Induced Drift Collapse Damages EBS Components)), and seismic-induced rockfall (excluded FEP 1.2.03.02.0B (Seismic-Induced Rockfall Damages EBS Components)) are potential initiating events that are capable of creating advective flow paths into the waste package. Such failures may allow the influx of water (either advective or diffusive) into the waste package, which, in turn, has the potential to initiate processes leading to degradation and transport of the fissile material to the far-field location.

Note that excluded FEP 1.2.03.02.0B (Seismic-Induced Rockfall Damages EBS Components) has been screened from performance assessment on the basis of low consequence, which is not directly applicable to criticality potential evaluations. FEP 1.2.03.02.0B (Seismic-Induced Rockfall Damages EBS Components) indicates that seismic-induced damage to the waste package and its internals from rock block impacts in nonlithophysal units is screened out from the TSPA model on the basis of low probability. However, FEP 1.2.03.02.0B (Seismic-Induced

Rockfall Damages EBS Components) screens out tearing or rupture of the drip shield plates from large block impacts because of low consequence, which is not directly applicable to criticality potential evaluations. Drip shield failure could result in an advective flow path to the waste package OCB creating an environment for subsequent localized corrosion processes (FEP 2.1.03.03.0A (Localized Corrosion of Waste Packages)) that could breach the waste package OCB.

The probability of drip shield and waste package failure from a fault event varies with the magnitude of the earth quake but ranges from 1.2×10^{-4} to 4.3×10^{-4} for the TAD waste packages and from 3.0×10^{-5} to 6.9×10^{-4} for the codisposal waste packages (SNL 2008 [DIRS 173869], Table 6.4-7).

There are several hundred distinct types of DOE SNF and it is not practical to attempt to determine the impact of each individual type on repository performance. These fuels come from a wide range of reactor types, such as light- and heavy-water-moderated reactors, graphite-moderated reactors, and breeder reactors, with various cladding materials and enrichments, varying from depleted uranium to over 93% enriched ^{235}U. Many of these reactors, now decommissioned, had unique design features, such as core configuration, fuel element and assembly geometry, moderator and coolant materials, operational characteristics, and neutron spatial and spectral properties (DOE 2004 [DIRS 171271]).

Therefore, to facilitate DOE SNF waste form evaluations, the DOE SNF inventory was first reduced to 34 DOE SNF groups based on fuel matrix, cladding, cladding condition, and enrichment. These parameters are the fuel characteristics that were determined to have major impacts on the release of radionuclides from the DOE SNF and contributed to nuclear criticality scenarios (DOE 2000 [DIRS 118968], Section 5). Separate groups were further refined for the purposes of criticality, design basis events, and TSPA based on key parameters such as fuel matrix, cladding, and fuel condition, as well as fissile species and enrichment, and reactor and fuel design (DOE 2000 [DIRS 118968], Section 5.1). For criticality, nine DOE SNF criticality groups have been identified and are listed in *General Description of Database Information Version 5.0.1* (DOE 2007 [DIRS 182577], Table 6).

Within each of the nine DOE SNF criticality groups, a single fuel design was selected as being representative of the remaining fuel within each group. The term representative means that all fuels would perform similarly regarding chemical interactions within the waste package and basket, and that canister loading limits from the representative fuel (ranges of key parameters important to criticality such as linear fissile loading and total fissile mass) are established, which other fuels within the group can be shown to not exceed. Waste forms within a single criticality group that have configurations or key criticality parameters outside the range of applicability of the representative fuel will require supplemental analysis and/or additional reactivity control mechanisms.

A miscellaneous waste form category which has a variety of fuel matrix properties originating from various postirradiation examinations and other testing are not included in the criticality evaluations for the fuel groups as they will need to be evaluated on a case-by-case basis. Thus, the disposal criticality analysis methodology (YMP 2003 [DIRS 165505]) can be applied to the DOE SNF representative fuel groups for criticality evaluations.

The minimum fissile mass necessary for criticality external to the waste packages is discussed in *Geochemistry Model Validation Report: External Accumulation Model* (SNL 2007 [DIRS 181395], Section 8.1.4[a]), where it was concluded that insufficient fissile material can collect over 10,000 years to achieve a critical mass for the seismic scenario. Note that the material degradation of the internals and subsequent accumulation in the near-field based on the seismic scenario are bounding for localized corrosion because the seismic seepage flux is based on the entire waste package footprint area collecting seeps whereas localized corrosion seeps would only be a fraction of the total area with a reduced seepage flux. In addition, these values are predicated on having an initiating event (i.e., seismic fault displacement rupturing the drip shield and waste package), which is an unlikely event (1.2×10^{-8} per year). The critical mass limits were evaluated for commercial SNF and DOE SNF waste forms using bounding parameters with regards to optimizing reactivity potential, so the actual masses that would be necessary to achieve criticality would need to be far greater than what was identified (SNL 2007 [DIRS 181395], Section 8.1.4[a]).

Model abstractions were performed for commercial SNF and three DOE SNF waste forms in *Geochemistry Model Validation Report: External Accumulation Model* (SNL 2007 [DIRS 181395]) (i.e., N Reactor (DOE3), TMI (DOE9), and FFTF (DOE1)) (SNL 2008 [DIRS 173869], Table 4.1-2), which make up approximately 90% of the metric tons of heavy metal in the DOE SNF inventory expected to be stored in the repository. In addition to these waste forms making up ~90% of the inventory by mass, they were selected because they provide degradation and accumulation characteristics of uranium-metal (N Reactor), mixed-oxide (FFTF), and damaged uranium dioxide (TMI) waste forms which may be applicable to other representative DOE waste forms. Some of the other DOE SNF waste forms, such as Shippingport light-water breeder reactor (LWBR) (DOE5) and Ft. St. Vrain (DOE6) are not expected to be a concern for external criticality due to the corrosion resistance of the waste form (SNL 2007 [DIRS 181395], Section 6.9.3[a]).

Ft. St. Vrain fuels (DOE6) have an integral silicon carbide (SiC) protective layer that not only retains the fission products but also protects the uranium and thorium dicarbide (ThC_2) from oxidation and hydrolysis (DOE 2003 [DIRS 166027], p. 48). Comparative analysis has indicated that the Ft. St. Vrain fuel has the lowest degradation rate of all DOE SNF and should behave significantly better in terms of fissile material dissolution, transport, and accumulation. In some residual quantities (< 250 grams per block), ^{233}U bred into the ThC_2 fertile particles. A canister loaded with five Ft. St. Vrain blocks contains sufficient quantities of ^{233}U to have criticality potential in solution; however, a mechanism to separate the uranium from within the SiC-coated fertile particles, and then a mechanism to accumulate in a concentrated fissile mass in a favorable geometry, is not credible.

For Shippingport LWBR fuel (DOE5), a number of studies has indicated both air and water oxidation of uranium and thorium oxide fuel pellets [$(Th, U)O_2$] proceed more slowly than in pure uranium oxide (UO_2), and decreases with decreasing UO_2 content in the $(Th, U)O_2$ (DOE 2003 [DIRS 166027], p. 33). Tests have shown that the thorium oxide pellets in the Shippingport LWBR fuel have excellent corrosion resistance with an estimated solubility of

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- Separation of the fissile materials from the degraded waste form
- Sufficient seepage water to transport fissile materials from the waste package
- Accumulating sufficient fissile material into a potentially critical configuration in the far-field environment.

Excluded FEP 2.1.07.01.0A (Rockfall) indicates that rockfall related to nonseismic processes such as drift degradation induced by in situ gravitational and excavation-induced stresses as well as thermally induced stresses do not generate rock block sizes sufficient to tear or rupture the drip shield plates. Drip shield damage from rockfall induced by thermal loading is found to be minor since the block sizes for such rockfall are small with a mean mass of less than 0.2 MT (BSC 2004 [DIRS 166107], p. 6-102). In addition, drift degradation (i.e., considering thermal and time-dependent effects on drift collapse, but excluding seismic effects) results in only partial collapse of the emplacement drifts at 20,000 years (see excluded FEP 2.1.07.02.0A (Drift Collapse)). The conclusion for the nominal scenario is that negligible drift degradation will occur over the initial 10,000-year postclosure period (BSC 2004 [DIRS 166107], p. x).

A waste package must be breached in order to transport fissile material out. If a waste package is breached, water and solutes might enter and leave the waste package by several mechanisms, including diffusion, condensation of vapor, and advection of liquid water. Therefore, rockfall does not result in waste package outer barrier breaching. Without a waste package breach, there is no potential for external criticality.

Summary—Since the drip shield continues to function through rockfall events as described previously, the waste package will be protected from rockfall during the postclosure period, for as long as the drip shield remains intact, thereby precluding the introduction of water to the waste package, which is necessary to degrade the internals and transport material into the far-field location. The probability of the occurrence of configurations with criticality potential for the far-field location resulting from rockfall is insignificant since no damage to the waste package OCBs is expected from the nonseismically initiated rockfall events. Accordingly, this FEP is excluded from the performance assessments conducted to demonstrate compliance with proposed 10 CFR 63.311 and 63.321 (70 FR 53313 [DIRS 178394]), and with 10 CFR 63.331 [DIRS 180319], on the basis of low probability. This result is applicable for all waste forms and waste package variants.

FEP: 2.2.14.12.0A

FEP NAME:

Far-Field Criticality Resulting from an Igneous Event

FEP DESCRIPTION:

Either during or as a result of an igneous disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505], Figure 3.3b).

SCREENING DECISION:

Excluded – low probability

SCREENING JUSTIFICATION:

This FEP justification accounts for external criticality for the far-field location for the igneous scenario, where *far-field* is defined as the region outside the drift. A prerequisite for any of the spent fuel waste forms to have potential for criticality is the introduction of water in liquid or vapor form to the inside of the TAD or DOE SNF canister. 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. Therefore, for a configuration to have potential for criticality, all of the following conditions must occur: (1) sufficient mechanical or corrosive damage to the waste package OCB 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 of fissionable material in a critical geometric configuration. The probability of developing a configuration with criticality potential is insignificant unless all four conditions are realized, and then is only representative of a conservative estimate since the probability values associated with the many other events required to generate a critical configuration that would be less than 1 are not evaluated, but are conservatively set to 1.

Far-field criticality cannot occur unless the waste package and waste form are degraded. Water infiltration is required to degrade the waste package internals and waste form and transport them to the far-field location. Criticality cannot occur unless at least the minimum critical mass of a waste form can be accumulated in a favorable geometry. The probability of an external criticality event is expected to be lower than the probability of an in-package criticality event. This is because, in addition to the events evaluated to calculate the probability of water infiltrating a breached waste package, the probability of the following events or processes must also be considered for external criticality:

- Separation of the fissile materials from the degraded waste form

A miscellaneous waste form category which has a variety of fuel matrix properties originating from various postirradiation examinations and other testing is not included in the criticality evaluations for the fuel groups as they will need to be evaluated on a case-by-case basis. Thus, the disposal criticality analysis methodology (YMP 2003 [DIRS 165505]) can be applied to the DOE SNF representative fuel groups for criticality evaluations.

The minimum fissile mass necessary for criticality external to the waste packages is discussed in *Geochemistry Model Validation Report: External Accumulation Model* (SNL 2007 [DIRS 181395], Section 8.1.4[a]), where it was concluded that insufficient fissile material can collect over 10,000 years to achieve a critical mass for the igneous scenario. In addition, these values are predicated on having an initiating event (i.e., igneous intrusive event causing drip shield and waste package failure), which is an unlikely event (1.7×10^{-8} per year). The critical mass limits were evaluated for commercial SNF and DOE SNF waste forms using bounding parameters with regards to optimizing reactivity potential, so the actual masses that would be necessary to achieve criticality would most likely need to be far greater than what was identified (SNL 2007 [DIRS 181395], Section 8.1.4[a]).

Model abstractions were performed for commercial SNF and three DOE SNF waste forms in *Geochemistry Model Validation Report: External Accumulation Model* (SNL 2007 [DIRS 181395]) (i.e., N Reactor (DOE3), TMI (DOE9), and FFTF (DOE1)) (SNL 2008 [DIRS 173869], Section 4.1.15), which make up approximately 90% of the metric tons of heavy metal in the DOE SNF inventory expected to be stored in the repository. In addition to these waste forms making up ~90% of the inventory by mass, they were selected because they provide degradation and accumulation characteristics of uranium-metal (N Reactor), mixed-oxide (FFTF), and damaged uranium dioxide (TMI) waste forms which may be applicable to other representative DOE waste forms. Some of the other DOE SNF waste forms, such as Shippingport light-water breeder reactor (LWBR) (DOE5) and Ft. St. Vrain (DOE6) are not expected to be a concern for external criticality due to the corrosion resistance of the waste form (SNL 2007 [DIRS 181395], Section 6.9.3[a]).

Ft. St. Vrain fuels (DOE6) have an integral silicon carbide (SiC) protective layer that not only retains the fission products but also protects the uranium and thorium dicarbide (ThC_2) from oxidation and hydrolysis (DOE 2003 [DIRS 166027], p. 48). Comparative analysis has indicated that the Ft. St. Vrain fuel has the lowest degradation rate of all DOE SNF and should behave significantly better in terms of fissile material dissolution, transport, and accumulation. In some residual quantities (< 250 grams per block), ^{233}U bred into the ThC_2 fertile particles. A canister loaded with five Ft. St. Vrain blocks contains sufficient quantities of ^{233}U to have criticality potential in solution; however, a mechanism to separate the uranium from within the SiC-coated fertile particles, and then a mechanism to accumulate in a concentrated fissile mass in a favorable geometry is not credible.

For Shippingport LWBR fuel (DOE5), a number of studies has indicated that air and water oxidation of uranium and thorium oxide fuel pellets [$(Th, U)O_2$] proceeds more slowly than in pure uranium oxide (UO_2), and decreases with decreasing UO_2 content in the $(Th, U)O_2$ (DOE 2003 [DIRS 166027], p. 33). Tests have shown that the thorium oxide pellets in the Shippingport LWBR fuel have excellent corrosion resistance with an estimated solubility of

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Table A-1. Repository Design Use in Performance Assessment

Control Parameter	Representative FEPs Relying on Design/Control Parameter	Control Parameter Use in Performance Assessment
01-01 Repository Geographic and Geologic Location	• FEP 0.1.03.00.0A – Spatial Domain of Concern* • FEP 1.1.01.01.0A – Open Site Investigation Boreholes (Excluded) • FEP 1.1.07.00.0A – Repository Design • FEP 2.1.06.01.0A – Chemical Effects of Rock Reinforcement and Cementitious Materials in EBS (Excluded) • FEP 2.1.07.04.0A – Hydrostatic Pressure on Waste Package (Excluded) • FEP 2.1.07.04.0B – Hydrostatic Pressure on Drip Shield (Excluded) • FEP 2.1.08.09.0A – Saturated Flow in the EBS (Excluded) • FEP 2.2.08.03.0B – Geochemical Interactions and Evolution in the UZ (Excluded) • FEP 2.2.08.12.0A – Chemistry of Water Flowing into the Drift	Supports spatial domain of concern and boundary conditions for various mountain-scale, repository-scale, and drift-scale models Supports basis for FEP exclusion
01-02 Repository Layout	• FEP 1.1.07.00.0A – Repository Design • FEP 1.2.04.03.0A – Igneous Intrusion into Repository* • FEP 2.1.05.01.0A – Flow Through Seals (Access Ramps and Ventilation Shafts) (Excluded) • FEP 2.1.08.04.0A – Condensation Forms on Roofs of Drifts (Drift-Scale Cold Traps) • FEP 2.1.08.04.0B – Condensation Forms at Repository Edges (Repository-Scale Cold Traps) • FEP 2.1.08.09.0A – Saturated Flow in the EBS (Excluded) • FEP 2.1.11.03.0A – Exothermic Reactions in the EBS (Excluded) • FEP 2.1.13.02.0A – Radiation Damage in EBS (Excluded)	Supports spatial domain of concern and boundary conditions for various mountain-scale, repository-scale, and drift-scale models Supports basis for FEPs exclusion
01-03 Repository Geologic Location	• FEP 1.1.01.01.0A – Open Site Investigation Boreholes (Excluded) • FEP 1.2.03.02.0B – Seismic Induced Rockfall Damages EBS Components (Excluded) • FEP 1.2.03.02.0C – Seismic-Induced Drift Collapse Damages EBS Components • FEP 2.2.01.02.0A – Thermally-Induced Stress Changes in the Near-Field (Excluded) • FEP 2.2.01.03.0A – Changes in Fluid Saturations in the Excavation Disturbed Zone (Excluded) • FEP 2.2.03.01.0A – Stratigraphy • FEP 2.2.08.12.0A – Chemistry of Water Flowing into the Drift • FEP 2.1.03.10.0B – Advection of Liquids and Solids Through Cracks in the Drip Shield (Excluded)	Supports spatial domain of concern and boundary conditions for various mountain-scale, repository-scale, and drift-scale models Supports basis for FEPs exclusion
01-04 Repository Elevation – Standoff from Water Table	• FEP 2.1.08.12.0A – Induced Hydrologic Changes in Invert (Excluded) • FEP 2.2.10.04.0A – Thermal-Mechanical Stresses Alter Characteristics of Fractures Near Repository (Excluded)* • FEP 2.2.11.01.0A – Gas Effects in the SZ (Excluded)*	Supports basis for FEPs exclusion

Table A-1. Repository Design Use in Performance Assessment (Continued)

Control Parameter	Representative FEPs Relying on Design/Control Parameter	Control Parameter Use in Performance Assessment
06-05 Maximum Temperature of HLW Glass Canisters – Ventilation	• FEP 2.1.02.03.0A – HLW Glass Degradation (Alteration, Dissolution, and Radionuclide Release)* • FEP 2.1.02.06.0A – HLW Glass Recrystallization (Excluded)*	Supports basis for HLW degradation rate in performance assessment Supports basis for FEP exclusion
06-06 Average Airflow Rate for Preclosure Ventilation Period	• FEP 1.1.02.00.0A – Chemical Effects of Excavation and Construction in EBS (Excluded) • FEP 1.1.02.02.0A – Preclosure Ventilation* • FEP 2.1.11.01.0A – Heat Generation in EBS* • FEP 2.2.10.13.0A – Repository-Induced Thermal Effects on Flow in the SZ (Excluded)*	Supports the basis for performance assessment initial conditions
07-01 Drip Shield Design	• FEP 1.2.03.02.0B – Seismic-Induced Rockfall Damages EBS Components (Excluded) • FEP 2.1.03.03.0B – Localized Corrosion of Drip Shields (Excluded) • FEP 2.1.03.04.0B – Hydride Cracking of Drip Shields (Excluded) • FEP 2.1.06.05.0B – Mechanical Degradation of Invert (Excluded) • FEP 2.1.06.06.0A – Effects of Drip Shield on Flow • FEP 2.1.09.03.0C – Volume Increase of Corrosion Products Impacts Other EBS Components (Excluded) • FEP 2.1.09.09.0A – Electrochemical Effects in EBS (Excluded) • FEP 2.1.03.10.0B – Advection of Liquids and Solids Through Cracks in the Drip Shield (Excluded)* • FEP 2.1.03.11.0A – Physical Form of Waste Package and Drip Shield	Supports the basis for performance assessment initial conditions Supports basis for FEP exclusion
07-02 Drip Shield Design and Installation	• FEP 1.1.07.00.0A – Repository Design • FEP 2.1.06.06.0A – Effects of Drip Shield on Flow	Supports the basis for performance assessment initial conditions
07-03		Not used

Considering two bounding arrangements for the through-wall cracks in the drip shields (SNL 2007 [DIRS 181953], Section 6.8.5.2), the crack opening area density (crack opening area per unit seismically damaged area) (ρ_{SCCA}) is calculated as follows:

$$\rho_{SCCA} = C \times \frac{\pi \sigma_{YS}}{\sqrt{3}\, E} \quad \text{(Eq. C-3)}$$

$$C = uniform(1,4) \quad \text{(Eq. C-4)}$$

where C is an epistemic uncertainty factor given by a uniform distribution between 1 and 4. Details of this bounding crack arrangement and geometry are given in *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007 [DIRS 181953], Section 6.8.5.2). The total through-wall SCC crack opening area per drip shield (A_{DS_SCC}) that results from the seismic damage is calculated as:

$$A_{DS\_SCC} = C \frac{\pi \sigma_{YS\_DS}}{\sqrt{3}\, E_{DS}} \cdot A_{SD\_DS} \quad \text{(Eq. C-5)}$$

where A_{SD_DS} is the seismically damaged area on the drip shield (similar to SNL 2007 [DIRS 181953], Equation 32 in Section 6.7.2), and is provided by the seismic consequence abstraction analysis (DTN: MO0703PASDSTAT.001 [DIRS 183148], files: *DS Damaged Areas with Rubble.xls* and *Nonlith Damage Abstraction for DS.xls*; DTN: MO0703PASEISDA.002 [DIRS 185278]). Regions of seismic damage are assumed to be distributed randomly over the drip shield surface.

C.2.2.1 Seismic-induced damage area of drip shield

Damage to a drip shield could occur in either the lithophysal or nonlithophysal host rock. The nonlithophysal zone comprises approximately 15% of the repository area (SNL 2007 [DIRS 179466], Table 4-1, Parameter Number 01-03). To evaluate drift degradation and rockfall impact damage on drip shields, from seismic ground motion in the first 10,000 years, a peak ground velocity (PGV) of 1.05 m/s was selected as a representative seismic ground motion. This corresponds to a mean annual exceedance frequency of approximately 10^{-5}/yr (DTN: MO0501BPVELEMP.001 [DIRS 172682]), which roughly equates to 1 chance in 10 of occurring in the first 10,000 years. The full plate thickness for drip shields was selected as appropriate for the first 10,000 years because the extent of general corrosion of Titanium Grade 7 during this time will be very small, and will not markedly alter structural performance.

For drift degradation in the lithophysal zone at the 1.05 m/s PGV level, the resulting degraded drift volume, on a per meter basis (also the volume of rock needed to fill the drift) is quantified as a uniform distribution between 30 and 120 m^3 (DTN: MO0703PASEISDA.002 [DIRS 185278], Section 1.1, step 5.e.). For this evaluation, the median value (75 m^3 per meter of drift length) was selected for a nominal collapsed drift volume. An estimate of how much rock volume is produced during such an event is quantified in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Figure 6-57) and, at the 1.05 m/s PGV, has a mean value of 7.47 m^3

All MathCad files that are relevant for the calculation are included in output DTN: MO0707NONLITHO.000.

E.4 INPUTS

E.4.1 Direct Input

Table E-1 presents the direct input information for this calculation. The numerical values in Table E-1 are presented with the same number of significant figures and in the same units as the data in the source, unless otherwise noted. The technical product inputs identified in Table E-1 are appropriate for the development of a scientific analysis for the dose related to failures of drip shield plates in the nonlithophysal units of the repository.

E.4.2 Criteria

No criteria are specific to the calculation in this appendix.

E.4.3 Codes, Standards, and Regulations

No additional codes, standards, or regulations apply to the calculation in this appendix.

Table E-1. Direct Inputs for Appendix E

Input Data or Information	Value	Source
Bounded hazard curve at the emplacement drifts	See Table 1-1 or parameter PGV in Table 1-15 in the DTN	DTN: MO0703PASEISDA.002 [DIRS 185278], file: *Seismic Damage Abstractions for TSPA Compliance Case.doc*
Maximum annual exceedance frequency on the bounded hazard curve	4.287×10^{-4} per year	DTN: MO0703PASEISDA.002 [DIRS 185278], Step 2 or parameter LAMBDA_MAX in Table 1-15 in file: *Seismic Damage Abstractions for TSPA Compliance Case.doc*
Minimum annual exceedance frequency on the bounded hazard curve	10^{-8} per year	DTN: MO0703PASEISDA.002 [DIRS 185278], Step 2 or parameter LAMBDA_MIN in Table 1-15 in file: *Seismic Damage Abstractions for TSPA Compliance Case.doc*
Probability of damage to the drip shield or failure of the drip shield plates from seismic-induced rock block impacts in the nonlithophysal units	Values are tabulated in the DTN	DTN: MO0703PASEISDA.002 [DIRS 185278], Table 1-10 or parameter PD_DSNL in Table 1-18 in file: *Seismic Damage Abstractions for TSPA Compliance Case.doc*
Probability of the number of drip shields with failed plates from seismic-induced rock block impacts in the nonlithophysal units. This probability is conditional on the occurrence of drip shield damage or drip shield plate failures.	Values are tabulated in the DTN	DTN: MO0703PASEISDA.002 [DIRS 185278], Table 1-11 or parameters: PD_DSNL-STATE1, PD_DSNL_STATE2, PD_DSNL_STATE3, PD_DSNL_STATE4, and PD_DSNL-STATE5 in Table 1-18 in file: *Seismic Damage Abstractions for TSPA Compliance Case.doc*
Mean corrosion rate for Titanium Grade 7 under aggressive conditions, which applies to the top side of the drip shield plates	46.1 nm/yr	DTN: SN0704PADSGCMT.001 [DIRS 182122], Section 2 in file: *TSPA Implementation_DS GC Model.pdf*

where

λ_F	is the frequency of drip shield failure due to rock block impacts caused by seismic events. This frequency is a calculated parameter in the MathCad file, based on 100,000 realizations
$T_{LC}\left(p, b, \mathbf{e}_i\right)$	is the latest time that localized corrosion could occur on a waste package of type p in bin b for epistemic vector $\mathbf{e}_i$, based on data in DTN: MO0709TSPALOCO.000 [DIRS 182994], files: *LC_Initiation_Analysis_v2_CSNF_Bin1.TXT* *LC_Initiation_Analysis_v2_CSNF_Bin2.TXT* *LC_Initiation_Analysis_v2_CSNF_Bin3.TXT* *LC_Initiation_Analysis_v2_CSNF_Bin4.TXT* *LC_Initiation_Analysis_v2_CDSP_Bin1.TXT* *LC_Initiation_Analysis_v2_CDSP_Bin2.TXT* *LC_Initiation_Analysis_v2_CDSP_Bin3.TXT* *LC_Initiation_Analysis_v2_CDSP_Bin4.TXT*.
$(f_p \times f_b \times N_{WP})$	is the total number of waste packages of type p in seepage bin b
f_p	is the fraction of waste packages of type p in the inventory for the TSPA model, based on DTN: MO0702PASTREAM.001 [DIRS 179925], file: *DTN-Inventory-Rev00.xlsI*, worksheet: "UNIT CELL," cells: "G49 and K49"
f_b	is the fraction of waste packages in seepage bin b (SNL 2008 [DIRS 183478], Section 6.3.2.2.1)
$f_{NL}\left(b\right)$	is the fraction of seepage bin b that is in the nonlithophysal units (DTN: MO0709TSPALOCO.000 [DIRS 182994], TSPA parameter: NonLith_Frac_CSNF_out)
$\boldsymbol{N_{WP}}$	is the total number of waste packages in the repository, based on DTN: MO0702PASTREAM.001 [DIRS 179925], file: *DTN-Inventory-Rev00.xlsI*, worksheet: "UNIT CELL," cells: G49 and K49
$f_{LC}\left(p, b, \mathbf{e}_i\right)$	is the maximum fraction of waste packages of type p in bin b on which localized corrosion may occur for epistemic vector $\mathbf{e}_i$.

Equation E-3 assumes that $\lambda_F \times T_{LC}$ represents the expected number of seismic events that cause drip shield failure and that can occur during the time when localized corrosion can occur. This is a conservative formulation because it assumes that localized corrosion can begin at time zero, rather than after rewetting occurs in percolation subregion *b*.

The MathCad calculation for λ_F, the frequency of drip shield failure due to rock block impacts, is a function of the following parameters: (1) the bounded hazard curve at the emplacement drifts, (2) the maximum and minimum annual exceedance frequencies on the bounded hazard curve, (3) the probability of damage/failure of the drip shield plates from seismic-induced rock block impacts in the nonlithophysal units, and (4) the conditional probability for the number of drip shields with failed plates from seismic-induced rock block impacts in the nonlithophysal units. These quantities are defined by Table 1-1, Step 2, Table 1-10, and Table 1-11, respectively, in DTN: MO0703PASEISDA.002 [DIRS 185278]. λ_F is also a function of the thickness of the drip shield plates as a function of time, based on mean corrosion rates for Titanium Grade 7 under aggressive and benign conditions (DTN: SN0704PADSGCMT.001 [DIRS 182122], Sections 2 and 3 in file: *TSPA Implementation_DS GC Model.pdf*) and the initial thickness of the plates (SNL 2007 [DIRS 179354], Section 4.1.2, Table 4-2, Parameter 07-04A).

E.6.3 Computational Results

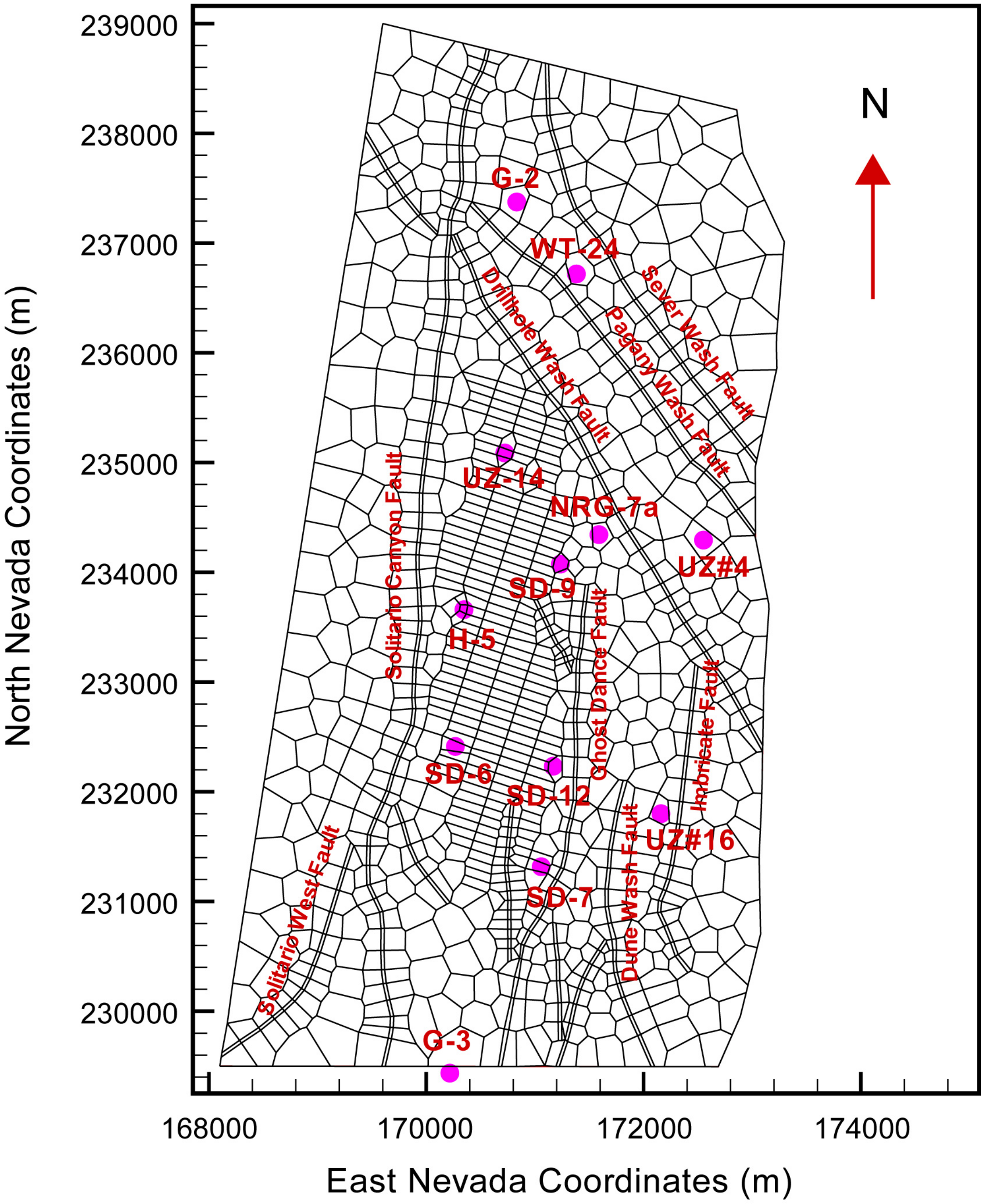
Table E-3 presents the mean annual dose due to nonlithophysal rockfall, $\overline{\overline{D}}_{NL}(\tau)$, at 1,000, 2,000, 5,000, and 10,000 years. Table E-3 also presents the corresponding values for the seismic ground motion modeling case. The seismic ground motion modeling case represents the dose from damage to EBS components caused by vibratory ground motion and caused by rockfall induced in the lithophysal zones by vibratory ground motion. The mean annual dose due to nonlithophysal rockfall would be included as a component of the seismic ground motion modeling case if it is included in TSPA. A comparison of the mean annual doses from nonlithophysal rockfall and from the seismic ground motion modeling case is therefore appropriate for demonstrating low consequence.

Table E-3. Comparison of Mean Annual Dose Due to Nonlithophysal Rockfall with the Dose from the Seismic Ground Motion Modeling Case

Time after Repository Closure (years)	Mean Annual Dose – Nonlithophysal Rockfall (mrem)	Mean Annual Dose – Seismic Ground Motion Modeling Case (mrem)	Ratio of Nonlithophysal Rockfall Dose to Seismic Ground Motion Modeling Case Dose (%)
1,000	0.00098	0.002	49
2,000	0.00096	0.03	3.2
5,000	0.00037	0.1	0.37
10,000	0.00031	0.2	0.16

Sources: Output DTN: MO0707NONLITHO.000, file: *LA_v5_ED_003000_007_NL_LC_Dose.txt* for the nonlithophysal rock. Numerical values estimated from Figure 8.2-11(a)[a] in SNL 2008 [DIRS 183478] for the seismic ground motion modeling case.

A comparison of the ratios in Table E-3 demonstrates that: (1) the mean annual dose from the seismic ground motion modeling case is always greater than the estimated dose due to nonlithophysal rockfall; (2) at 1,000 years, the mean annual dose due to nonlithophysal rockfall is about 50% of the dose from the seismic ground motion modeling case, although the magnitude of the nonlithophysal-related dose is very small compared to the individual protection standard of 15 mrem during the first 10,000 years after closure (proposed 10 CFR 63.311(a)(1) [DIRS 178394]); and (3) after 2,000 years, the mean annual dose due to nonlithophysal rockfall is about 3% or less of the dose from the seismic ground motion modeling case. These results



Source: BSC 2001 [DIRS 158726], Figure 6-2.

NOTE: Repository location is the relatively uniformly gridded section in the central part of the domain.

Figure I-3a. Plan View of the UZ Flow Model Domain for Site Recommendation Showing Nearby Faults and Boreholes