OCRWM	ERRATA	3. QA: QA 4. Page 1 of 1

1. Condition Report No.	2. DC Tracking Number
1869	39333

5. Product DI	6. Title	7. Revision
ANL-WIS-MD-000005	Features, Events, and Processes: Disruptive Events	001

8. Description of Error	9. Clarification/Restriction
Contrary to the requirement in AP-SIII.9Q Rev 01 ICN 02 Section 5.2.1(j), the Attachment to the report was identified by the letter "A" rather than the Roman numeral "I."	Attachment A should be identified as Attachment I and pages should be numbered I-# rather than A-#. There is no impact to the technical content of the report and no restrictions on use of the information in the Attachment.

10. Responsible Manager (Print Name)	Initials	Date
Jerry King	JK	March 31, 2004

OCRWM	ERRATA	3. QA: QA 4. Page 1 of 2

1. Condition Report No.	2. DC Tracking Number
N/A	38304

DOC.20040209.0001

5. Product DI ANL-WIS-MD-000005	6. Title Features, Events, and Processes: Disruptive Events	7. Revision 001

8. Description of Error	9. Clarification/Restriction
Table 6-1 – FEP 2.2.06.02.00 was omitted from the table.	The information for FEP 2.2.06.02.00 that should be included in Table 6-1, between the rows for FEP 2.2.06.01.00 and FEP 2.2.06.03.00, is provided on page 2 of these errata.
Page 90, Section 6.2.1.7: FEP 1.2.03.03.0A – Seismicity Associated with Igneous Activity: Under the "Descriptor Phrases" subheading, a bracketed paragraph incorrectly indicates that this FEP is shared with other departments.	The bracketed information indicating that FEP 1.2.03.03.0A is shared should be ignored. FEP 1.2.03.03.0A is not shared.
Page 136, Section 6.2.2.6: FEP 1.2.04.07.0A – Ashfall: Under the "Descriptor Phrases" subheading, a bracketed paragraph was omitted that should have indicated that this FEP is shared with other departments.	In Section 6.2.2.6, under the "Descriptor Phrases" subheading, the following paragraph was omitted: "[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]" FEP 1.2.04.07.0A is shared.
Page 151, References: DIRS Number for BSC 2003 (MDL-MGR-GS-000003, REV 00) is incorrectly listed as "6.166274"	DIRS number should be listed as "166274" for this reference.

10. Responsible Manager (Print Name)	Initials	Date
Jerry King	JK	January 29, 2004

Insertion to Table 6-1 for FEP 2.2.02.06.00:

TSPA-SR FEP and Description	**TSPA-SR Screening Decision**	**TSPA-LA FEP and Description** (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	**Basis for Change from TSPA-SR to TSPA-LA FEP List**	**Analysis Report Section**
2.2.02.06.00 Changes in stress (due to thermal, seismic, or tectonic effects) produce change in permeability of faults Stress changes due to thermal, tectonic and seismic processes result in strains that alter the permeability along and across faults	*Excluded*–Low Consequence	2.2.06.02.0A Seismic activity changes porosity and permeability of faults. Seismic activity (fault displacement or vibratory ground motion) has a potential to produce jointed-rock motion and change stress and strains that alter the permeability along faults. This could result in reactivation of preexisting faults or generate new faults and significantly change the flow and transport paths, alter or short-circuit the flow paths and flow distributions close to the repository, and create new pathways through the repository. These effects may decrease the transport times for potentially released radionuclides.	FEP Description modified to limit discussion in this FEP to seismic-related events. Due to the linkage between changes in stress, fault displacement, and change in fault characteristics, these aspects of faulting have been incorporated from the TSPA-SR FEP 1.2.02.02.00 Faulting. Thermal effects of the repository are addressed as part of the nominal case analysis.	6.2.1.10

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SCIENTIFIC ANALYSIS COVER SHEET

1. QA: QA
Page: 1 Of: 161

2. Scientific Analyses Title
Features, Events, and Processes: Disruptive Events

3. DI (including Revision Number)
ANL-WIS-MD-000005 Rev 01

4. Total Attachments
1

5. Attachment Numbers - Number of pages in each
A-9

	Print Name	Signature	Date
6. Originator	Daniel L. McGregor	SIGNATURE ON FILE	12/05/03
7. Checker	Kathryn Hanson	SIGNATURE ON FILE	12/08/03
8. QER	Ken McFall	SIGNATURE ON FILE	12/09/03
9. Responsible Manager/Lead	Richard Quittmeyer	SIGNATURE ON FILE	12/9/2003
10. Responsible Manager	Jerry King	SIGNATURE ON FILE	12/9/2003

11. Remarks
None

Technical Contact/Department: Daniel L. McGregor / Disruptive Events

Revision History

12. Revision/ICN No.	13. Description of Revision/Change
00	Initial Issue
00/01	This ICN addresses FEP screening for the no backfill design and drift reorientation. Also, screening arguments include a statement of the potential consequence of the FEP to clarify arguments. Table 3 (now Table 4) has
	been expanded to include all Secondary FEPs for the Primary FEPs of interest. Attachment II has been added to show relationships and traceability from the Secondary FEPs to the Primary FEPs, to provide mapping of the
	FEPs to KTI SubIssues and to Integrated Subissues, and to show relationships to other non-Disruptive Events FEPs. This ICN is being issued in its entirety due to the number of affected pages.
01	Addresses changes to the FEPs list based on TDR-WIS-PA-000005, and incorporates changes necessary to comply with AP-SIII.9Q, Scientific Analyses. The changes are extensive and the document is being reissued
	in its entirety, so no margin change bars are used. Attachment II information in previous ICN has been incorporated into main body of text consistent with eliminating Secondary FEP designations.

AP-SIII.9Q.1 Rev. 12/21/2001

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CONTENTS

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CONTENTS (Continued)

TABLES

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ACRONYMS AND ABBREVIATIONS

AMR	analysis model report
AMRs	analysis model reports
AP	administrative procedure
BSC	Bechtel-SAIC Company, LLC
CDF	cumulative distribution function
CFR	Code of Federal Regulations
CRWMS	Civilian Radioactive Waste Management System
CSNF	commercial spent nuclear fuel
DE	disruptive events
DHLW	defense high-level (radioactive) waste
DOE	U.S. Department of Energy
DRKBA	Discrete Regional Key Block Analysis
DSNF	defense spent nuclear fuel
DTN	Data Tracking Number
EBS	engineered barrier system
ECRB	Enhanced Characterization of the Repository Block
EPA	U.S. Environmental Protection Agency
ESF	Exploratory Studies Facility
FEP	feature, event, and process
FR	Federal Register
ICN	Interim Change Notice
ka	thousand years (before present)
LA	license application
Ma	million years (before present)
M&O	Management and Operating Contractor
Mw	moment magnitude (a measure of earthquake magnitude)
NBS	natural barrier system
NEA	U.S. Nuclear Energy Agency
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
OCRWM	Office of Civilian Radioactive Waste Management
PGV	peak ground velocity
PRD	Project requirements document

ACRONYMS AND ABBREVIATIONS (Continued)

PSHA	*Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada*
PTn	Paintbrush, nonwelded tuff
PWR	pressurized water reactor
PVHA	*Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada*
QA	quality assurance
QARD	*Quality Assurance Requirements and Description*
RMEI	reasonably maximally exposed individual
SDS	seismicity and structural deformation
SME	subject-matter expert
SPGM	*Scientific Processes Guidelines Manual*
SR	site recommendation
SZ	saturated zone
TBV	to be verified
TSPA	total system performance assessment
TSPA-SR	total system performance assessment for site recommendation
TPSA-LA	total system performance assessment for license application
TWP	technical work plan
USGS	U.S. Geological Survey
UZ	unsaturated zone
YMP	Yucca Mountain Project
YMRP	*Yucca Mountain Review Plan*

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1. PURPOSE

The primary purpose of this analysis is to evaluate seismic- and igneous-related features, events, and processes (FEPs). These FEPs represent areas of natural system processes that have the potential to produce disruptive events (DE) that could impact repository performance and are related to the geologic processes of tectonism, structural deformation, seismicity, and igneous activity. Collectively, they are referred to as the DE FEPs. This evaluation determines which of the DE FEPs are excluded from modeling used to support the total system performance assessment for license application (TSPA-LA). The evaluation is based on the data and results presented in supporting analysis reports, model reports, technical information, or corroborative documents that are cited in the individual FEP discussions in Section 6.2 of this analysis report.

By default, FEPs are included in the TSPA-LA unless they can be excluded based on low probability, low consequence, or by regulation. The U. S. Nuclear Regulatory Commission (NRC) provides the evaluation criteria, or screening criteria, in the Code of Federal Regulations (CFR) at 10 CFR Part 63.114(d, e, and f) (66 Federal Register (FR) 55732 [DIRS 156671]). The NRC regulations also incorporate the performance standards of the U.S. Environmental Protection Agency (EPA) found at 40 CFR Part 197 (66 FR 32074 [DIRS 155216]). A FEP can be excluded from the TSPA-LA per 10 CFR 63.114(d) (66 FR 55732 [DIRS 156671]) by showing that the probability of occurrence is less than 1 in 10,000 in 10,000 years (or an approximately equivalent annualized probability of 10^{-8}). A FEP also can be excluded from the TSPA-LA per 10 CFR 63.114(e or f) (66 FR 55732 [DIRS 156671]), by showing that omitting the FEP would not significantly change the resulting radiological exposure to the reasonably maximally exposed individual (RMEI) or change the radionuclide release to the accessible environment. In a few instances, FEPs may also be excluded "by regulation" based on characteristics, definitions, or concepts specifically stated in applicable NRC and EPA regulations. Results of the FEP evaluations are such that the DE FEPs are either included or are excluded based on low consequence.

This revision addresses updates in the Yucca Mountain Project (YMP) administrative procedures as they pertain to this analysis report; the current procedures are discussed in Section 2. Sections 4 and 6 incorporate updates to the technical basis that are provided in supporting analysis model reports (AMRs) and also provide additional information pertaining to the relevant FEP-related acceptance criteria presented in the *Yucca Mountain Review Plan, Final Report* NUREG-1804 (NRC 2003, [DIRS 163274]), herein referred to as the YMRP.

More importantly, this report documents changes to the DE FEP list that have occurred since issuance of REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151553]). These changes resulted from reevaluation of the FEP list as outlined in *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966]) and *KTI Letter Report, Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [DIRS 165394]). Reorganization and redefinition of the DE FEPs between the Total System Performance Assessment for Site Recommendation (TSPA-SR) and TSPA-LA are more fully addressed in Section 6.1.

Preceding versions of this report include REV 00 (CRWMS M&O 2000 [DIRS 146681]) and REV 00 ICN 01 (CRWMS M&O 2000 [DIRS 151553]). REV 00 was originally issued based on consideration of a repository with backfill and drip shields, as described in the *License Application Design Selection Report* (CRWMS M&O 1999, EDA II pp. 5-41 and 5-42 [DIRS 102715]). REV 00 ICN 01 addressed a repository design without backfill and with changes to resolve certain thermal design issues, reorientation of the drift azimuths, and 70,000-metric-ton of uranium (MTU) and 95,000 MTU designs (CRWMS M&O 2000 [DIRS 150088] and CRWMS M&O 2000 [DIRS 149137]), which were not addressed in REV 00.

1.1 PLANNING AND DOCUMENTATION

Documentation requirements for this analysis report are described in the technical work plan (TWP), *Development of Seismic Design Inputs, Preparation of a Seismic Topical Report, and Evaluation of Disruptive Events Features, Events, and Processes* (BSC 2002 [DIRS 161737]).

Detailed planning information and work scope for the seismic-related FEPs are provided in the TWP. Information and work scope for igneous-related FEPs are described in detail in the related TWP *Igneous Activity Analyses for Disruptive Events* (BSC 2003 [DIRS 164143]). The work described in the TWPs was based on the TSPA-SR DE FEP list. Changes in the assigned DE FEP list for the TSPA-LA resulted from the planned work scope and are further described in Table 6-1.

1.2 SCOPE

The scope of this report is to describe, evaluate, and document DE FEPs for the TSPA-LA. Activities for TSPA-LA FEPs were described in *The Enhanced Plan for Features Events and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966]) and the *KTI Letter Report Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [DIRS 165394]). The results of the TSPA-LA FEP activities included FEP reorganization (eliminating Primary and Secondary FEP classification and eliminating redundant FEPs); changes in the level-of-detail of FEP descriptions; and reevaluation of FEP screening decisions, arguments, and TSPA dispositions. Changes from the FEP list used for the TSPA-SR evaluation include: revising the descriptions, deleting and reassigning FEPs, and creating and assigning new FEPs. The reorganization and reevaluation of the DE FEPs for TSPA-LA has resulted in a revised list of 20 DE FEPs, as extracted from the LA FEP list (DTN: MO0307SEPFEPS4.000 [DIRS 164527]) and as modified during the review process for this analysis report. These revisions and changes are discussed in Section 6.1.1 and are summarized in Table 6-1.

For a DE FEP that is *Included* in the TSPA-LA, this analysis report summarizes how the DE FEP is included and addressed in the TSPA-LA model, and cites the AMRs that fully provide the technical basis and detailed description of disposition of the DE FEP. For a DE FEP that is *Excluded* from the TSPA-LA, this analysis report identifies the basis for the screening decision (i.e., low probability, low consequence, or by regulation) and discusses the technical basis that supports that decision. In some cases, where an included or excluded DE FEP covers multiple technical areas and is shared with other FEP AMRs, this report may provide only a partial technical basis for the screening of the FEP. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP AMRs.

In cases where a FEP covers multiple technical areas and is shared with other FEP AMRs, this analysis report provides only a partial technical basis for the screening decision as it relates to the initiating event. For those cases, the scope and intent of this FEP is only to define the probability of the event, describe the post-event conditions of the repository (e.g., in-drift conditions following an igneous intrusion), or quantify the event (e.g., amplitude of fault displacement or ground motion hazard). In some cases, a summary of the related information in sharing FEP AMRs is cited. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP AMRs. Each DE FEP may, as indicated in parentheses in the list below, be shared with one or more of the analysis reports addressing the FEPs for the unsaturated zone (UZ), the saturated zone (SZ), the engineered barrier system (EBS), waste form, and the biosphere. The sharing FEP AMRs are listed in DTN: MO0307SEPFEPS4.000 [DIRS 164527]. The following list of 20 DE FEPs for TSPA-LA, and the sharing FEPs AMRs, results from the above-mentioned activities and includes:

Seismic - Related FEPs:

- 1.2.01.01.0A Tectonic activity—large-scale (DE only)
- 1.2.02.03.0A Fault displacement damages EBS components (DE, EBS)
- 1.2.03.02.0A Seismic ground motion damages EBS components (DE, EBS)
- 1.2.03.02.0B Seismic-induced rockfall damages EBS components (DE, EBS)
- 1.2.03.02.0C Seismic-induced drift collapse damages EBS components (DE, EBS)
- 1.2.03.02.0D Seismic-induced drift collapse alters in-drift thermohydrology (DE, EBS)
- 1.2.03.03.0A Seismicity associated with igneous activity (DE only)
- 1.2.10.01.0A Hydrologic response to seismic activity (DE, US, SZ)
- 2.2.06.01.0A Seismic activity changes porosity and permeability of rock (DE, UZ, SZ)
- 2.2.06.02.0A Seismic activity changes porosity and permeability of faults (DE, UZ, SZ)
- 2.2.06.02.0B Seismic activity changes porosity and permeability of fractures (DE, UZ, SZ)
- 2.2.06.03.0A Seismic activity alters perched water zones (DE, UZ)

Igneous-Related FEPs:

- 1.2.04.02.0A Igneous activity changes rock properties (DE, UZ, SZ)
- 1.2.04.03.0A Igneous intrusion into repository (DE only)
- 1.2.04.04.0A Igneous intrusion interacts with EBS components (DE, Waste Form)
- 1.2.04.05.0A Magma or pyroclastic base surge transports waste (DE only)
- 1.2.04.06.0A Eruptive conduit to surface intersects repository (DE only)
- 1.2.04.07.0A Ashfall (DE, Biosphere)
- 1.2.04.07.0C Ash redistribution via soil and sediment transport (DE only)
- 1.2.10.02.0A Hydrologic response to igneous activity (DE, UZ, SZ)

1.3 SCIENTIFIC ANALYSIS USE AND LIMITATIONS

The intended use of this analysis report is to provide FEP screening information for a project-specific FEP database and to promote traceability and transparency for FEP dispositions. This report also is intended to be used as the source documentation and to provide the technical basis and supporting arguments for exclusion of DE FEPs from the TSPA-LA model. For shared FEPs, this report may provide only the DE-related portion of the technical basis. A short summary of the related discussions in other analysis reports is provided, as appropriate. For the DE FEPs that are designated for inclusion into the TSPA-LA model, the manner in which the

FEP has been included, the associated list of parameters, and any uncertainty considerations are provided in the cited analysis and model reports.

The following limitations apply to this report:

- Because this report cites supporting AMRs, the limitations inherently include any limitations or constraints described in the supporting AMRs.

- In some cases where DE FEPs are shared, the scope of this analysis report is limited to providing only a quantification of the initiating DE (e.g., the amplitude of fault displacements and ground motions, or in some cases, probability of a given event or the resulting in-drift conditions). This is particularly germane for FEPs dealing with the response of the EBS components to fault displacement and ground motion. The discussion of the remainder of the technical basis is deferred to the technical AMRs, because analysis of the consequence for engineered features of the repository are better addressed by subject matter experts (SMEs) familiar with the performance of engineered components of the repository.

- For screening purposes, this report generally uses mean values of probabilities, mean amplitude of events, or mean value of consequences as a basis for reaching a decision to include or exclude. Mean values are determined based on the range of possible values.

- The results of the FEP screening presented herein are specific to the repository design and processes for YMP available at the time of the TSPA-LA. Changes in direct inputs listed in Section 4.1, in baseline conditions used for this evaluation, or in other subsurface conditions will need to be evaluated to determine whether the changes are within the limits stated in the FEP evaluation. Engineering and design changes are subject to evaluation to determine whether there are any adverse impacts to safety, as codified at 10 CFR 63.73 and in Subparts F and G (66 FR 55732 [DIRS 156671]). (See also the requirements at 10 CFR 63.44 and 10 CFR 63.131 (66 Federal Register (FR) 55732 [DIRS 156671]).

2. QUALITY ASSURANCE

This work constitutes an analysis report that has been prepared according to AP-SIII.9Q, *Scientific Analyses*, and in accordance with related procedures and guidance documents as outlined in the TWP and Section 2 of this report.

Development of this analysis report and the supporting analyses has been determined to be subject to the Office of Civilian Radioactive Waste Management (OCRWM) quality assurance (QA) program (BSC 2002, Section 8.3, Work Package ADEM06 [DIRS 161737]). Approved QA procedures identified in the TWP (BSC 2002, Section 4.3 [DIRS 161737]) have been used to conduct and document the activities described in this report. The TWP also identifies that no special controls beyond current work processes and procedures for the electronic management of data were applicable (BSC 2002, Section 8.3 [DIRS 161737]) during the analysis and documentation activities.

The report contributes to the analysis and modeling used to support performance assessment. The DE FEPs documented herein have the potential to affect the performance of the natural barriers and various EBS components but do not themselves qualify as "Q-List" items. The evaluations and conclusions do not directly impact engineered features important to safety, as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q*-List.

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3. COMPUTER SOFTWARE AND MODEL USAGE

This analysis report uses no computational software; therefore, the analysis is not subject to software controls. The analyses and arguments presented herein are based on guidance and regulatory requirements, results of analyses presented and documented in other analysis reports, or other technical literature. Software and models used in the supporting documents are cited, as appropriate, in this report for traceability and transparency purposes but were not used in its development.

This analysis report was developed using only commercial off-the-shelf software (Microsoft® *Word 2000*) for word processing, which is exempt from qualification requirements in accordance with AP-SI.1Q *Software Management* (Section 2.1). No additional applications (routines or macros) were developed using this commercial off-the-shelf software.

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4. INPUTS

The data, product output, technical information, and references used in this report were obtained from controlled source documents and other appropriate sources in accordance with the controlling procedure AP-3.15Q, *Managing Technical Product Inputs*.

4.1 DIRECT INPUTS

The procedure for managing inputs categorizes technical product inputs as either Direct Input or Reference Only. Direct Input constitutes the input used to address safety and waste isolation issues. Direct Input is further classified as Data-Qualified or as Other Direct Technical Product Input, which is further subdivided as Product Output, Technical Information, To Be Verified (TBV) data or factual information, Preliminary Technical Information (also denoted as TBV), Assumptions, or Software.

No assumptions needing further confirmation are cited in this report. Software and models developed in the supporting documents are cited for traceability and transparency purposes; however, they were not used directly in development of the analyses and arguments presented herein.

4.1.1 Data-Qualified and Factual Information

This section identifies qualified data and other factual information used to justify exclusion of DE FEPs. The governing procedure, AP-3.15Q , defines qualified data. Table 4-1 lists qualified data and includes data and information developed for or by the Project, which are statused as to be verified (TBV). The TBV information is noted in Table 4-1 with an asterisk. In these cases, the factual information comprises site characterization samples and values that were collected prior to QA program implementation or collected by other entities that may or may not have had an approved QA program. Table 4-1 lists all Document Tracking Numbers (DTN) cited to justify the FEP exclusion regardless of qualification status.

Table 4-1. Data-Qualified and Factual Information Used for DE FEP Exclusion

Analysis Report Section	Data Name	Data Description	DTN / Data Source
		Seismic–Related FEPs	
6.2.1.1	Dip-steepening of lithologic units	No more than 20°: based on Bow Ridge fault, faulted tuffs dip steeply to the east (20° to 30°) into the graben(s) relative to the beds farther west in the unfaulted areas (8° to 15°)	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Day et al. 1996, p. 2-7 [DIRS 124302]
	Critical angle of tilting	About 25°	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Fridrich et al. 1996, pp. 2-21 and 2-22 [DIRS 105086]
	Source depth of basaltic magma	About 60 km	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Crowe et al. 1995, pp. 5-2, 5-5, and Figure 5.1 [DIRS 100110]

Table 4-1. Data-Qualified and Factual Information Used for DE FEP Exclusion (Continued)

Analysis Report Section	Data Name	Data Description	DTN / Data Source
Seismic–Related FEPs (continued)			
6.2.1.8	Water level rise at Yucca Mountain due to earthquakes	Fluctuations range from 90 cm related to a 7.5 magnitude earthquake near Landers, CA, to 20 cm for a second quake of 6.6 magnitude near Big Bear Lake, CA.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *O'Brien 1993 [DIRS 101276]
	Water level rise due to seismic pumping	Results of evaluation indicate at most a rise of a few tens of meters	DTN: MO0310INPDEFEP.000 [DIRS 165880] *National Research Council 1992 [DIRS 105162]
6.2.1.10, 6.2.1.11	Results of the Yucca Mountain Probabilistic Seismic Hazard Analysis (PSHA)	Mean displacement in intact rock: less than 0.1 cm for a 10^{-8} annual-exceedance probability Mean value for displacement along the Solitario Canyon fault of 10 m	DTN: MO0004MWDRIFM3.002 [DIRS 149092] CRWMS M&O 1998, p. 8-7 and Figure 8.3 [DIRS 103731] Mean displacements at selected points taken from files: ./displ/tot_haz/s7d.frac_mean.gz ./displ/tot_haz/s8d.frac_mean.gz
6.2.1.11	Results of the Yucca Mountain Probabilistic Seismic Hazard Analysis (PSHA)	Mean displacement on existing fractures: less than 1 cm for a 10^{-8} annual-exceedance probability	DTN: MO0004MWDRIFM3.002 [DIRS 149092] CRWMS M&O 1998, Figures 8.10 and 8.13 [DIRS 103731] Mean displacements at selected points taken from files: ./displ/tot_haz/s7c.frac_mean.gz ./displ/tot_haz/s8c.frac_mean.gz
Igneous-Related FEPs			
6.2.2.1	Field observations for intruded dikes at Paiute Ridge	Fused wall rock extends only 20-100 cm into the wall rock. Cooling joints extend 10-20 cm into the wall rock. Evidence of interaction with faults. Presence of platy texture along margin of dike, and vesicles in the welded tuff.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Carter-Krogh and Valentine (1996, pp. 7 and 8 [DIRS 160928])
	Width of zone of alteration around intruding dikes	Limited to a few meters to a few hundred meters for observed dikes. Analogue site at Nevada Test Site indicates less than 10 m.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *CRWMS M&O 1998, pp. 5-41, 5-42, 5-57, 5-71 and 5-72 [DIRS 105347]

Table 4-1. Data-Qualified and Factual Information Used for DE FEP Exclusion (Continued)

Analysis Report Section	Data Name	Data Description	DTN / Data Soure
Igneous-Related FEPs (continued)			
6.2.2.4	Extent of base surge deposits	Base surge deposits at Lathrop Wells Cone extend no more than 1 km.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Crowe et al. (1986, p. 32-34 [DIRS 101532])
	Relative frequency of crater depths for known hydrovolcanic craters.	Mean value of 91 m and maximum depth of 365 m. Crater depths greater than 215 m occur approximately 15 percent of the time.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Crowe et al. (1986,Figure 19 [DIRS 101532])
	Topographic elevations at select points in the eastern part of the repository	Coordinates and elevations selected included <u>Northing Easting</u> <u>Elevations:</u> 775,000 565,500 1262 m 771,300 564,100 1267 m 769,300 563,500 1283 m	DTN MO0002SPATOP00.001 [DIRS 152643] (for grid node coordinates shown)
6.2.2.8	Field observations for intruded dikes at Paiute Ridge	Fused wall rock extends only 20-100 cm into the wall rock. Cooling joints extend 10-20 cm into the wall rock. Evidence of interaction with faults. Presence of platy texture along margin of dike, and vesicles in the welded tuff.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Carter-Krogh and Valentine (1996, pp. 7 and 8 [DIRS 160928]
	Width of zone of alteration around intruding dikes	Limited to between a few meters to a few hundred meters for observed dikes. Analogue site at Nevada Test Site indicates less than 10 m.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *CRWMS M&O 1998, pp. 5-1, 5-2, 5-41, 5-42, 5-57 5-71, and 5-72 [DIRS 105347]
	Potential for development of hydrothermal systems	Analogue site indicates thermal transfer to surrounding rock is minimal.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *CRWMS M&O 1998, p. 5-57 [DIRS 105347]
	Influence of soil thickness on infiltration	Soils exceeding 6 m thickness eliminate the infiltration of water to the soil/bedrock contact except in channels.	DTN: MO0310INPDEFEP.000 [DIRS 165880] *Flint and Flint 1995 [DIRS 100394]

Note: Citations marked with an * were classified as TBV as part of DTN MO0310INPDEFEP.000 [DIRS 165880] per the governing procedure. In accordance with AP-3.15Q, data that need to be verified comprise "factual information comprising site characterization samples and values that were collected prior to QA program implementation or collected by other entities that do not or did not have an approved QA program." If the data cannot be verified it will be qualified or replaced as part of the data confirmation process.

4.1.2 Product Outputs

Where possible, other direct input has been obtained from controlled source documents (product output) using the appropriate document identifiers or records system accession numbers. Sources include, but are not limited, to YMP-prepared databases, drawings, and other technical documents.

4.1.2.1 YMP FEP Database and Included FEPs

The FEP list used for the TSPA-LA screening documented in this report was extracted from DTN: MO0307SEPFEPS4.000 [DIRS 164527]. The list of FEPs was reviewed for possible DE FEPs and evaluated for appropriateness of use and comprehensiveness and was determined to be comparable and traceable to the list of DE FEPs presented for site recommendation (SR) and suitable for use as a preliminary list of DE FEPs to be further evaluated for the LA. Modifications to the DE FEP list for the LA are detailed in Section 6.1.1.

The process- and model-level AMRs provide a list of included FEPs and discuss the technical basis for inclusion. The list of included FEPs is taken from supporting AMRs and is considered as direct input for this report. Table 4-2 lists the included FEPs and the source AMRs wherein the technical basis for including the FEP is discussed. However, the technical basis for inclusion given in the supporting AMRs and cited in the FEP discussions in Section 6.2 is considered as "reference only" material within the context of this report. Furthermore, data sets developed in those process- and model-level AMRs are referenced for transparency; unless the numeric values are used directly in a calculation or screening decision in this report, the data sets are not considered as direct input and are not addressed in this section. The supporting AMRs for included FEPs are discussed briefly in Section 6.1.3. Tables 6-2 and 6-3 list the documents that include DE FEPs and describe the DE-related conceptual models included in TSPA-LA.

Table 4-2. Included DE FEPs and Supporting AMRs

Analysis Report Section	TSPA-LA FEP Number	TSPA-LA FEP Name	Supporting AMR Documentation
Seismic-Related FEPs			
6.2.1.2	1.2.02.03.0A	Fault displacement damages EBS components	BSC 2003, Table 4 [DIRS 161812]
6.2.1.3	1.2.03.02.0A	Seismic ground motion damages EBS components	BSC 2003, Table 4 [DIRS 161812]
6.2.1.4	1.2.03.02.0B	Seismic-induced rockfall damages EBS components	BSC 2003, Table 4 [DIRS 161812]
6.2.1.6	1.2.03.02.0D	Seismic-induced drift collapse alters in-drift thermohydrology	This FEP is derived from 2.1.07.02.0A Drift Collapse, see Table 6-1 of this report for additional clarification. Supporting documentation for this new FEP is taken from BSC 2003, Table 4 [DIRS 161812] from FEP 1.2.03.02.0D.
6.2.1.7	1.2.03.03.0A	Seismicity associated with igneous activity	BSC 2003, Table 6.4.2 [DIRS 166274]

Table 4-2. Included DE FEPs and Supporting AMRs (Continued)

Analysis Report Section	TSPA-LA FEP Number	TSPA-LA FEP Name	Supporting AMR Documentation
Igneous-Related FEPs			
6.2.2.2	1.2.04.03.0A	Igneous intrusion into repository	BSC 2003, Table 9 [DIRS 163769]; BSC 2003, Table 5 [DIRS 161838]; BSC 2003, Table 4 [DIRS 165923]
6.2.2.3	1.2.04.04.0A	Igneous intrusion interacts with EBS components	BSC 2003 Table 5 [DIRS 161838]; BSC 2003 Table 4 [DIRS 165923]; BSC 2003, Table 3 [DIRS 161851]; BSC 2003, Table 6-1 [DIRS 165002]
6.2.2.5	1.2.04.06.0A	Eruptive conduit to surface intersects repository	BSC 2003 Table 5 [DIRS 161838]; BSC 2003 Table 3 [DIRS 161851]; BSC 2003, Table 6 [DIRS 161840]
6.2.2.6	1.2.04.07.0A	Ashfall	BSC 2003 Table 5 [DIRS 161838]; BSC 2003, Table 6 [DIRS 161840]
6.2.2.7	1.2.04.07.0C	Ash redistribution via soil and sediment transport	BSC 2003 Table 5 [DIRS 161838]

4.1.2.2 Information Exchange Drawings

Information exchange drawings (IEDs) or design documents used to provide technical information for DE FEP exclusion include those shown in Table 4-3.

Table 4-3. Drawings and Design Documents Used as Basis for DE FEP Exclusion

Analysis Report Section	Type of Information	Value			IED Reference
Seismic-Related FEPs					
(None Used)					
Igneous-Related FEPs					
6.2.2.4	Elevation of drift ends in the eastern repository	Maximum of Elevation of Drifts Within Block 2E 1042 m for Drift 2-1E 1055 m for Drift 2-12E 1063 m for Drift 2-19E			800-IED-EBSO-00402-000-00B [DIRS 161727]
	Approximate drift end coordinates (ft) from State Plane Coordinate grid	Drift 2-1E 2-12E 2-19E	Northing 775,000 771,300 769,300	Easting 565,500 564,100 563,500	800-IED-EBSO-00401-000-00C [DIRS 162289]

4.1.2.3 Product Output and Preliminary Technical Information Used for DE FEP Exclusion

Table 4-4 lists product output from supporting AMRs that is specifically cited to exclude DE FEPs.

Table 4-4. Specific Product Output Used for DE FEP Exclusion

Analysis Report Section	Type of Input	Value	Data Source
Seismic–Related FEPs			
6.2.1.1	Extensional strain rate for Basin and Range and relative seismicity Time of peak tectonism	Low to moderate rate, with low to moderate historical seismicity. Experiencing declining strain rates. 12.7 to 11.6 million years ago	CRWMS M&O 2000, Section 6.3.2 [DIRS 142321]
6.2.1.1, 6.2.1.2	Local fault slip rates	0.001–0.03 mm/yr	CRWMS M&O 2000, Table 6 [DIRS 142321]
6.2.1.5	Volume and number of blocks for seismic-induced drift collapse in non-lithophysal zone. Seismic-induced collapse of lithophysal zone	46 blocks with total volume of 50.6 m3, and maximum block size of 7.63 m3 for 10-7 ground motions in non-lithophysal zone. Collapse is total at 10–6 ground motions	BSC 2003, Tables 31 and 33 [DIRS 162711] BSC 2003, Section 6.4.1.1 [DIRS 162711]
6.2.1.9	Flowing interval spacing in SZ Method of inclusion of fractures	Overestimation is conservative Conceptual approach	BSC 2001, Section 1 [DIRS 156965] BSC 2003, Section 6.2.5 [DIRS 164870]
6.2.1.1, 6.2.1.8, 6.2.1.9, 6.2.1.10 6.2.1.11	Sensitivity analysis for change in fracture aperture	Results of sensitivity analysis	CRWMS M&O 2000, Section 7 [DIRS 151953]
6.2.1.11	Extensional strain rate for Basin and Range and relative seismicity	Low to moderate rate, with low to moderate historical seismicity. Experiencing declining strain rates.	CRWMS M&O 2000, Section 6.3.2 [DIRS 142321]
6.2.1.12	Perched water zone calculation	Volume of water in fracture space of perched water zone compared to annual flux	BSC 2003 Attachment I [DIRS 164873]
Igneous–Related FEPs			
6.2.2.1	Most commonly assigned dike orientation and highest probabilities of dike orientation. Sensitivity analysis for change in fracture aperture. Direction of maximum transmissivity for horizontal anisotropy	Centers around N30E, and highest probabilities for azimuths of between 20 and 40 degrees Results of sensitivity analysis The direction of maximum transmissivity may be about N 15 E	BSC 2003, Section 6.3.2 and Table 18 [DIRS 163769] CRWMS M&O 2000, Section 7 [DIRS 151953] BSC 2003, Section 6.2.5.10 [DIRS 164870]
6.2.2.4	Extent of lava flows and other surface flow related volcanic deposits Depth of Repository below surface	Basalt flows extend no more than 1 km from the scoria cone Surface topography contours above the repository	BSC 2003, Section 6.2 [DIRS 163769] BSC2002, Figure 1 [DIRS 159124]

Table 4-4. Specific Product Output Used for DE FEP Exclusion (Continued)

Analysis Report Section	Type of Input	Value	Data Source
Igneous–Related FEPs (continued)			
6.2.2.8	Most commonly assigned dike orientation and highest probabilities of dike orientation.	Centers around N30E, and highest probabilities for azimuths of between 20 and 40 degrees	BSC 2003, Section 6.3.2 and Table 18 [DIRS 163769]
	Sensitivity analysis for change in fracture aperture.	Results of sensitivity analysis	CRWMS M&O 2000, Section 7 [DIRS 151953]
	Direction of maximum transmissivity for horizontal anisotropy	The direction of maximum transmissivity is about N15E	BSC 2003, Section 6.2.5.10 [DIRS 164870]
	Relation of soil thickness to infiltration rates	Thicker soils tend to decrease infiltration	USGS 2001, Section 6.1.2 [DIRS 160355]

4.1.3 Other Technical Information

For this report, other technical information consists of CFR citations and non-YMP specific technical journal articles.

4.1.3.1 Regulations that Provide Direct Input for FEP Screening

The nature of the FEP screening arguments and TSPA dispositions is such that the NRC regulations (and the corresponding and incorporated portions of 40 CFR 197) serve as direct inputs for determining whether a FEP can be excluded from further considerations.

Regulatory Basis for Screening FEPs on Low Probability–The application of the low-probability threshold for FEP screening is further described in Section 6.1.2. For probability, the direct input is expressed as:

One chance in 10,000 of occurring over 10,000 years	10 CFR 63.114(d) (66 FR 55732 [DIRS 156671]).

The EPA provides essentially the same criterion in 40 CFR 197.36 (66 FR 32074 [DIRS 155216]):

> The DOE's performance assessments should not include consideration of very unlikely features, events, or processes, i.e., those that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal. The NRC shall exclude unlikely features, events, and processes, or sequence of processes from the assessments for the human intrusion and ground water protection standards. The specific probability of the unlikely features, events, and processes is to be specified by NRC.

The low-probability criterion is stated as less than one chance in 10,000 of occurring in 10,000 years ($10^{-4}/10^{4}$ yr). As explained in Assumption 5.1, this is assumed equivalent to a 10^{-8} annual-exceedance probability.

Regulatory Basis for Screening FEPs on Low Consequence–The application of the low-consequence arguments for FEP screening is described further in Section 6.1.2 of this report. For low consequence, the direct input is expressed as:

Would be significantly changed by its omission	10 CFR 63.114 (e and f) (66 FR 55732 [DIRS 156671]).

The terms "significantly changed" and "changed significantly" are undefined terms in the NRC and EPA regulations. The absence of significant change, or an insignificant change, if the FEP is omitted, is inferred for FEP-screening purposes to be equivalent to having no effect or negligible effect.

The low-consequence criteria described in 10 CFR 63.114(e and f) (66 FR 55732 [DIRS 156671]), are provided as follows:

> Provide the technical basis for either inclusion or exclusion of specific features, events, and processes in the performance assessment. Specific features, events, and processes must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, would be significantly changed by their omission.
>
> Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, would be significantly changed by their omission.

The EPA provides essentially the same criteria for low consequence at 40 CFR 197.36 (66 FR 32074 [DIRS 155216]):

> In addition, unless specified in NRC regulations, the DOE's performance assessments need not evaluate the impacts resulting from any features, events and processes or sequences of events or processes with a higher chance of occurrence if the results of the performance assessments would not be changed significantly.

In addition to the regulatory FEP screening criteria, the characteristics, definitions, and concepts given in the regulations also provide direct input for screening the DE FEPs "by regulation."

Regulatory Basis for Screening FEPs By Regulation–Regulations also address required characteristics, definitions, and concepts, which may serve as the basis for exclusion of FEPs by regulation, as further discussed in Section 4.2. Because the regulatory concepts and definitions are used as part of the technical basis for an exclude decision, the relevant regulatory cites are listed and addressed as direct input and listed in Table 4-5.

By specifying characteristics, concepts, and definitions, the regulations serve as de facto inputs used for screening related FEPs. For the DE FEPs, these criteria include the characteristics, concepts, and definitions pertaining to the reference biosphere, the geologic setting, and the RMEI. Also pertinent are characteristics, concepts, and definitions that must be considered during the FEP screening, such as the areal extent of the accessible environment and of the controlled area, and the spatial relationship to the distance from the repository to the RMEI. These terms define or imply geographical limits or constrain the consideration of the future state of the reference biosphere and/or geologic setting.

Table 4-5. Direct Input from Regulations Used for DE FEP Exclusion

Analysis Report Section	Type of Input	Value	Data Source
Igneous-Related FEPs			
6.2.2.4	Location of the RMEI	Within the accessible environment	10 CFR 63.312 (a, b, c, d, e) (66 FR 55732 [DIRS 156671])
	Definition of the accessible environment and limit of controlled area	No closer than 18 km to the south in direction of groundwater flow and over a contaminated groundwater plume No greater than 5 km in any direction other than direction of groundwater flow	10 CFR 63.302 (66 FR 55732 [DIRS 156671]).
6.2.2.8	Characteristics of reference biosphere	DOE should not project changes to the biosphere or than climate	10 CFR 63.305 (b and c) (66 FR 55732 [DIRS 156671])
	Definition of reference biosphere	DOE must vary factors related to geology, hydrology and climate Definition specifically includes topography and soils	10 CFR 63.2 (66 FR 55732 [DIRS 156671])

Reasonably Maximum Exposed Individual–The characteristics of the RMEI to be used in exposure calculations are given at 10 CFR 63.312 (a, b, c, d, and e) (66 FR 55732 [DIRS 156671], and also at 40 CFR 197.21(a, b, and c) (66 FR 32074 [DIRS 155216])). Pertinent to the DE FEPs is the criterion in 10 CFR 63.312(a) (66 FR 55732 [DIRS 156671]) that the RMEI:

> Lives in the accessible environment above the highest concentration of radionuclides in the plume of contamination.

For the DE FEPs, the distance from the repository to the receptor is a criterion of primary interest. From 10 CFR 63.302 (66 FR 55732 [DIRS 156671] and also at 40 CFR 197.12 (66 FR 32074 [DIRS 155216])):

> Accessible environment means any location outside the controlled area.

Moreover, the controlled area is:

(1) The surface area identified by passive institutional controls that encompasses no more than 300 square kilometers. It must not extend farther:

i. South than 36° 40′ 13.6661″ north latitude, in the predominant direction of ground water flow; and

ii. Than five kilometers from the potential repository footprint in any other direction; and

(2) The subsurface underlying the surface area.

The preamble in the regulations for 40 CFR 197 (66 FR 32074, p. 32117 [DIRS 155216]) states further that:

> If fully employed by DOE, and based on current repository design, the controlled area could extend approximately 18 km in the direction of ground water flow (presently believed to be in a southerly direction) and extend no more than 5 km from the repository footprint in any other direction.

Furthermore, the NRC states in the preamble to 10 CFR Part 63 (66 FR 55732, p. 55753 [DIRS 156671]) that:

> At distances less than 18 km to the Yucca Mountain site, there is evidence of intermittent or temporary occupation in modern (historic) times in and around the site—for prospecting or ranching. … There also are a number of Native American archeological sites reported throughout NTS closer to the site than the Lathrop Wells location. However, the literature indicates that these were never permanently occupied, and most were abandoned by the end of the 1800's. Overall, the literature suggests many reasons for the absence of permanent inhabitation at distances much closer than 18 km to the site - unfavorable agricultural conditions, inhospitable terrain, the scarcity of mineral resources, and limitations on water availability.

These concepts are pertinent because the distance from the repository is of primary interest in evaluating potential exposure risk from igneous-related releases. These definitions and concepts indicate that the RMEI is located no closer than 18 km to the south in the direction of groundwater flow and over a contaminated groundwater plume (in accordance with 10 CFR 63.312 (a, b, c, d, and e) 66 FR 55732 [DIRS 156671]), and that the limit of the controlled area is no greater than 5 km from the repository in any other direction (as specified at 10 CFR 63.302 66 FR 55732 [DIRS 156671]). The location and characteristics of the RMEI for the nominal scenario also are used for the disruptive scenario. The location of the RMEI is also of importance for determining exposure and is part of the technical basis for included FEPs.

Reference Biosphere and Geologic Setting–Per 10 CFR 63.2 (66 FR 55732 [DIRS 156671]), the *reference biosphere* is defined as:

> Reference biosphere means the description of the environment inhabited by the reasonably maximally exposed individual. The reference biosphere comprises the set of specific biotic and abiotic characteristics of the environment, including, but not necessarily limited to, climate, topography, soils, flora, fauna, and human activities.

Characteristics pertaining to the reference biosphere are presented in 10 CFR 63.305(a) and (b) (66 FR 55732 [DIRS 156671]).

(a) Features, events, and processes that describe the reference biosphere must be consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain site.

(b) DOE should not project changes in society, the biosphere (other than climate), human biology, and increase or decreases of human knowledge or technology. In all analyses done to demonstrate compliance with this part, DOE must assume that all those factors remain constant as they are at the time of license application.

The evolution of the reference biosphere and the geologic setting are linked by the NRC at 10 CFR 63.305(c) ((66 FR 5732 [DIRS 156671]; also by the EPA at 40 CFR 197.15 (66 FR 32074 [DIRS 155216])).

(c) DOE must vary factors relating 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 in the next 10,000 years.

The EPA language varies slightly by stating *reasonable assumptions of the changes in these factors*; in contrast, the NRC states *consistent with present knowledge of factor*s. Per 10 CFR 63.2 (66 FR 55732 [DIRS 156671]), the geologic setting is defined as:

> The geologic, hydrologic, and geochemical systems of the region in which a geologic repository is or may be located.

It is inferred from 10 CFR 63.114(a) that the evolution of the geologic setting is to be based on data related to Yucca Mountain and the surrounding regions, inclusive of disruptive process and events. Although not specifically defined in 10 CFR Part 63, as applied to the geologic setting and for purposes of this report, "disruptive events" is inferred to mean seismic- and igneous-related events and processes. Other YMP project documents also list criticality and human intrusion as disruptive events. FEPs relevant to those considerations are beyond the scope of this document and are addressed separately.

By NRC's juxtaposition of the geologic and hydrologic factors within the subsection that is addressing the required characteristics of the reference biosphere, it is inferred that the listed regulatory constraint of changes in the reference biosphere also may be applicable to conditions that may occur at Yucca Mountain. In particular, it is inferred that changes in the biosphere (other than climate) that result from geologic disruptive events should not be projected. Changes to soil, topography, and flora are specifically identified in the definition of the referenced biosphere. This has particular application for FEPs related to changes triggered by an eruptive igneous event. Such an event has the potential to change or influence soil characteristics (e.g., water retention characteristics rates and distribution of percolation); alter the topography (e.g., changes to hillside slopes, creation of lava flows and volcanic cones, changes in drainage patterns, drainages clogging with eroding ash, drainages damming); and alter the surrounding flora. Seismic events also have the potential for altering topography. The application of this regulatory input with regard to changes in topography and soils stemming from an eruptive event, and more-restrictive alternative interpretations, are further discussed in Section 6.2.2.8.

Consequently, the required characteristics of the reference biosphere as defined by the regulations are considered as direct input for an exclusion argument, because constraint on changes to the reference biosphere contributes to, but does not constitute, the technical basis for exclusion of FEP 1.2.04.07.0C (Ash redistribution via soil and sediment transport).

4.1.3.2 Other Technical Information

No other technical information is cited as a direct input to the technical basis for excluding DE FEPs. Other corroborating citations are used as "reference only" material.

4.2 CRITERIA

This section addresses the various criteria relevant to the FEP screening process. These criteria stem from the applicable regulations at 10 CFR Part 63 (and also those incorporated from 40 CFR Part 197), as identified in the *Project Requirements Document* (PRD) (Canori and Leitner 2003 [DIRS 161770]). These criteria find expression as specific acceptance criteria presented by the NRC in the YMRP (NRC 2003 [DIRS 163274]). The correlation of the various regulations and criteria are listed in Table 4-6, and applications of the criteria for FEP screening are described in Section 4.1.3.1 of this report.

Table 4-6. Relationship of EPA and NRC Regulations to the PRD and the Acceptance Criteria from YMRP

Description of the Applicable Regulatory Requirement or Acceptance Criteria	40 CFR Part 197	10 CFR Part 63		
	Regulatory Citation [DIRS 155216]	Regulatory Citation [DIRS 156671]	Associated PRD [DIRS 161770]	Associated YMRP Criteria [DIRS 163274]
General Requirements and Scope Pertinent to FEP Screening				
Include data related to geology, hydrology, geochemistry, and geophysics	Not Applicable	63.114(a).	PRD-002/ T-015	2.2.1.2.1.3 Acceptance Criterion 1
Include information of the design of the engineered barrier system used to define parameters and conceptual models	Not Applicable	63.114(a)	PRD-002/ T-015	2.2.1.2.1.3 Acceptance Criterion 1
Account for uncertainties and variabilities in parameter values and provide the technical basis for parameter ranges, probability distributions, or bounding values	197.14	63.114(b)	PRD-002/ T-015	2.2.1.2.2.3 Acceptance Criteria 1 through 5

Table 4-6. Relationship of EPA and NRC Regulations to the PRD and the Acceptance Criteria from YMRP (Continued)

Description of the Applicable Regulatory Requirement or Acceptance Criteria	40 CFR Part 197	10 CFR Part 63		
	Regulatory Citation [DIRS 155216]	Regulatory Citation [DIRS 156671]	Associated PRD [DIRS 161770]	Associated YMRP Criteria [DIRS 163274]
FEP Screening Criteria				
Consider disruptive events, (specifically volcanism and seismicity)	Not Applicable	63.114 (a)	PRD-002/T-015	2.2.1.2.1.3 Acceptance Criterion 1
Provide justification and technical basis for excluding features, events, and processes specifically excluded by regulation	Not Applicable	Not Applicable	Not Applicable	2.2.1.2.1.3 Acceptance Criterion 2
Provide technical basis for either inclusion or exclusion of features, events, and processes. Provide justification and technical basis for those excluded based on probability	197.36	63.114(d) 63.342	PRD-002/ T-015 PRD-002/ T-034	2.2.1.2.1.3 Acceptance Criterion 2 2.2.1.2.2.3 Acceptance Criteria 1 through 5
Provide technical basis for either inclusion or exclusion of features, events. Provide justification and technical basis for those excluded based on lack of significant change in resulting radiological exposure or release to the accessible environment	197.36	63.114 (e and f) 63.342	PRD-002/ T-015 PRD-002/ T-034	2.2.1.2.1.3 Acceptance Criterion 2 2.2.1.2.2.3 Acceptance Criteria 1 and 2

The PRD (Canori and Leitner 2003 [DIRS 161770]) documents and categorizes the regulatory requirements and other project requirements, and provides a crosswalk to the various YMRP subprojects that are responsible for ensuring that the criteria have been satisfied in the LA. The regulatory requirements include criteria relevant to performance assessment activities in general, and to FEP-related activities as they pertain to performance assessment, in particular. Table 4-6 provides a crosswalk between the regulatory requirements, the PRD (Canori and Leitner 2003 [DIRS 161770]), and the acceptance criteria provided in the YMRP (NRC 2003, Sections 2.2.1.2 [DIRS 163274]).

The NRC will be reviewing the LA. The basis of the review is described in the YMRP (NRC 2003, Sections 2.2.1.2 [DIRS 163274]) and the bases for acceptance are stated as acceptance criteria. Table 4-6 correlates the acceptance criteria to the corresponding regulations and related PRDs as they pertain to FEP-related criteria. With only a few exceptions, the regulatory requirements at 40 CFR Part 197 (66 FR 32074 [DIRS 155216]) have been incorporated within the requirements of 10 CFR Part 63 (66 FR 55732 [DIRS 156671]). However, because the EPA regulations at 40 CFR Part 197 have not been superceded, this report has for completeness sake, retained cites in the individual FEP discussions. In a few instances, differences in the regulations are also cited to clarify a particular FEP concept, definition, or approach to a screening argument.

The cited YMRP criteria are provided in Table 4-7. The Acceptance Criteria for FEP screening presented in the YMRP echo the screening criteria of low probability and low consequence (NRC 2003 Section 2.2.1.2.1.3 Acceptance Criterion 2 *Screening of the Initial List of Features, Events, and Processes Is Appropriate* [DIRS 163274]), but also allow for exclusion of a FEP if the process is specifically excluded by the regulations. To wit:

> The U.S. Department of Energy has justified excluding each feature, event, and process. An acceptable justification for excluding features, events, and processes is that either the feature, event, and process is specifically excluded by regulation; probability of the feature, event, and process (generally an event) falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment.

The application of the FEP screening criteria is described further in Section 6.1.2. The regulatory criteria for determining low probability, determining low consequence, and the characteristics, definitions, and concepts used to screen on the basis of regulation are listed in Section 4.1.3.1 as Direct Input.

4.3 CODES AND STANDARDS

Applicable codes and standards include 10 CFR Part 63 (66 FR 55732 [DIRS 156671]). As applicable for FEP evaluation, portions of the NRC regulations (and the corresponding portions of the EPA regulation at 40 Part 197 that have been incorporated into the NRC regulations) may serve as direct input and/or criterion. Regulations used as direct input, including the criterion used for FEP screening, are cited in Section 4.1.3.1, and those providing criteria as identified in the PRD are cited in Section 4.2.

Table 4-7. YMRP Criteria and the DE FEPs AMR.

YMRP Criteria	Acceptance Criteria	Description	How Addressed in this Analysis Report
Scenario Analysis and Event Probability: Scenario Analysis (from Section 2.2.1.2.1.3 [DIRS 163274])	1. The Identification of a List of Features, Events, and Processes Is Adequate	The Safety Analysis Report contains a complete list of features, events, and processes, related to the geologic setting or the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers) that have the potential to influence repository performance. The list is consistent with the site characterization data. Moreover, the comprehensive features, events, and processes list includes, but is not limited to, potentially disruptive events related to igneous activity (extrusive and intrusive); seismic shaking (high-frequency-low magnitude, and rare large-magnitude events); tectonic evolution (slip on existing faults and formation of new faults); climatic change (change to pluvial conditions); and criticality.	The list of DE FEPs is provided in Section 1.2, and FEP Descriptions are provided in Section 6.2. See Section 6.1.1 for a description and origin of the DE FEP list and descriptions. This report does not address climatic change or criticality.
	2. Screening of the Initial List of Features, Events, and Processes Is Appropriate	The DOE has identified all features, events, and processes related to either the geologic setting or to the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers) that have been excluded.	See Table 7-1 for a list of excluded DE FEPs.
		The DOE has provided justification for those features, events, and processes that have been excluded. An acceptable justification for excluding features, events, and processes is that either the feature, event, and process is specifically excluded by regulation; probability of the feature, event, and process (generally an event) falls below the regulatory criterion; or omission of the feature, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment.	See the method and approach discussion provided in Section 6.1.2, and the individual justifications (by regulation, low probability, low consequence) for excluding FEPs provided in Section 6.2. The justification is also included in Table 7-1.
		The DOE has provided an adequate technical basis for each feature, event, and process, excluded from the performance assessment, to support the conclusion that either the feature, event, or process is specifically excluded by regulation; the probability of the feature, event, and process falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment.	See Section 6.2 for discussion of the individual FEP depositions and supporting technical bases.

Table 4-7. YMRP Criteria and the DE FEPs AMR (Continued)

YMRP Criteria	Acceptance Criteria	Description	How Addressed in this Analysis Report
Scenario Analysis and Event Probability: Identification of Events with Probability Greater than 10^{-8} Per Year (from Section 2.2.1.2.2.3 [DIRS 163274])	1. Events are Adequately Defined	Events or event classes are defined without ambiguity and used consistently in probability models, such that probabilities for each event or event class are estimated separately;	See the FEP Description provided for each FEP in Section 6.2 and the cited supporting AMRs.
		Probabilities of intrusive and extrusive igneous events are calculated separately. Definitions of faulting and earthquakes are derived from the historical record, paleoseismic studies, or geological analyses. Criticality events are calculated separately by location.	Probabilities related to igneous processes were developed based on the results of the expert elicitation documented in the PVHA (CRWMS M&O 1996 [DIRS 100116]), and further developed in Characterize Framework for Igneous Activity at Yucca Mountain Nevada ANL-MGR-GS-000001 REV 01 (BSC 2003 [DIRS 163769]). Separate probabilities are determined for an intrusive and an eruptive event. This report does not address criticality FEPs.
	2. Probability Estimates for Future Events Are Supported by Appropriate Technical Bases	Probabilities for future natural events are based on past patterns of the natural events in the Yucca Mountain region, considering the likely future conditions and interactions of the natural and engineered repository system. These probability estimates have specifically included igneous events, faulting and seismic events, and criticality events.	See FEP discussions in Section 6.2 for a list of naturally occuring seismic and igneous FEPs that are addressed. Probability discussions are provided for each FEP as needed. This analysis report does not address criticality FEPs.

Table 4-7. YMRP Criteria and the DE FEPs AMR (Continued)

YMRP Criteria	Acceptance Criteria	Description	How Addressed in this Analysis Report
Scenario Analysis and Event Probability: Identification of Events with Probability Greater than 10^{-8} Per Year from Section 2.2.1.2.2.3 [DIRS 163274])	3. Probability Model Support is Adequate	1. Probability models are justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, or natural analogs, including Yucca Mountain site data). Specifically: a. For infrequent events, the DOE justifies, to the extent possible, proposed probability models with data from reasonably analogous systems. Analog systems should contain significantly more events that the Yucca Mountain system, to provide reasonable evaluations of probability model performance. b. The DOE justifies, to the extent possible, the ability of probability models to reproduce the timing and characteristics (e.g., location and magnitude) of successive past events in the Yucca Mountain system; and c. The DOE probability models for natural events use underlying geologic basis (e.g., tectonic models) that are consistent with other relevant features, events, and processes evaluated, using Section 4.2.1.2.1.	Although the DE FEPs do not develop any probability estimates (aside from that for a hydrovolcanic event), the criterion is applicable to the probability estimates cited as a basis for inclusion. Annualized probabilities for various seismic events and fault displacements were determined using the expert elicitation process and are provided in the PSHA (CRWMS M&O 1998 [DIRS 103731]). Probabilities related to igneous processes were developed based on the results of the expert elicitation documented in the PVHA (CRWMS M&O 1996 [DIRS 100116]), and further developed in *Characterize Framework for Igneous Activity at Yucca Mountain Nevada* ANL-MGR-GS-000001 REV 01 (BSC 2003 [DIRS 163769]). The expert elicitations considered the issues of trying to determine probabilities from infrequent events and considered natural analogs, site data, and multiple alternative conceptual models including tectonic-based models.

Table 4-7. YMRP Criteria and the DE FEPs AMR (Continued)

YMRP Criteria	Acceptance Criteria	Description	How Addressed in this Analysis Report
Scenario Analysis and Event Probability: Identification of Events with Probability Greater than 10^{-8} Per Year (From Section 2.2.1.2.2.3 [DIRS 163274])	4. Probability Model Parameters Have Been Adequately Established	1. Parameters used in probability models are technically justified and documented by the DOE. Specifically: a. Parameters for probability models are constrained by data from the Yucca Mountain region and engineered repository system to the extent practical; b. The DOE appropriately establishes reasonable and consistent correlations between parameters: and c. Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of other sources, such as expert elicitation conducted in accordance with appropriate guidance.	Although the DE FEPs do not develop any probability estimates (aside from that for a hydrovolcanic event), the criterion is applicable to the probability estimates cited as a basis for inclusion. Annualized probabilities for various seismic events and fault displacements were determined using the expert elicitation process and are provided in the PSHA (CRWMS M&O 1998 [DIRS 103731]). Probabilities related to igneous processes were developed based on the results of the expert elicitation documented in the PVHA (CRWMS M&O 1996 [DIRS 100116]), and further developed in *Characterize Framework for Igneous Activity at Yucca Mountain Nevada* ANL-MGR-GS-000001 REV 01 (BSC 2003 [DIRS 163769]). The expert elicitations considered the issues of trying to determine probabilities from infrequent events and considered natural analogs, site data, and multiple alternative conceptual models including tectonic-based models.
Scenario Analysis and Event Probability: Identification of Events with Probability Greater than 10^{-8} Per Year (From Section 2.2.1.2.2.3 [DIRS 163274])	5. Uncertainty in Event Probability is Adequately Evaluated	1. Probability values appropriately reflect uncertainties. Specifically: a. The DOE provides a technical basis for probability values used, and the values account for the uncertainty in the probability estimates: and b. The uncertainty for reported probability values adequately reflects the influence of parameter uncertainty on the range of model results (i.e., precision) and the model uncertainty, as it affects the timing and magnitude of past events (i.e., accuracy).	Annualized probabilities for various seismic events and fault displacements were determined using the expert elicitation process and are provided in the PSHA (CRWMS M&O 1998 [DIRS 103731]). Probabilities related to igneous processes were developed based on the results of the expert elicitation documented in the PVHA (CRWMS M&O 1996 [DIRS 100116]), and further developed in *Characterize Framework for Igneous Activity at Yucca Mountain Nevada* ANL-MGR-GS-000001 REV 01 (BSC 2003 [DIRS 163769]). The expert elicitations considered the issues of uncertainty and included the uncertainties in the estimation of the probability distributions and estimation of the mean value.

5. ASSUMPTIONS

Only one generic assumption is used in screening the DE FEPs for the TSPA-LA.

Assumption 5.1: For DE FEPs, it is assumed that regulations expressed as probability criterion can also be expressed as an annual exceedance probability, which is defined as "the probability that a specified value will be exceeded during one year". More specifically, a stated probability screening criterion for very unlikely FEPs of one chance in 10,000 in 10,000 years ($10^{-4}/10^{4}$ yr) criterion is assumed equivalent to a 10^{-8} annual-exceedance probability or annual-exceedance frequency. A stated definition of unlikely events as having one chance in 10 in 10,000 years ($10^{-1}/10^{4}$ yr) of occurring is assumed equivalent to a 10^{-5} annual-exceedance probability or annual-exceedance frequency.

Justification: The definition of annual-exceedance probability is taken from *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000, Glossary [DIRS 142321]). The use of this assumption is also justified in the same document, which indicates that the behavior of the earth is generally Poissonian or random, and is the underlying assumption in all probabilistic hazard analyses.

The assumption of equivalence of annual-exceedance probability is appropriate if the possibility of an event is equal for any given year. This satisfies the definition of a Poisson distribution as " …a mathematical model of the number of outcomes obtained in a suitable interval of time and space, that has its mean equal to its variance …" (Merriam-Webster 1993, p. 899 [DIRS 100468]). This is inferred to mean that naturally occurring, infrequent, and independent events can be represented as stochastic processes in which distinct events occur in such a way that the number of events occurring in a given period depends only on the length of the time period.

In terms of application to the DE FEPs, all earthquakes and igneous events are considered as independent events with regard to size, time, and location. Although there may be cases where sufficient data and information exist to depart from this assumption, the Poissonian model is generally an effective representation of nature and represents a compromise between the complexity of natural processes, availability of information, and the sensitivity of results of engineering relevance. Consequently, for geologic processes that occur over long time spans, assuming annual equivalence over a 10,000-year period (a relatively short time span for geologic-related events) is reasonable and consistent with the basis of probabilistic hazard analyses. Therefore, no further confirmation is required.

Use: This assumption is used throughout Section 6.2 of this report, either implicitly or explicitly, for each of the FEPs addressed in the analysis model report (AMR) that cite to an annualized probability or annual-exceedance frequency.

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6. SCIENTIFIC ANALYSES

The following subsections discuss the DE FEP analyses. Section 6.1 discusses the method and approach used for the DE FEP screening process, as well as changes in the DE FEP list from TSPA-SR to the TSPA-LA. Section 6.1 identifies the source of the DE FEPs, describes the FEP screening process, and provides documentation of generic issues related to uncertainty, alternative conceptual models, and model and software issues. Section 6.2 addresses the technical basis for the DE FEP screening. The FEP analyses presented in Section 6.2 are appropriate because, as described in Section 6.1, they are consistent with the TSPA approach to satisfy the performance-assessment requirements. Additionally, these analyses are also appropriate because they address NRC's Acceptance Criteria in the YMRP (NRC 2003, Section 2.2.1.2 [DIRS 163274] and are previously discussed in Section 4.2 of this analysis report).

6.1 METHOD AND APPROACH

The method and approach for FEP screening for TSPA-LA is provided in generic form in *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966]) and the KTI Letter Report *Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [DIRS 165394]). As described in the aforementioned documents, the YMP TSPA has chosen to satisfy the performance-assessment requirements by adopting a FEP analysis and scenario development approach. A review of FEP analysis and scenario development in other radioactive waste disposal programs is also provided in BSC 2002 (Section 2 [DIRS 158966]) and includes a discussion of alternative FEP analysis methods and scenario development approaches. Regardless of the specific approach chosen to perform the screening, the screening process is, in essence, a comparison of the FEP against the criteria specified in Section 6.1.2 of this report.

6.1.1 DE FEPs Origin and Identification

The first step of FEP analysis is the identification of FEPs potentially relevant to the performance of the Yucca Mountain repository. FEP analysis of the DE FEPs uses the following definitions, as taken from Freeze et al. (2001, Appendix A [DIRS 154365]):

feature – an object, structure, or condition that has a potential to affect disposal system performance

event – a natural or anthropogenic phenomenon that has a potential to affect disposal system performance and that occurs during an interval that is short compared to the period of performance

process – a natural or anthropogenic phenomenon that has a potential to affect disposal system performance and that operates during all or a significant part of the period of performance.

The development of a comprehensive list of FEPs that are potentially relevant to performance of the Yucca Mountain repository is an ongoing, iterative process based on site-specific information, design, and regulations. The approach for developing an initial list of FEPs in support of TSPA–SR was documented in Freeze et al. (2001) [DIRS 154365]. The initial FEP list contained 328 FEPs, 176 of which were included in TSPA-SR models (CRWMS M&O 2000, Tables B-9 through B-17 [DIRS 153246]). Each FEP was assigned a unique YMP FEP database number, based on the Nuclear Energy Agency classification scheme (NEA 1992 [DIRS 100479]). The database number is the primary method for identifying FEPs, and consists of an eight-digit number having a format of ***x.x.xx.xx.xx.*** A similar numbering system is used for the TSPA-LA FEP list to provide a unique identifier for each FEP. In general, TSPA-SR FEPs with numbers ending in .00 were converted to TSPA-LA FEPs with numbers ending in .0A. Where splitting existing TSPA-SR FEPs created new FEPs for TSPA-LA, the new FEPs end in .0B, .0C, etcetera, to ensure traceability to their origin in TSPA-SR FEP list.

The results of the FEP activities planned in the TWP (BSC 2002 [DIRS 161737]) are documented in this analysis report as shown in Section 6.2. The revision of the FEPs organization and description was needed to implement *The Enhanced Plan for Features Events and Processes (FEPs) at Yucca Mountain* (BSC 2002 Section 3.2 [DIRS 158966]) and the KTI Letter Report *Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [DIRS 165394]). The particular revision efforts included:

- Review of the FEPs hierarchical system
- Re-categorization and redefinition of the DE FEPs as needed to provide a consistent and appropriate level of detail
- Review of updated analysis reports and model reports as needed, and integration with SMEs.

The reorganization and reevaluation of the TSPA-SR DE FEPs resulted in a revised list of 20 DE FEPs as extracted from the TSPA-LA FEP list (DTN: MO0307SEPFEPS4.000 [DIRS 164527]. Changes to the list, including additions and deletions during the review process, are given in Table 6-1. Table 6-1 summarizes the changes from TSPA–SR to the FEP organization and descriptions being used for TSPA-LA that appear in this report, and provides a comparison of the resulting screening decisions and report basis as provided in Section 6.2. Additional changes made in the descriptions from the cited DTN also are presented in Table 6-1 under the TSPA-LA description heading. The changes are shown italicized in Table 6-1.

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA

TSPA–SR FEP and Description	TSPA-SR SCREENING DECISION	TSPA-LA FEP and Description (*italics d*enote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	Basis for Change from TSPA-SR to TSPA-LA FEP list	Analysis Report Section
1.2.01.01.00 Tectonic activity—large scale Large-scale tectonic activity includes regional uplift, subsidence, folding, mountain building, and other processes related to plate movements. These tectonic events and processes could affect repository performance by altering the physical and thermo-hydrologic properties of the geosphere.	*Excluded*—Low Consequence	1.2.01.01.0A Tectonic activity—large scale Large-scale tectonic activity includes regional uplift, subsidence, folding, mountain building, and other processes related to plate movements. These tectonic events and processes could affect repository performance by altering the physical and *thermohydrologic* properties of the geosphere.	No changes in FEP Description between TSPA-SR and TSPA-LA FEP Lists.	6.2.1.1
1.2.02.01.00 Fractures Groundwater flow in the Yucca Mountain region and transport of any released radionuclides may take place along fractures. Transmissive fractures may be existing, reactivated, or newly formed fractures. The rate of flow and the extent of transport in fractures is influenced by characteristics such as orientation, aperture, asperity, fracture length, connectivity, and the nature of any linings or infills. Generation of new fractures and reactivation of preexisting fractures may significantly change the flow and transport paths. Newly formed and reactivated fractures typically result from thermal, seismic, or tectonic events.	*Included* for existing characteristics: *Excluded* for changes to characteristics—Low Consequence	Not Applicable—Not Assigned to DE FEPs for TSPA-LA.	FEP Description redefined to address existing characteristics only. Changes, reactivation, new fracture development due to disruptive events now addressed in a new FEP 2.2.06.02.0B Seismic activity changes porosity and permeability of fractures.	Not Applicable

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued)

TSPA–SR FEP and Description	**TSPA-SR SCREENING DECISION**	**TSPA-LA FEP and Description** (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	**Basis for Change from TSPA-SR to TSPA-LA FEP list**	**Analysis Report Section**
1.2.02.02.00 Faulting Faulting may occur due to sudden major changes in the stress situation (e.g., seismic activity) or due to slow motions in the rock mass (e.g., tectonic activity). Movement along existing fractures and faults is more likely than the formation of new faults. Faulting may alter the rock permeability in the rock mass and alter or short-circuit the flow paths and flow distributions close to the repository and create new pathways through the repository. New faults or the reactivation of existing faults may enhance the groundwater flow, thus decreasing the transport times for potentially released radionuclides.	*Included* for existing characteristics: *Excluded* for changes in fault properties and new faults—Low Consequence for changes to existing characteristics and low probability for new faults.	Not Applicable—Not Assigned to DE FEPs for TSPA-LA	FEP redefined to address existing characteristics only. Changes, reactivation, new fracture development due to disruptive events now addressed in a new FEP 2.2.06.02.0A Seismic activity changes porosity and permeability of faults.	Not Applicable
1.2.02.03.00 Fault movement shears waste container A fault intersects the repository and a line of waste containers. That intersection shears containers by virtue of the relative offset across the containers.	*Excluded*—Low Probability	1.2.02.03.0A Fault displacement damages EBS components A fault intersects drifts within the repository. The fault undergoes movement. The EBS components experience related movement or displacement such that performance is degraded by such things as tilting of components, component-to-component contact, or drip shield separation. Or, it could be as significant as failure due to the shearing of drip shields and waste packages by virtue of the relative offset across the fault, or as extreme as exhumation to the surface.	FEP redefined to address the potential for a variety of damage types to EBS components stemming from fault movement, rather than limiting discussion to only shearing and waste containers only.	6.2.1.2

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued).

TSPA–SR FEP and Description	TSPA-SR SCREENING DECISION	TSPA-LA FEP and Description (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	Basis for Change from TSPA-SR to TSPA-LA FEP list	Analysis Report Section
1.2.03.01.00 Seismic activity Seismic activity (i.e., earthquakes) could produce jointed-rock motion, rapid fault growth, slow fault growth or new fault formation, resulting in changes in hydraulic heads, changes in groundwater recharge or discharge zones, changes in rock stresses, and severe disruption of the integrity of the drifts (e.g., vibration damage, rockfall).	*Excluded for* indirect effects—Low Consequence *Excluded* for breaching of drip shield, and of the emplacement pallet and waste package—Low Consequence *Included*—for fuel-rod-cladding damage.	Not Applicable—Not Assigned to DE FEPs for TSPA-LA.	This FEP description was reevaluated and found to be too broad and redundant with other seismic-related FEPs and was deleted.	Not Applicable
1.2.03.02.00 Seismic vibration causes container failure Seismic activity causes repeated vibration of container and/or container-rock wall contact, damaging the container and its contents.	*Excluded* for breaching of drip shield, and of the emplacement pallet and waste package—Low Consequence *Included* for fuel-rod cladding damage.	1.2.03.02.0A Seismic ground motion damages EBS components Seismic activity causes repeated vibration of the EBS components (drip shield, waste package, *pallet*, and invert). This could result in severe disruption of the drip shields and waste packages through vibration damage or contact between EBS components. Such damage mechanisms could lead to degraded performance.	FEP Description was split to better address effects due to ground motion and rockfall effects as related to events, and each description was expanded to address EBS components in addition to waste containers. See also FEP 1.2.03.02.0B Seismic-induced rockfall damages EBS component.	6.2.1.3

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued)

TSPA–SR FEP and Description	TSPA-SR SCREENING DECISION	TSPA-LA FEP and Description (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	Basis for Change from TSPA-SR to TSPA-LA FEP list	Analysis Report Section
Not Applicable (NEW FEP)	Not Applicable	1.2.03.02.0B Seismic-induced rockfall damages EBS components Seismic activity could produce jointed-rock motion and/or changes in rock stress *leading to enhanced rockfall that could* impact drip shields, waste packages, or other EBS components.	NEW FEP. Previous FEP Description was split to better address effects due to ground motion and rockfall effects as related to events, and each description expanded to address EBS components in addition to waste packages. See also FEP 1.2.03.02.0A Seismic ground motion damages EBS components.	6.2.1.4
Not Applicable (NEW FEP)	Not Applicable	*1.2.03.02.0C Seismic-induced drift collapse damages EBS components* *Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse that could impact drip shields, waste packages, or other EBS components. Possible effects include both dynamic and static loading.*	NEW FEP. Previous TSPA-LA FEP Description for drift collapse was split to better address effects on EBS components and waste packages and better parallel the discussion of seismic-induced rockfall effects.	6.2.1.5
Not Applicable (NEW FEP)	Not Applicable	*1.2.03.02.0D Seismic-induced drift collapse alters in-drift thermohydrology* *Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse and/or rubble infill throughout part or all of the drifts. Drift collapse could impact flow pathways within the EBS, mechanisms for water contact with EBS components, and thermal properties within the EBS.*	NEW FEP. Previous TSPA-LA FEP Description for drift collapse was split to better address effects in the in-drift environment following drift collapse.	6.2.1.6
1.2.03.03.00 Seismicity associated with igneous activity Seismicity associated with future igneous activity in the Yucca Mountain region may affect repository performance.	*Excluded* for indirect effects—Low Consequence *Included* for fuel-rod cladding damage.	1.2.03.03.0A Seismicity associated with igneous activity Seismicity associated with future igneous activity in the Yucca Mountain region may affect repository performance.	No changes in FEP Description between TSPA-SR and TSPA-LA FEP Lists.	6.2.1.7

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued).

TSPA–SR FEP and Description	TSPA-SR SCREENING DECISION	TSPA-LA FEP and Description (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	Basis for Change from TSPA-SR to TSPA-LA FEP list	Analysis Report Section
1.2.10.01.00 Hydrological response to seismic activity Seismic activity, associated with fault movement, may create new or enhanced flow pathways and/or connections between stratigraphic units, or it may change the stress (and therefore fluid pressure) within the rock. These responses have the potential to significantly change the surface- and groundwater flow directions, water level, water chemistry and temperature.	*Excluded*—Low Consequence	1.2.10.01.0A *Hydrologic*-response to seismic activity Seismic activity, associated with fault movement, may create new or enhanced flow pathways and/or connections between stratigraphic units, or it may change the stress (and therefore fluid pressure) within the rock. These responses have the potential to significantly change the surface and groundwater-flow directions, water level, water chemistry, and temperature.	No changes in FEP Description between TSPA-SR and TSPA-LA FEP Lists.	6.2.1.8
2.1.07.01.00 Rockfall (large block) Rockfalls occur large enough to mechanically tear or rupture waste packages.	*Excluded*—Low Consequence	Not Applicable—Not Assigned to DE FEPs for TSPA-LA.	Seismic-related rockfall is addressed now by a separate FEP 1.2.03.02.0B Seismic-induced rockfall damages EBS components, to better address the level of detail.	Not Applicable

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued).

TSPA–SR FEP and Description	**TSPA-SR SCREENING DECISION**	**TSPA-LA FEP and Description** (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	**Basis for Change from TSPA-SR to TSPA-LA FEP list**	**Analysis Report Section**
2.1.07.02.00 Mechanical degradation or collapse of drift Partial or complete collapse of the drifts, as opposed to discrete rockfall, could occur as a result of seismic activity, thermal effects, stresses related to excavation, or possibly other mechanisms. Drift collapse could affect stability of the engineered barriers and waste packages. Drift collapse may be localized as stoping at faults or other geologic features. Rockfall of small blocks may produce rubble throughout part or all of the drifts.	*Excluded* —Low Consequence	*Not Applicable—Not Assigned to DE FEPs for TSPA-LA.*	Seismic –induced drift collapse effects now addressed by two new FEPs 1.2.03.02.0C Seismic-induced drift collapse damages EBS components, and FEP 1.2.03.02.0D Seismic-induced drift collapse alters in-drift thermohydrology.	Not Applicable
2.2.06.01.00 Changes in stress (due to thermal seismic or tectonic effects) change porosity and permeability of rock. Changes in stress due to all causes, including heating, seismic activity, and regional tectonic activity, have a potential [to] result in strains that affect flow properties in rock outside the excavation-disturbed zone.	*Excluded*—Low Consequence	2.2.06.01.0A Seismic activity changes porosity and permeability of rock. Seismic activity (fault displacement or vibratory ground motion) has a potential to change rock stresses and result in strains that affect flow properties in rock outside the excavation-disturbed zone. It could result in strains that alter the permeability in the rock matrix. These effects may decrease the transport times for potentially released radionuclides.	FEP Description modified to limit discussion in this FEP to seismic-related events. Thermal effects of the repository are addressed as part of the nominal case analysis.	6.2.1.9

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued).

TSPA–SR FEP and Description	**TSPA-SR SCREENING DECISION**	**TSPA-LA FEP and Description** (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	**Basis for Change from TSPA-SR to TSPA-LA FEP list**	**Analysis Report Section**
Not Applicable (NEW FEP)	Not Applicable	2.2.06.02.0B Seismic activity changes porosity and permeability of fractures Seismic activity (fault displacement or vibratory ground motion) has a potential to change stress and strains that alter the permeability along fractures. This could result in reactivation of preexisting fractures or generation of new fractures. Generation of new fractures and reactivation of preexisting fractures may significantly change the flow and transport paths, alter or short-circuit the flow paths and flow distributions close to the repository and create new pathways through the repository. These effects may decrease the transport times for potentially released radionuclides.	NEW FEP created for consistent level of detail to address changes in fractures, similar to that for rocks and faults. This FEP Description limits discussion in this FEP to seismic-related events. Due to the linkage between changes in stress, fracturing, and changes in fractures characteristics, these aspects of fracturing have been incorporated from the TSPA-SR FEP 1.2.02.01.00 Fractures. Thermal effects of the repository are addressed as part of the nominal case analysis.	6.2.1.11
2.2.06.03.00 Changes in stress (due to seismic or tectonic effects) alters perched-water zones. Strain caused by stress changes from tectonic or seismic events alters the rock permeabilities that allow formation and persistence of perched-water zones.	*Excluded*—Low Consequence	2.2.06.03.0A Seismic activity alters perched water zones Strain caused by stress changes from tectonic or seismic events alters the rock permeabilities that allow formation and persistence of perched water zones.	No changes in FEP Description between TSPA-SR and TSPA-LA FEP Lists.	6.2.1.12

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued).

TSPA–SR FEP and Description	TSPA-SR SCREENING DECISION	TSPA-LA FEP and Description (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	Basis for Change from TSPA-SR to TSPA-LA FEP list	Analysis Report Section
1.2.04.01.00 Igneous activity Volcanism and magmatic activity could cause activation, creation and sealing of faults, changes in topography, changes in rock stress, deformation of rock, changes in groundwater temperatures, and severe perturbation to the integrity of the drifts.	*Included* for direct effects *Excluded* for indirect effects—Low Consequence	Not Applicable—Not Assigned to DE FEPs for TSPA-LA	This FEP Description was reevaluated and found to be too broad and redundant with other igneous-related FEPs and was deleted.	Not Applicable
1.2.04.02.00 Igneous activity causes changes to rock properties. Igneous activity near the underground facility causes extreme changes to rock hydrologic and mineralogic properties. Permeabilities of dikes and sills and the heated regions immediately around them can differ from those of country rock. Mineral alterations can also change the chemical response to contaminants.	*Excluded*—Low Consequence	1.2.04.02.0A Igneous activity changes rock properties Igneous activity near the underground facility causes extreme changes in rock stress and the thermal regime, and may lead to rock deformation including activation, creation, and sealing of faults and fractures. This may cause changes in the rock hydrologic and mineralogic properties. Permeabilities of dikes and sills and the heated regions immediately around them can differ from those of country rock. Mineral alterations can also change the chemical response of the host rock to contaminants.	FEP Description modified to address concerns with thermal changes due to intrusion and to clarify that chemical response of host rock is at issue.	6.2.2.1
1.2.04.03.00 Igneous intrusion into repository Magma from an igneous intrusion flows into the drifts and extends over a portion of the repository site, forming a sill. The sill could be limited to the drifts or a continuous sill could form along the plane of the repository, bridging between adjacent drifts.	*Included*	1.2.04.03.0A Igneous intrusion into repository Magma from an igneous intrusion flows into the drifts and extends over a large portion of the repository site, forming a sill, dike, or dike swarm depending on the stress conditions. This could involve multiple drifts. The sill could be limited to the drifts or a continuous sill could form along the plane of the repository, bridging between adjacent drifts.	FEP Description modified to address concerns with dike/repository interaction associated with intrusion.	6.2.2.2

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued).

TSPA–SR FEP and Description	TSPA-SR SCREENING DECISION	TSPA-LA FEP and Description (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	Basis for Change from TSPA-SR to TSPA-LA FEP list	Analysis Report Section
1.2.04.04.00 Magma interacts with waste An igneous intrusion in the form [of a dike] occurs through the repository, intersecting waste. This leads to accelerated waste container failure (e.g., attack by magmatic volatiles, damage by fragmented magma, thermal effects) and dissolution of waste (CSNF, DSNF, DHLW).	*Included*	1.2.04.04.0A Igneous intrusion interacts with EBS components An igneous intrusion in the form of a dike occurs through the repository, intersecting the repository drifts. Magma, pyroclastics, and volcanic gases enter the drift and interact with the EBS components including the drip shields, the waste packages, *pallet*, and invert. This leads to accelerated drip shield and waste package failure (e.g., attack by magmatic volatiles, damage by flowing or fragmented magma, thermal effects) and dissolution or volatilization of waste.	FEP Description modified to address concerns with dike/repository interaction associated with intrusion and to clarify that interaction is with EBS components, not just waste.	6.2.2.3
1.2.04.05.00 Magmatic transport of waste An igneous intrusion occurs through the repository, intersecting waste. Some of the waste (entrained, dissolved, or volatilized) is then transported away from the repository. Of most concern is transport directly to the surface.	*Excluded* for transport in liquid magma and other types of transport—Low Consequence *Included* for transport through eruptive events.	1.2.04.05.0A Magma or pyroclastic *base surge transports* waste. As a result of the igneous intrusion, extrusive processes result in a pyroclastic density flow, base surge, dike apron, effusive lava flows and/or development of a volcanic vent at land surface. Some of the waste (entrained, dissolved, or volatized) is then transported away from the repository. Of most concern is transport directly *along the land surface to the RMEI.*	FEP Description and Name modified to better address surface effects associated with effusive flow, interaction associated with intrusion, and to clarify that interaction is with EBS components, not just waste.	6.2.2.4
1.2.04.06.00 Basaltic cinder cone erupts through the repository As a result of an igneous intrusion, a cinder cone forms on the surface. The conduit(s) supplying the vent(s) of the cone pass(es) through the repository, interacting with and entraining waste.	*Included*	1.2.04.06.0A Eruptive conduit to surface intersects repository As a result of an igneous intrusion, one or more volcanic vents forms at land surface. The conduit(s) supplying the vent(s) pass(es) through the repository, interacting with and entraining waste.	FEP Description and Name modified to be more technically correct regarding development of surface and subsurface features and related concerns.	6.2.2.5

Table 6-1. Changes to the DE FEPs from TSPA-SR to TSPA-LA (Continued).

TSPA–SR FEP and Description	**TSPA-SR SCREENING DECISION**	**TSPA-LA FEP and Description** (*italics* denote changes from DTN: MO0307SEPFEPS4.000 [DIRS 164527])	**Basis for Change from TSPA-SR to TSPA-LA FEP list.**	**Analysis Report Section**
1.2.04.07.0A Ashfall Finely-divided waste particles are carried up a volcanic vent and deposited [at land] surface from an ash cloud or pyroclastic flow.	*Included* *Excluded* for pyroclastic base surge flow—Low Consequence.	1.2.04.07.0A Ashfall Finely-divided waste particles are carried up a volcanic vent and deposited at land surface from an ash cloud.	No changes in FEP Description between TSPA-SR and TSPA-LA FEP Lists.	6.2.2.6
Not Applicable (NEW FEP)	Not Applicable	1.2.04.07.0C Ash redistribution via soil and sediment transport Following deposition of contaminated ash on the surface, ash deposits may be redistributed on the surface via aeolian and fluvial processes.	New FEP created to address post-eruptive effects of ashfall with regard to mechanisms for contaminant transport.	6.2.2.7
1.2.10.02.00 Hydrologic response to igneous activity Igneous activity may change the groundwater flow directions, water level, water chemistry and temperature. Igneous activity includes magmatic intrusions, which may change rock properties and flow pathways, and thermal effects which may heat up groundwater and rock.	*Excluded*—Low Consequence	1.2.10.02.0A Hydrologic response to igneous activity Igneous activity includes magmatic intrusions, which may alter groundwater flow pathways, and thermal effects, which may heat up groundwater and rock. Igneous activity may change the groundwater flow directions, water level, water chemistry, and temperature. Eruptive and extrusive phases may change the topography, surface drainage patterns, and surface soil conditions. This may affect infiltration rates and locations.	FEP Description modified to more clearly identify potential for hydrologic response due to surface effects of igneous activity.	6.2.2.8

6.1.2 FEP Screening Process

As described in Section 6.1.1, the first step in the FEP analysis was the identification of the FEPs. The second step includes the screening of each FEP against the FEP screening criteria. Each FEP is screened against regulations, guidance, or specific criteria that are summarized in the form of three FEP screening statements:

(1) The event has at least one chance in 10,000 of occurring over 10,000 years (see 10 CFR 63.114(d) (66 FR 55732 [DIRS 156671]))

(2) The magnitude and time of the resulting radiological exposure to the RMEI, or radionuclide release to the accessible environment, would be significantly changed by its omission (see 10 CFR 63.114 (e and f) (66 FR 55732 [DIRS 156671])).

Additionally, the Acceptance Criteria in the YMRP (NRC 2003, Section 2.2.1.2.1.3 [DIRS 163274]) calls for evaluating the FEPs based on the regulations. This criterion can be summarized in the form of a third FEP screening statement:

(3) The FEP is not excluded by regulation.

If there are affirmative conditions for all three screening criteria, the FEP is *Included* in the TSPA-LA model. By default, FEPs are included in the TSPA, unless they are shown to be of low probability, of low consequence, or excluded by regulation. Any negating condition in the three screening criteria *Excludes* the FEP from the TSPA-LA model.

For postclosure evaluation of fault-displacement and ground-motion related DE FEPs for TSPA-LA FEPs, the FEP screening statements are applied based on the mean value of the event at an annual-exceedance probability of 10^{-8} (see Assumption 5.1). For the TSPA-SR, the DOE elected to use median hazard curves to screen seismic FEPs, considering the median curve representative of the hazard's central tendency at an annual-exceedance frequencies lower than approximately 10^{-6}. However, NRC reviewers suggested that using the median hazard for FEP screening is inconsistent with established NRC practice for use of PSHA in risk assessment. Consequently, the DOE has implemented an alternative approach for TSPA-LA that uses the mean values. This alternative approach is documented in Williams 2001 [DIRS 161728].

The use of the mean value is consistent with the requirements of 10 CFR 63.305(c) (66 FR 55732 [DIRS 156671]), which requires that "DOE vary factors related to geology, hydrology and climate, based upon *cautious, but reasonable assumptions,* consistent with present knowledge of factors that could affect the Yucca Mountain disposal system in the next 10,000 years." The justification and reasoning for using the mean value is fully explained in Williams (2001 [DIRS 161728]). The use of the mean value is cautious in that it incorporates large uncertainties and significantly exceeds any single-event displacements observed along existing structures at Yucca Mountain. The use of the mean values is also consistent with established NRC practice and guidance procedures that use the mean value as the appropriate representation of hazard uncertainty. Moreover, the use of the mean value is "consistent with present knowledge of factors" in that ground-motion and fault-displacement hazard evaluations, following standard practice, have been modeled assuming an unbounded lognormal distribution for the ground motion uncertainty.

The use of the mean value from the hazard curve is particularly pertinent to the following FEPs:

1.2.02.03.0A Fault displacement damages EBS components (Section 6.2.1.2)

1.2.03.02.0A Seismic ground motion damages EBS components (Section 6.2.1.3)

1.2.03.02.0B Seismic-induced rockfall damages EBS components (Section 6.2.1.4)

1.2.03.02.0C Seismic-induced drift collapse damages EBS components (Section 6.2.1.5)

1.2.03.02.0D Seismic-induced drift collapse alters in-drift thermohydrology (Section 6.2.1.6).

The postclosure FEP screening considers the three screening criteria, two of which are: (1) the probability of the phenomenon occurring (Section 6.1.2.1), and (2) the consequence of omitting the FEP (the potential to affect disposal system performance; i.e., the *associated combinations of repository system component failures in response to the phenomenon*) (Section 6.1.2.2). The third criterion (By Regulation) is discussed in Section 6.1.2.3.

6.1.2.1 Exclusion by Low Probability

For the TSPA postclosure consideration, an event is defined as “a natural or anthropogenic phenomenon that has a potential to affect disposal system performance and that occurs during an interval that is short compared to the period of performance” (Freeze et al. 2001, Appendix A [DIRS 154365]). For postclosure, the event probability criterion is set at one chance in 10,000 of the event occurring in 10,000 years (10 CFR 63.114(d) 66 FR 55732 [DIRS 156671]).

Event probability screening is the consideration of the probability of a phenomenon occurring, independent of its effect on the repository. This is particularly germane to processes where the phenomena are well defined. If it can be demonstrated that a phenomenon, independent of its effect on the repository, is of sufficiently low probability, then the phenomenon is *Excluded* from the TSPA based on low probability. This report does not use this screening criterion as the sole basis for FEP exclusion, as the evaluated events (volcanism and seismic events) occur at annual frequencies greater than 10^{-8}.

6.1.2.2 Exclusion by Low Consequence

This screening criterion allows FEPs to be excluded from further consideration if the magnitude and time of the resulting radiological exposures to the RMEI, or radionuclide releases to the accessible environment would not be “significantly changed” by the omission of the FEP from the TSPA-LA model. The terms “significantly changed” and “changed significantly” are undefined terms in the NRC and EPA regulations. The absence of significant change (i.e., an insignificant change if the FEP is omitted) is inferred for FEP-screening purposes to be equivalent to having no effect or negligible effect.

The low-consequence argument can be made for FEP screening by demonstrating that a particular FEP has negligible effect on the distribution of an intermediate-performance measure that can be linked to radiological exposure or radionuclide release, or it may be given directly in terms of the effect on radiological exposure or radionuclide release. If a FEP can be shown to have negligible impact on UZ or SZ flow and transport, waste-package integrity, and/or other components of the engineered barrier system (EBS) or natural barrier system (NBS) as modeled in the TSPA, then the FEP does not provide a mechanism that could result in a radiological exposure or radiological release increase.

Various means to demonstrate negligible impact include site-specific data, sensitivity analyses, SMEs expertise (including, in some cases, the expert elicitation process), natural analogues, modeling studies outside the TSPA, and reasoned arguments based on literature research or corroborative data. Complicated processes, such as igneous- and seismic-related activity or waste corrosion FEPs, may require detailed analyses conducted specifically for the YMP. In some cases, the demonstration may be direct, using results of potential event or process computer simulations. For example, for FEP 2.2.06.01.0A (seismic activity changes porosity and permeability of rock), FEP 2.2.06.02.0A (seismic activity changes porosity and permeability of faults), and FEP 2.2.06.02.0B (seismic activity changes porosity and permeability of fractures), the FEP analysis considers the computer model results used to analyze the flow sensitivity to flow properties that would be affected by stress condition changes. The evaluation is based on intermediate properties (UZ flow) that are critical to radionuclide transport from the repository to the accessible environment.

A low consequence argument, but based on probability, can be invoked if an event is defined in terms of its potential to affect the behavior (or response) of the disposal system (consequence), rather than solely in terms of the independent phenomenon probability. To evaluate this aspect one defines a threshold value at which an event has the potential to affect repository performance, and then defines the probability of that threshold being violated. Using the design-based FEP screening approach is justified because:

(1) FEPs can be defined temporally, spatially, and in amplitude;

(2) The phenomena and effect of the interaction can be quantified (or at least bounded) and, therefore, incorporated into the design in such a way that the potential effect of the FEP is eliminated or minimized;

(3) The implementation of the design and changes to the design are subject to a performance-confirmation process; and

(4) The "as-built" design can be verified (see Section 6.1.7).

This use of probability to support a low consequence argument is particularly germane to FEPs involving potential container breaching due to a geologic phenomenon. This report does not use the probability of exceeding a threshold tied to repository performance as the sole basis for FEP exclusion.

Although a FEP is evaluated with regard to consequence, a low-consequence argument may also be supported by a low-probability argument for some portion of the FEP. In such cases, the basis for exclusion is shown as low consequence with the screening argument discussion mentioning the low probability of some portion of the FEP. An example of this is FEP 2.2.06.02.0A (seismic activity changes porosity and permeability of faults) wherein the potential for new fault creation in intact rock is inferred to be of low probability based on the PSHA. However, the PSHA also indicates that significant movement along existing faults is likely to occur and, thus, the remainder of the FEP is further considered based solely on this consequence. In this particular case, the screening basis is listed as low consequence, as the phenomenon of fault displacement as a whole is not of low probability.

Another method of supporting a low-consequence argument is to quantify the conditional exposure or conditional radionuclide release (i.e., that exposure or release which results presuming that the FEP occurs) and demonstrate that once weighted by the probability of the associated scenario class occurring, the exposure or release is of no significance. This particular method of supporting a low-consequence decision is not used to exclude any of the DE FEPs.

6.1.2.3 Exclusion by Regulation

The NRC Acceptance Criteria for FEP screening published in the YMRP (NRC 2003, Section 2.2.1.2.1.3 [DIRS 163274]) allows for exclusion of a FEP if the process is specifically excluded by the regulations as described in *Acceptance Criterion 2, Screening of the Initial List of Features, Events, and Processes Is Appropriate.* FEPs that are contrary to specific regulations, regulatory assumptions, or regulatory intent as stated in the preamble sections of the regulations can be excluded from further consideration. Examples would include FEPs or assumptions that are contrary to the key concepts and definitions outlined in Section 4.1.3.1 of this report. Regulatory input for exclusion are used in the DE FEPs screening, particularly with regard to definition of the controlled area and its relationship to the location characteristics of the RMEI.

6.1.3 Background, Supporting AMRs, Technical Information, and Literature Searches

The data sources, product output, technical information, and references used for the FEP evaluations are cited within each of the individual FEPs discussions. The direct inputs for the excluded FEPs, and the list of included FEPs, are documented in Section 4 per YMP procedural requirements and guidance.

Where possible, technical products and technical information used as direct inputs to support the *Exclude* screening decisions presented in this report have been obtained from controlled source documents and references using the appropriate document identifiers or records system accession numbers. Sources include, but are not limited to, YMP AMRs, YMP technical reports, and other YMP documents and databases. Results of analysis and models cited in this report are drawn primarily from supporting YMP AMRs listed in Section 4.1.2.3.

Other project and external source documents are cited as needed in individual FEP to amplify the discussions, but are identified as corroborative or referential in nature and are cited in the Section 8 reference list, but are not addressed in Section 4.

Seismic-Related AMRs: For seismic-related FEPs, this report cites the results stated in the *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (or PSHA) (CRWMS M&O 1998 [DIRS 103731]). The PSHA presents the ground motion and fault displacement evaluations resulting from the expert-elicitation process. Data and analysis for seismic ground motions and fault displacement are drawn directly from the PSHA (CRWMS M&O 1998 [DIRS 103731]) or its associated DTN. The ground motion hazard curves present the data as the annualized exceedance probability for a specified ground motion. The fault displacement hazard curves present the data as probabilities of fault displacements at various representative reference points for the repository.

In cases where DE FEPs are shared, the scope of this report is to provide a quantification of the initiating disruptive event. This is particularly germane for FEPs dealing with EBS component responses to fault displacement and ground motion events. Table 6-2 provides the list of supporting AMRs that describe the seismic events in terms of amplitude, characteristics of ground motion, and probability of such events. The fault displacement and ground motion outputs developed in the supporting AMRs are used in other supporting AMRs such as *Drift Degradation Analysis* ANL-EBS-MD-0000027 (BSC 2003 [DIRS 162711]) and *Seismic Consequence Abstraction* MDL-WIS-PA-000003 (BSC 2003 [DIRS 161812]), to describe potential consequences.

Table 6-2. Supporting AMRs Used to Quantify Seismic-Related FEPs

Disruptive Events AMRs	Document Identifier Number for Document Supporting TSPA–SR	Document Identifier Number for Document Supporting TSPA-LA	Scope and Objective for TSPA-LA
Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada.	ANL-CRW-GS-000003 REV 00 (CRWMS 2000 [DIRS 142321])	Same—Not Updated since there are no related changes to the PSHA.	Summarizes the PSHA for the Yucca Mountain site. In addition, it furnishes indirect support to analyses addressing the effects of ground motion and fault displacement for the postclosure period, to an analysis of seismic-related FEPs, and to an evaluation of the extent to which the NRC subissues and acceptance criteria associated with the Seismicity and Structural Deformation (SDS) and other key technical issues are addressed.
Development of Seismic Design Ground Motion Inputs for a Geologic Repository at Yucca Mountain, Nevada.	Not Applicable	MDL-MGR-GS-000003 REV 00 (BSC 2003 [DIRS 166274])	Updates and provides specific ground motion time histories for postclosure analysis.

Igneous-Related AMRs: For volcanic-related FEPs, the *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* (or PVHA) (CRWMS M&O 1996 [DIRS 100116]) documents the results of an expert elicitation project that provided the technical basis for assessing volcanism related hazards. The methods and findings of that expert elicitation serve as the basis for evaluating the probability of a dike intersecting the TSPA-LA repository footprint. Although results of the expert elicitation focused on hazard, the documentation also contained information relevant to the consequence analysis used in the igneous-related AMRs, which support the FEPs evaluation.

In cases where DE FEPs are shared, the scope of this report is to provide a quantification of the initiating disruptive event. This is particularly germane for FEPs dealing with the response of the EBS components to igneous events. Table 6-3 provides the list of supporting AMRs that describe the igneous events in terms of magmatic properties, in-drift conditions, size and spatial aspects, and the probability of such events. The in-drift conditions and spatial aspects developed in the supporting AMRs are used in *Igneous Intrusion Impacts on Waste Package and Waste Form* MDL-EBS-GS-000002 (BSC 2003 [DIRS 165002]), to describe potential consequences.

Table 6-3. Supporting AMRs Used to Quantify Igneous-Related FEPs

Disruptive Events AMRs	Document Identifier for AMR supporting TSPA–SR	Document Identifier Number for Document Supporting TSPA-LA	Scope and Objective
Characterize Framework for Igneous Activity at Yucca Mountain, Nevada	ANL-MGR-GS-000001 REV 00 ICN 01	ANL-MGR-GS-000001 REV 01 (BSC 2003 [DIRS 163769])	Provide TSPA-LA with a conceptual model of the igneous framework and parameters to support probability and consequence analysis of the Disruptive Events igneous scenarios.
Characterize Eruptive Processes at Yucca Mountain, Nevada	ANL-MGR-GS-000002 REV 00	ANL-MGR-GS-000002 REV 01 (BSC 2003 [DIRS 161838])	Provide TSPA-LA with conceptual models and parameters to support analysis of the disruptive events volcanic eruption modeling case, as well as ash redistribution conceptual modeling.
Dike/Drift Interactions	(Previously *Dike Propagation Near Drifts*) ANL-WIS-MD-000015 REV 00 ICN 01	MDL-MGR-GS-000005 REV 00 (BSC 2003 [DIRS 165923]	Provide TSPA-LA with an improved basis for igneous consequence modeling in the area of dike propagation and the interaction of magma with emplacement drifts.
Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada	Not Applicable (see *Igneous Consequence Modeling* for the TSPA-SR ANL-WIS-MD-000017 REV 00 ICN 02)	MDL-MGR-GS-000002 REV 00 (BSC 2003 [DIRS 161840])	Provide a stand-alone report to document the ash dispersal conceptualization, parameterization, and calculations, as wells as ash redistribution conceptual modeling. Provide an improved technical basis for using the ASHPLUME code to model volcanic ash dispersal for the volcanic eruption modeling case for TSPA-LA. Provide ASHPLUME input parameters for implementing ASHPLUME in the GoldSim code.
Number of Waste Packages Hit by Igneous Intrusion	CAL-WIS-PA-000001 REV 01	ANL-MGR-GS-000003 REV 00 (BSC 2003 [DIRS 161851])	Provide calculation documenting the number of waste packages hit by igneous intrusion. Provide input parameters to the TSPA model.

6.1.4 Assumptions and Simplifications, Alternative Conceptual Models, and Consideration of Uncertainty in FEP Screening

The generic assumption (Assumption 5.1) used in the DE FEPs evaluation is provided in Section 5, along with the justification and description of its use. No other assumptions or simplifications are used directly in the FEP analyses unless specifically described in the individual FEPs discussions.

Specific guidance and criteria for alternative conceptual model considerations (and their relationship to FEPs) and the treatment of uncertainty were addressed, as appropriate, following guidance outlined in Section 5 and Appendices A and C of the SPGM (BSC 2002 [DIRS 160313]). The issues of alternative conceptual models and uncertainty are addressed in the supporting documentation cited as part of the FEP evaluation. For included DE FEPs, these alternative conceptual models are then incorporated, or not, into the TSPA-LA model based on their development and evaluation in the supporting AMRs. For excluded DE FEPs, the discussions of the alternative conceptual models from the supporting AMRs are cited in the FEP discussions.

The quantification of uncertainty, as described in the SPGM, is not applicable to DE FEPs screening because the DE FEP evaluations do not directly address parameter quantification, model development, or abstraction. Rather, by default, the FEPs are included, but screening process may result in an exclude decision. The decision is, therefore, "binary" (included or excluded). The issue for such binary decisions is one of confidence rather than quantitative uncertainty. The measure of confidence in the decision, however, is related to uncertainty in the data or information used for the technical basis. How this underlying uncertainty affects the confidence in the screening decision and how it is addressed in the DE FEP evaluation is discussed below for each of the following screening criteria: low probability, low consequence, and by regulation.

In the case of the low-probability screening arguments, the mean probability of an event (which reflects the range in the underlying uncertainty in supporting information) is used for the evaluation. For the DE FEPs, the mean probability was based on, or derived from, an expert-elicitation process that considered multiple factors and alternative conceptual models. Therefore, specific consideration of uncertainty is of concern during the DE FEP screening process only if the mean probability of the event is roughly equivalent to the screening criteria of 10^{-8}, and only if the mean probability is the only basis used to exclude the FEP (i.e., the exclusion is not also coupled to a low-consequence argument). If the screening decision is to include a FEP into the performance assessment, and the resulting consequence is to be probabilistically weighted within TSPA-LA, then uncertainty becomes a potentially important consideration in parameter or model development and implementation, per the SPGM (BSC 2002, Appendix A [DIRS 160313]).

In the case of low-consequence arguments, it is important to identify the mechanisms or sequence of events that could impact the repository performance and any associated intermediate performance measures. Low-consequence arguments can be postulated using either "worst-case" values for the sequence of events or the associated intermediate performance measures. If it can be demonstrated that such values have negligible impact on repository performance, then the issue of uncertainty is addressed by the use of the bounding conditions. However, the use of low-consequence arguments also is more subject to uncertainties stemming from substantiated and reasonable alternative conceptual models. Inherent in the evaluation of such alternative conceptual models are a dependence on data, ranges in field observation and, in some cases, on modeling results that have associated uncertainties. Thus, for low-consequence arguments, consideration of alternative conceptual models and the range in available data and results is more extensively discussed than for probability screening arguments. Alternately, modeling that considers uncertainty and alternative conceptual models, and shows a minimal impact on exposure or other measures that are representative of release of radionuclides to the accessible environment, can be used to support the low-consequence argument. In either case (use of bounding condition or models that consider uncertainty), the issue of parameter uncertainty is not as critical as the consideration of alternative conceptual models (or model uncertainty).

In the case of FEPs exclusion by regulation, uncertainty (as represented by alternative views of regulatory meaning and intent, or appropriate regulatory application) cannot be readily quantified. Rather, this type of uncertainty is resolved through the regulatory review and licensing process. Thus, in the DE FEP discussions, specific citations to the regulations or regulatory discussions are provided, and the application of the regulations to DE FEP screening is explicitly expressed for the individual FEPs.

6.1.5 Alternative Approaches, Mathematical Formulations, and Units of Measure

Alternative approaches/technical methods to the FEP development and screening process used by YMP are discussed in *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966]).

In general, FEP screening involves the comparison of the measure of some feature, event, or process to some threshold level of probability, or a threshold measure that defines the onset of consequence to repository performance. Mathematical and numerical formulations typically are used in the supporting AMRs or cited literature to define the measure of the feature, event, or process of interest, in order to define the probability of the event or process (e.g., development of the seismic hazard curves), and to define the threshold measure for consequence (e.g., change in rock properties). Beyond simple calculations (e.g., rate of fault displacement multiplied by the time period of interest) described for each FEP, no mathematical and numerical formulations are used directly in the DE FEP evaluations. Rather, the FEP evaluations cite supporting information for definition of amplitude and probability of events and processes.

Depending on the FEP evaluated, the units of measure may vary between FEPs and between cited source documents. In all cases, the units as they appeared in the cited source are provided to allow traceability, and metric equivalents are provided in parentheses for consistency and transparency.

6.1.6 Model and Software Issues for Previously Developed and Validated Models

No models were used directly in the FEP evaluations. The results of models and documents developed by others are cited as the technical basis in some instances. This cited documentation for those model reports provides documentation of the model formulation, consideration of uncertainty and consideration of alternative conceptual models. No software beyond that listed in Section 3 was used in the development of this analysis.

6.1.7 Intended Use and Limitations

The intended use of this analysis report is to provide FEP screening information for a project-specific FEP database, and to promote traceability and transparency regarding FEP dispositions. Except as previously noted for some instances of shared FEPs, this report is also intended to be used as the source documentation, to provide the technical basis and the supporting arguments for exclusion of DE FEPs from the TSPA-LA model. For the DE FEPs that are designated for inclusion into the TSPA-LA model, the manner in which the FEP has been included, the associated list of parameters, and any uncertainty considerations are provided in the cited analysis and model reports.

The results of the FEP screening presented herein are specific to the repository design evaluated for TSPA-LA. Inherent in this evaluation approach is the limitation that the repository will be constructed, operated, and closed according to the design used as the basis for the FEP screening and in accordance with NRC license requirements. This is inherent in performance evaluation of any engineering project, and design/construct confirmation is required as part of the construction process. This design dependency is due in part to the probability of intersection by an igneous intrusion being dependent on the repository footprint, size, location, and orientation. Additionally, the response of the repository to seismicity (ground motion and fault displacement) is dependent on the drift orientation respective to existing features, and the location of emplacement drifts with respect to faults or other significant discontinuities.

Any changes in direct inputs listed in Section 4.1, in baseline conditions used for this evaluation, or in other subsurface conditions will need to be evaluated to determine if the changes are within the limits stated in the FEP evaluation. Engineering and design changes are subject to evaluation to determine if there are any adverse manner impacts to safety as codified at 10 CFR 63.73 and in Subparts F and G (66 FR 55732 [DIRS 156671]). (see also the requirements stated at 10 CFR 63.44 and 10 CFR 63.131 (66 FR 55732 [DIRS 156671]).

6.2 DISRUPTIVE EVENTS FEP EVALUATION AND ANALYSIS

This report addresses the 20 DE FEPs that are identified for TSPA-LA consideration. Section 6.2.1 addresses the FEPs classified and assigned as seismic-related FEPs, and Section 6.2.2 addresses the FEPs classified and assigned as igneous-related FEPs.

6.2.1 Seismic-Related FEPs

The following subsections provide the screening decision and technical basis for inclusion and exclusion of the following seismic-related FEPs.

1.2.01.01.0A	Tectonic activity—large scale (Section 6.2.1.1)
1.2.02.03.0A	Fault displacement damages EBS components (Section 6.2.1.2)
1.2.03.02.0A	Seismic ground motion damages EBS components (Section 6.2.1.3)
1.2.03.02.0B	Seismic-induced rockfall damages EBS components (Section 6.2.1.4)
1.2.03.02.0C	Seismic-induced drift collapse damages EBS components (Section 6.2.1.5)
1.2.03.02.0D	Seismic-induced drift collapse alters in-drift thermohydrology (Section 6.2.1.6)
1.2.03.03.0A	Seismicity associated with igneous activity (Section 6.2.1.7)
1.2.10.01.0A	Hydrologic response to seismic activity (Section 6.2.1.8)
2.2.06.01.0A	Seismic activity changes porosity and permeability of rock (Section 6.2.1.9)
2.2.06.02.0A	Seismic activity changes porosity and permeability of faults (Section 6.2.1.10)
2.2.06.02.0B	Seismic activity changes porosity and permeability of fractures (Section 6.2.1.11)
2.2.06.03.0A	Seismic activity alters perched water zones (Section 6.2.1.12).

6.2.1.1 Tectonic Activity—Large Scale (1.2.01.01.0A)

FEP Description: Large-scale tectonic activity includes regional uplift, subsidence, folding, mountain building, and other processes related to plate movements. These tectonic events and processes could affect repository performance by altering the physical and thermohydrologic properties of the geosphere.

Descriptor Phrases: Tectonic activity (uplift), Tectonic activity (subsidence)

Screening Decision: *Excluded*—Low Consequence

Screening Argument: Global- or plate-scale tectonics, ultimately, drive the tectonism at the regional scale. Other processes related to tectonic activity, such as volcanism, faulting, seismicity, and fracturing, are evaluated as separate FEPs.

Large-scale tectonic activity is interpreted for this FEP to refer to tectonism that is expressed at a regional scale (1:250,000 or less) and has the potential for broad uplift, subsidence, folding, and geothermal effects. These changes would have the potential to alter the groundwater flux through the repository and the amount of water contacting EBS components and, thereby, alter the performance characteristics of the repository and its engineered components. These changes, if they occur at a sufficient rate, could also potentially impact UZ and SZ flow-and-transport properties during the repository-performance period (10,000 years), thereby affecting dose and radionuclide release to the accessible environment.

Yucca Mountain is within the Southern Great Basin of the Basin and Range tectonic province. As described in Section 6.3.1 of *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 142321]), tectonically, the Basin and Range is experiencing extensional strain at a low to moderate rate, with low to moderate historical seismicity. Yucca Mountain is located on the south flank of a large Miocene caldera complex. Structurally, the mountain is dominated by subparallel fault blocks that trend to the north and dip to the east. The blocks of ash-flow tuff are bounded by typical Basin and Range, high-angle, generally west-dipping, normal faults formed by rapid east-west extension during the waning phases of Miocene volcanism. Secondary intrablock faults are common. Although Basin and Range tectonic structure defines the structural pattern of Yucca Mountain blocks, the whole proposed repository area lies within the Walker Lane, a 100-km-wide structural belt along the western edge of the Basin and Range province. The Walker Lane is characterized by long, northwest-striking and shorter, north-to-northeast-striking, strike-slip faults that accommodate much of the early extension in this region. The peak phase of tectonism took place 12.7 to 11.6 million years ago (middle Miocene); and the region has since experienced declining strain rates.

By way of corroboration, the current pattern of Quaternary deformation mimics the middle Miocene activity; however, at substantially lower rates (Fridrich et al. 1998, pp. 1 and 2 [DIRS 164051]). At Yucca Mountain, tectonism is evolving westward through episodes of activity (inferred from Fridrich 1999, p. 191 [DIRS 118942]). Yucca Mountain is now about 50 km from the nearest zones of significant present-day tectonic activity in the Great Basin. The rate of subsidence appears to have diminished consistently over the last several million years and the locus of subsidence due to the waning extension has migrated west of Yucca Mountain (inferred from Fridrich 1999, p. 189 [DIRS 118942]; Dixon et al. 1995, p. 765 [DIRS 102793]). During that same period, the western part of Crater Flat basin subsided due to the basin extending from 18 to 40 percent in 1.1 million years or less. After 11.6 Ma, the rate of extension in the basin declined in a roughly exponential manner. The late Quaternary rate of extension is less than 1 percent of the initial rate (Fridrich et al. 1998, pp. 1 and 13 [DIRS 164051]), and may be as low as 0.1 to 0.2 percent per million years (Fridrich et al. 1998, pp. 19 and 20 [DIRS 164051]). Although Crater Flat basin remains, technically, active, it is now in a very advanced state of decline, according to Fridrich et al. (1998, p. 2 [DIRS 164051]).

By way of corroboration, the regional tectonic processes that are occurring in the Yucca Mountain region proceed at a low rate. Fridrich (1999, p. 190 [DIRS 118942]) indicates that across the southern part of the Crater Flat Basin, the northwest-southeast lengthening is approximately 0.1 m per thousand years, and also states that the late Quaternary extension rate is approximately one-half as great across central Yucca Mountain, and an order of magnitude lower across northern Yucca Mountain. Savage et al. (1999 [DIRS 118952]) present an evaluation of the rate of strain accumulation at Yucca Mountain, Nevada, for the period from 1983 to 1998, and address alternative interpretations indicating higher strain-accumulation rates presented by Wernicke et al. (1998 [DIRS 103485]). The very slow, contemporary strain-accumulation rate in the Yucca Mountain area (<2 mm/yr) (Savage et al. 1999, p. 17627 [DIRS 118952]; reported as "principal strain accumulation rate" of 2+/-12 nanostrain/year at N87W+/-12º and -22º+/-12º nanostrain/year N03E+/-12º) is consistent with the paleoseismic slip rates calculated from Quaternary fault-displacement studies. This strain information corroborates the local cumulative fault slip rates (used as direct input for this FEP) in the range of 0.001–0.03 mm/yr (CRWMS M&O 2000, Table 6 [DIRS 142321]). Since uncertainties in strain rates are reflected in uncertainties in recurrence and slip rates, uncertainty in the tectonic strain rate is implicitly evaluated through the consideration of multiple tectonic models and through uncertainties in the recurrence rates (CRWMS M&O 1998, Sections 7.1.1 and 8.1.3 and Appendix E [DIRS 103731]). The resulting hazard curves are used to evaluate FEPs specific to those issues.

The present extensional-tectonic regime of the Yucca Mountain region does not promote significant tectonic uplift and mountain building. Based on the history of the Crater Flat Basin as presented in CRWMS M&O 2000 [DIRS 142321] and described above, tectonic subsidence due to regional extension is a more likely scenario at Yucca Mountain than uplift. The local cumulative fault slip rate is low (0.001–0.03 mm/yr; CRWMS M&O 2000, Table 6 [DIRS 142321]) and subsidence will not perceptibly be advanced in the absence of slip along the block-bounding faults. The probability of such movement is reflected in the hazard curves presented in the PSHA (CRWMS M&O 1998 [DIRS 103731]) and used in the specific FEP evaluations for ground motion and faulting, which have been included. Thus, there is no mechanism not already considered (i.e., seismic ground motion and fault displacement) stemming from an extensional terrain that would lead to increased exposure or increased release of radionuclides to the accessible environment. This aspect of the FEP, therefore, is *Excluded* based on low consequence.

Folding and deformation at Yucca Mountain due to rollover along faults, which could hypothetically affect infiltration rates, is possible, but at a rate governed by rates for fault slip at Yucca Mountain. For the Bow Ridge fault, flattening foliations in the faulted tuffs dip steeply to the east (20° to 30°) into the graben(s) relative to the beds farther west in the unfaulted areas (8° to 15°) (Day et al. 1996, p. 2-7 [DIRS 124302] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). From this information, it is inferred that within the past 12 million years, rollover has led to a dip-steepening of lithologic units of no more than 20° (or about 1.6° per 1 million years). Any further rollover is expected to proceed at a rate less than or equal to that of the past, resulting in a steepening of less than 2° in one million years. Such a minor change will not significantly affect infiltration or groundwater flow characteristics. Given a critical tilting angle of approximately 25° (Fridrich et al. 1996, pp. 2-21 and 2-22 [DIRS 105086] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]), the tuff beds will likely fracture and slip before the change in their orientation (i.e., an increase in fold-limb dip associated with rollover) becomes a significant factor in determining local percolation. Therefore, the potential for increased permeability in hanging-wall rollover segments from fracturing far outweighs the significance of matrix permeability in rollover segments. Changes in porosity and permeability of the rock matrix, faults, and fractures are further addressed as specific FEPs. The effects of fractures on percolation flux are evaluated in the *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000 [DIRS 151953]). Changes in fracture aperture confined to fault zones show virtually no effect on transport behavior, and increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than other uncertainties related to infiltration (CRWMS M&O 2000, Section 7 [DIRS 151953]).

Uplift and subsidence associated with tectonic extension is an ongoing process in the Yucca Mountain region and, therefore, cannot be excluded as “low probability-not credible.” Earthquake-related events (due to ground motion and fault displacement) are specifically addressed in *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000 [DIRS 142321]). Fridrich et al. (1998, pp. 25–26 [DIRS 164051]) discuss the episodic tectonic activity in Crater Flat Basin. However, due to the slow rate at which tectonic processes proceed, tectonic activity at Yucca Mountain will not result in localized changes (uplift, subsidence, folding, or geothermal activity) during the repository-performance period (10,000 years) that would significantly and adversely affect repository performance. Additionally, uncertainty in the tectonics of the region was considered and incorporated into the hazard curves presented in the PSHA, which are used as a basis for evaluating ground motion and faulting. Since uncertainties in strain rates are reflected in uncertainties in recurrence and slip rates, the tectonic strain rate is implicitly evaluated through the consideration of multiple tectonic models and through uncertainties in the recurrence.

Therefore, consideration of large-scale tectonic activity with regard to uplift or subsidence is excluded because the magnitude of induced changes (i.e., minimal slip rate and rollover as it affects infiltration as discussed in the preceding paragraphs) would not significantly affect repository performance over at least a 10,000-year period. The related mechanisms of seismic ground motion and fault displacement are considered as separate FEPs and are *Included* in the TSPA-LA analysis. Thus, no mechanism is present that has not already been considered (i.e., seismic ground motion and fault displacement) as stemming solely from uplift or subsidence that would lead to an increased exposure or increased release of radionuclides to the accessible environment. This aspect of the FEP, therefore, is *Excluded* based on low consequence.

With regard to the geothermal regime, Yucca Mountain is now located in an area of moderate heat flow in the Southern Great Basin and lies south of the regions of relatively high crustal heat flow in the Great Basin (Lachenbruch and Sass 1978, pp. 212 and 246 [DIRS 142990]). The advent of basaltic volcanism at about 11 Ma, as described by Crowe et al. (1995, pp. 4-1 and 4-2 [DIRS 100110]), signals the end of crustal level magmatism near Yucca Mountain. It indicates generation of small, discrete batches of basaltic magma at upper-mantle depths (45 to 60 km [28 to 36 mi]) that are capable of making their way quickly to the surface (Crowe et al. 1995, pp. 5-2 and 5-6 [DIRS 100110]). Only small volumes (<0.5 km^3) of basaltic magma have been generated in the Yucca Mountain region during the Quaternary (Crowe et al. 1995, p. 5-5 [DIRS 100110]). The source depth of these magmas is approximately 60 km (Crowe et al. 1995, pp. 5-2 and Figure 5.1 [DIRS 100110] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]).

The existing geothermal gradient could be changed rapidly in the present tectonic setting, but only if a large volume of magma were emplaced high in the mid-to-upper crust (at approximately 5-km in depth) (inferred from Lachenbruch and Sass 1978, pp. 224 and 244 [DIRS 142990]). This could bring the Yucca Mountain area to a pre-eruptive state with attendant hot-spring activity. However, this would require great extension rates and crustal mobility, a rapidly evolving mantle, and subcrustal conditions that involve either a mantle plume hot spot (Parsons et al. 1994, p. 83 [DIRS 106479]) or melting of weakened subducting slab (inferred from Bohannon and Parsons 1995, p. 957 [DIRS 101865]).

Given the present tectonic state of Yucca Mountain and the present source of basaltic-magma generation at depths around 60 km (Crowe et al. 1995, p 5-2 and Figure 5-1 [DIRS 100110] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]), it is unlikely that localized effects will occur because of basaltic-magma generation. The existing conditions also indicate that a significant (i.e., potentially hazardous) increase in geothermal gradient associated with tectonic activity would require several million years of evolution. By way of corroboration, after a two-year study, scientists at the University of Nevada Las Vegas (UNLV) concluded that hydrothermal water has not invaded the rocks of Yucca Mountain in at least two million years (Wilson and Cline 2001 [DIRS 155426]). The study indicates that fluid inclusions within minerals found in roughly half of the 155 rock samples collected throughout Yucca Mountain were formed at temperatures ranging from 113° to 141°F (45° to 60°C), and that calcite deposited in fractures and voids was not the result of deposition from the upwelling of geothermal water. The uranium-lead dating for the study indicates that the two-phase fluid inclusions are older than a minimum age of 1.9 million years. More precise age constraints on the two-phase fluid inclusions (based on associated dateable material) indicated that the two-phase fluid inclusions were older than 4.0 to 5.3 million years. The UNLV study concluded that mineral precipitation at the site has been stable for at least the last two to three million years and is consistent with formation from low temperature, surficial fluids rather than saturation of the site by upwelling hydrothermal fluids.

Because the existing geothermal regime is currently addressed, and because conditions sufficient to create or allow a significant change in the regional geothermal regime within the 10,000-year performance period are absent, there is no feasible and additional geothermal regime related mechanism considered capable of leading to an increased exposure or an increased release of radionuclides into the accessible environment. This aspect of the FEP, therefore, is *Excluded* based on low consequence.

One hypothetical mechanism capable of changing the geothermal regime would be a tectonic-related increase in volcanism. Fridrich et al. (1998, pp. 23 and 24 [DIRS 164051]) address the relationship between volcanic activity at Yucca Mountain and tectonic regime. Although magmatism in the southwestern Nevada volcanic field and regional extension were broadly coeval, there is no apparent genetic link, or at least no correlation in relative extent or amount of activity (Sawyer et al. 1994 p. 1316 [DIRS 100075]). Details of igneous events as they relate to a proposed repository at Yucca Mountain are specifically addressed in C*haracterize Framework for Igneous Activity at Yucca Mountain*, *Nevada* (BSC 2003 [DIRS 163769]). Furthermore, the PVHA (CRWMS M&O 1996 [DIRS 100116]) documents the results of an expert elicitation project that provided the technical basis for assessing hazards related to volcanism. The use of tectonic models as they relate to volcanic hazard is summarized in the PVHA (CRWMS M&O 1996 [DIRS 100116]). The PVHA serves as the basis for current estimates of igneous intrusion probability. Thus, there is no igneous-related mechanism not already considered (i.e., increased igneous activity related to tectonic changes) that would lead to an increased exposure or an increased release of radionuclides into the accessible environment. This aspect of the FEP, therefore, is *Excluded* based on low consequence.

TSPA Disposition: Not Applicable

Related Documents: *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* ANL-CRW-GS-000003 (CRWMS M&O 2000 [DIRS 142321])

Characterize Framework for Igneous Activity at Yucca Mountain, Nevada ANL-MGR-GS-000001 (BSC 2003 [DIRS 163769])

Related FEPs:

<u>*FEPs that examine related but distinct, effects and consequences*</u>

Fault displacement damages EBS components (1.2.02.03.0A)
Seismic ground motion damages EBS components (1.2.03.02.0A)
Seismic-induced rockfall damages EBS components (1.2.03.02.0B)
Seismic-induced drift collapse damages EBS components (1.2.03.02.0C)
Seismic-induced drift collapse alters in-drift thermohydrology (1.2.03.02.0D)
Igneous intrusion into repository (1.2.04.03.0A)
Metamorphism (1.2.05.00.0A)
Hydrologic response to seismic activity (1.2.10.01.0A)
Hydrologic response to igneous activity (1.2.10.02.0A)
Seismic activity changes porosity and permeability of rock (2.2.06.01.0A)
Seismic activity changes porosity and permeability of faults (2.2.06.02.0A)
Seismic activity changes porosity and permeability of fractures (2.2.06.02.0B)
Seismic activity alters perched water zones (2.2.06.03.0A)

<u>*FEPs that examine related and similar effects and consequences*</u>

Hydrothermal activity (1.2.06.00.0A)
Effects of subsidence (2.2.06.04.0A)
Natural geothermal effects on flow in the SZ (2.2.10.03.0A)
Natural geothermal effects on flow in the UZ (2.2.10.03.0B)

Supplemental Discussion: Regional tectonic processes manifest themselves as patterns of systematic deformation that involve regional uplift, subsidence, folding, faulting, seismicity, igneous activity, or any distinctive combination of such processes.

In any given local area, such as Yucca Mountain, regional activity determines the style and recurrence of deformation expressed by local structure. Thus, the style and recurrence of fault slip at Yucca Mountain that occurred during the Quaternary approximates the major effects of regional tectonic process that will likely be felt at Yucca Mountain for the next several tens or hundreds of thousands of years.

<u>Tectonic Activity</u>: Tectonic activity at a regional scale typically is concentrated in zones or belts of ten, to hundreds of kilometers in width (Thatcher et al. 1999, pp. 1714 – 1715 [DIRS 119053]), and persists for millions of years. The significant tectonic zones relevant to discussion of Yucca Mountain include the eastern California shear zone, located west of the Funeral Mountains, and the intermountain seismic belt, located generally north of 37°N latitude (Savage et al. 1995, p. 20263 [DIRS 104553]). The zones and belts are characterized by relatively high geodetic strain rates and recurrent earthquakes (Thatcher et al. 1999, pp. 1714 and 1715 [DIRS 119053]). In contrast, Yucca Mountain and its setting (i.e., the Crater Flat domain)

have a lower geodetic strain rate (Savage et al. 1999, p. 17627 [DIRS 118952]). The low geodetic strain rate (Savage et al. 1995, p. 20263 and Figure 9 [DIRS 104553]), and low seismicity levels (e.g., Rogers et al. 1987, p. 82 [DIRS 100176]) found in the Crater Flat domain suggest that the site area is located in a tectonic domain that may be isolated from the zones of high geodetic strain located to the west and to the north.

The regional tectonic processes that are occurring in the Yucca Mountain region proceed at a very low rate, and the rate of regional tectonism has also decreased greatly since late Miocene epoch (Fridrich et al. 1998, p. 1 [DIRS 164051]). At Yucca Mountain, tectonism has evolved westward through episodes of activity (inferred from Fridrich 1999, p. 191 [DIRS 118942]). The current loci of tectonic activity have moved west of Yucca Mountain (inferred from Fridrich 1999, p. 189 [DIRS 118942]; and Dixon et al. 1995, p. 765 [DIRS 102793]). Fridrich et al. (1998, p. 26 [DIRS 164051]) indicate that data synthesized from Quaternary faults in the Crater Flat basin suggest that the rate of faulting has varied, typically over an order of magnitude, over cycles of hundred of thousands of years during the late Quaternary.

Based on the geologic history of Yucca Mountain, tectonic changes will occur at rates that are insignificant with respect to the repository-performance period (10,000 years), and the changes will be episodic. Episodic behavior can involve long time periods as demonstrated by formation of Yucca Mountain itself, which including deposition of the tuff layers and block faulting, that occurred over a period of approximately 2.5 to 3 million years (inferred from Fridrich 1999, pp. 184–189 [DIRS 118942]; and Sawyer et al. 1994, p. 1305 [DIRS 100075]). Episodic-volcanic behavior is demonstrated by the quiescent period between deposition of the Timber Mountain Group and the Paintbrush Canyon Group alone—a period of approximately 750,000 years (Sawyer et al. 1994, p. 1312 [DIRS 100075]). Deformational processes associated with tectonism also can be punctuated by local events such as volcanic eruptions and earthquakes, which are considered potentially disruptive events. Igneous and seismic events are treated as separate and distinct FEPs in the following sections.

<u>Uplift and Subsidence</u>: Uplift and subsidence associated with tectonic extension is an ongoing process in the Yucca Mountain region. The elevations of landforms (e.g., basins and ranges) in the Yucca Mountain region are a direct consequence of tectonic extension that has operated within the past 25 million years (e.g., the basins are loci of chronic subsidence, and the ranges are loci of uplift or relative stability). For example, Bare Mountain, the range closest to Yucca Mountain, has undergone uplift within the 12- to 8-million-year (Ma) interval (Hoisch et al. 1997, p. 2829 [DIRS 111854]). In this context, uplift is thought to result from either of two processes: (1) magmatic inflation of the crust (Smith et al. 1998, Figure 2(B) [DIRS 118967]), or (2) detachment faulting (Hoisch et al. 1997, p. 2829 [DIRS 111854]). Neither of these processes has affected Yucca Mountain directly, and neither process is thought to have been a factor in local deformation within the past 5 million years (as inferred from Fridrich 1999, p. 190 [DIRS 118942]; Hoisch and Simpson 1993, p. 6822 [DIRS 106162]; Hoisch et al. 1997, p. 2829 [DIRS 111854]). The present extensional-tectonic regime of the Yucca Mountain region does not promote significant tectonic uplift and mountain building. Given the waning effect of extension east of Death Valley and south of the intermountain seismic belt at around 37°N latitude (inferred from Fridrich 1999, p. 191 [DIRS 118942]; and Dixon et al. 1995, p. 765 [DIRS 102793]), significant uplift at Yucca Mountain is unlikely and could not develop within the next few million years. Because significant uplift will not occur during the

repository-performance period (10,000 years), uplift will not provide a mechanism for affecting groundwater flow; therefore, uplift will not affect exposure to, or release of, radionuclides. Accordingly, uplift is *Excluded* from the TSPA-LA based on low consequence.

Based on the history of the Crater Flat Basin as presented by Fridrich (1999 [DIRS 118942]), tectonic subsidence due to regional extension is a more likely scenario at Yucca Mountain than uplift. However, the rate of subsidence appears to have diminished consistently over the last several million years, and the locus of subsidence due to the waning extension has migrated west of Yucca Mountain (inferred from Fridrich 1999, p. 189 [DIRS 118942]; Dixon et al. 1995, p. 765 [DIRS 102793]). During that same period, the western part of Crater Flat basin subsided due to the basin extending from 18 to 40 percent in 1.1 million years or less. After 11.6 Ma, the rate of extension in the basin declined in a roughly exponential manner, and the late Quaternary rate of extension is less than 1 percent of the initial rate (Fridrich et al. 1998, pp. 1 and 13 [DIRS 164051]), and may be as low as 0.1 to 0.2 percent per million years (Fridrich et al. 1998, pp. 19 and 20 [DIRS 164051]). Although the Crater Flat basin remains tectonically active, it is now in a very advanced state of decline, according to Fridrich et al. (1998, p. 2 [DIRS 164051]). Given projected fault-slip rates on the order of a few tenths of mm/year, subsidence-related effects at Yucca Mountain will be minimal. Because subsidence will be minimal during the repository-performance period (10,000 years), subsidence does not provide a mechanism that significantly affects groundwater flow; therefore, subsidence will not affect dose. Accordingly, subsidence is *Excluded* from the TSPA-LA based on low consequence during the period of interest.

FEPs based on the mechanisms of regional-scale folding, uplift, and subsidence are *Excluded* from the TSPA-LA based on their low consequence. In the interest of specificity however, various potential aspects are discussed in additional detail as follows:

The evaluation of this FEP included consideration of the change in the spatial relationship of the repository and the current water table due to a tectonic-related mechanism. If a significant rise in the water table were to occur, Crater Flat and Jackass Flats could become areas of springs discharge and seasonal ponding, and hypothetically are of concern. The mechanisms for such changes to occur could involve: (1) rising of the water level; (2) lowering of the repository; or (3) a combination of effects (1) and (2). This consequence is excluded due to the factors described in conditions 1, 2, and 3 below.

(1) *Rising of the water level*. The vertical distance between the base of the repository and the saturated zone is approximately 300 meters. Stuckless et al. (1996, pp. 98-99 [DIRS 119051]) discuss excursions of the water table in Plio-Pleistocene time, and indicate that past water level elevations are estimated to have been about 115 meters high or less. They further indicate that "neither geologic evidence for these past elevations nor hydrologic flow models suggest that the rises in water table in response to climate changes similar to those of the past 2 million years would be sufficient to threaten the repository horizon in the future."

    These past elevations reflect the effects of wetter climates and greater strain rates than currently exist. Climate changes have been considered and are included in the TSPA-LA models. Changes in strain rates could, hypothetically also cause an increase in water levels. However, a significant change in rates is extremely unrealistic because the horizontal geodetic strain-accumulation rate in the Yucca Mountain region is currently low, at approximately <2 mm/yr (Savage et al. 1999, p. 17627 [DIRS 118952], with the strain reported as a nanostrain/yr rate). Furthermore, regional strain patterns indicate waning effects of strain extension east of Death Valley (inferred from Fridrich 1999, p. 191 [DIRS 118942]) with minimal changes in strain conditions. A rise in water level, or change in head, could also be related to sudden changes in the strain conditions due to an earthquake and result in seismic pumping (e.g., see Gauthier et al. 1996, pp. 163-164 [DIRS 100447]). This corroborative analysis was performed for TSPA-VA to simulate the timing, amplitude, and duration of water-table rise, and indicated a maximum and temporary rise of 50 meters within an hour of a simulated seismic event (Gauthier et al. 1996, p.164 [DIRS 100447]). This mechanism is described more fully for FEP 1.2.10.01.0A (Hydrologic Response to Seismic Activity) and has been excluded.

Based on past geologic evidence as previously discussed and on the current tectonic setting, the potential rise in water levels due to tectonic activity alone, can be *Excluded* based on low consequence. This is because the maximum water level evidenced occurring in the past 2 million years of 115 meters above present conditions, is insufficient to reach the repository level. Thus, there is no effect on radionuclide release to the environment due solely to tectonic changes.

(2) *Lowering the repository:* Under long-term extension, normal faulting has caused the faulted blocks of Yucca Mountain to subside into Crater Flat basin. However, the rate of subsidence is proportional to the paleoseismic slip rate, amounting to no more than 30 meters in a 1 million year period (i.e., the fault slip rate is 0.03 mm/yr through one million years). This cumulative displacement (i.e., lowering of the repository) is small compared to the distance separating the repository and the water table. Also, any subsidence of the repository would likely be matched by additional subsidence of the basin. Therefore, cumulative fault offset alone is insufficient to cause the water table to approach the repository level, and such conditions would require greater than 10,000 years to develop, given current rates of fault movement at Yucca Mountain.

(3) *Combination of effects*: Even if expected subsidence (3 m in 10,000 years) occurs, the accompanying water table rise would need to be on the order of 200 meters for this FEP to be of any consequence. Based on geologic evidence as previously discussed, and as shown in the discussion regarding water table rise, the maximum increase in water table would be no more than 115 meters. So, the distance between the water level and the repository would decrease by no more than approximately 120 meters. The combined effects of an extremely unlikely maximum water table rise and an expected subsidence of 3 meters are insufficient to cause the water table to reach the repository level. Even if these two mechanisms were coupled with a seismic event (resulting in a temporary 50 meter water table rise, as previously discussed), the water table would still remain below the repository level.

Elevation of the potentiometric surface is influenced by many factors, including terrain relief, percolation, and base level. Also, evaluation of this FEP specifically considered the potential for uplift or subsidence to change drainage at the site and, thereby, increase infiltration. Two principal controls on drainage development at Yucca Mountain are further discussed: (1) tectonic control (i.e., uplift and subsidence), which determines base level and regional slope; and (2) climate, which is the most significant factor affecting infiltration rates and which also determines stream-gradient adjustments and erosion/sediment transport rates. For purposes of this FEP, discussions regarding effects of tectonic processes, stratigraphic control and weathering are ignored.

Infiltration depends on how much water is fed directly into fractured bedrock, either through bare bedrock (hill crests) or through basal drainage of saturated colluvium/alluvium. Very high rainfalls produce channeled debris flows on colluvial slopes, indicating that these slopes shed water efficiently and are not reservoirs for water percolation into the bedrock. Given the rapidity of stream-grade adjustment to climate change (as represented by the presence of debris flows), percolation flux associated with tectonically-controlled changes in drainage (as previously described related to rollover or strata tilting) is not likely influenced significantly by rates of tectonic-induced slope change or local base-level subsidence. The change in percolation flux is likely to be undistinguishable from the change in infiltration caused by climate change, and supports the screening decision based on low consequence.

Because of the low rates of uplift and subsidence at Yucca Mountain during the repository-performance period (10,000 years), tectonic-related changes on infiltration will be insignificant due to the percolation-flux effects dominance of possible climate change. Therefore, FEPs related to tectonic-induced infiltration changes are *Excluded* from the TSPA-LA based on their low consequence.

<u>Folding and Deformation</u>: "Folding, uplift or subsidence," as used in the FEP description, refers to the effects of the tectonic compression or extension processes. Regional compressive stresses that could produce uplift or deformation related to subhorizontal (compressive) fold axes have not operated in the Yucca Mountain region, or in the entire Great Basin, within the past 50 million years (i.e., since Sevier orogeny) (inferred from Keefer and Fridrich 1996, pp. 1-12 and 1-13 [DIRS 106728]). In fact, the Great Basin generally is a region of crustal extension. Therefore, compressional folding at Yucca Mountain during the repository performance period (10,000 years) is not geologically reasonable, and the probability of compressional folding at Yucca Mountain during the repository-performance period (10,000 years) is negligible.

Deformation of the tuff beds, associated with extension at Yucca Mountain, is expressed chiefly as "rollover" (i.e., the anelastic behavior of the hanging wall proximal to the footwall) (Fridrich et al. 1996, pp. 2–29 [DIRS 105086]). Rollover, rather than being strictly a folding mechanism, is a deformation process that accompanies normal faulting of materials exhibiting low elastic strength; it requires repeated and significant displacement and sufficient hanging-wall fracturing to appreciably reduce its elastic strength. Normal-fault movements at Yucca Mountain also may be associated with extension across fault planes. Hanging-wall rollover occurs as the extension and vertical displacement occurs along a fault plane, and segments of hanging wall near the fault plane fracture and turn down into the fault plane. Consequently, rollover folds at Yucca Mountain affect relatively small segments of the downthrown blocks, and the rollover folds are typically associated with increased fracturing as the block-bounding fault is approached. The rollover segments have been mapped, and the repository design considers this geologic feature.

Deformation at Yucca Mountain due to rollover is possible, but at a rate governed by rates for fault slip at Yucca Mountain. For the Bow Ridge fault, flattening foliations in the faulted tuffs dip steeply to the east (20° to 30°) into the graben(s) relative to the beds farther west in the unfaulted areas (8° to 15°) (Day et al. 1996, p. 2-7 [DIRS 124302] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). From this, it is inferred that within the last 12 million years, rollover has led to a dip-steepening of lithologic units of no more than 20° (or about 1.6° per 1 million years). Any further rollover is expected to proceed at a rate less than, or equal to, that of the past, resulting in a steepening of less than 2° in 1 million years.

A potential consequence involves tectonic deformation altering the dip of tuff beds and changing the percolation flux. This is predicated on the presumption that tuff bed dip constrains percolation flux and, on the presumption that flux is primarily controlled by the strata-confined matrix permeability, as opposed to flow through fractures. At Yucca Mountain, the potential for increased permeability in hanging-wall rollover segments from fracturing far outweighs the significance of matrix permeability in rollover segments. Given an approximate 25° critical angle of tilting (Fridrich et al. 1996, pp. 2-21 and 22 [DIRS 105086] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]), the tuff beds will likely fracture and slip before the change in their orientation (i.e., an increase in fold-limb dip associated with rollover) becomes a significant factor in local percolation flux. Given the low rate of normal-fault activity at Yucca Mountain and the small offsets per slip event, any increase in hanging-wall rollover that would affect percolation flux is extremely unlikely. Because of the low dips involved, the very low folding rates (as expressed through local cumulative slip rates), and the significant influence of local fractures in local percolation flux, this FEP is *Excluded* from the TSPA-LA based on low consequence. The effects of fractures on percolation flux are evaluated in the *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000 [DIRS 151953]). Changes in fracture aperture confined to fault zones show virtually no effect on transport behavior, and an increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than other uncertainties related to infiltration (CRWMS M&O 2000, Section 7 [DIRS 151953]).

The rate of change in dip is insufficient to lead to a significant change in percolation rates. This portion of the FEP (folding and deformation) is, therefore, *Excluded* based on low consequence.

<u>Geothermal Effects</u>: Concerns that tectonic changes could induce local geothermal flux or convective flow in the saturated zone also are *Excluded* from the TSPA-LA based on low consequence.

Some of the conditions conducive to geothermal activity (and associated hydrothermal activity) previously occurred in the 14-9 Ma interval to form the southwest Nevada volcanic field (inferred from Axen et al. 1993, pp. 69-70 [DIRS 101597]). However, the crust at Yucca Mountain has been cooling since final eruption of the Timber Mountain caldera, which deposited the uppermost volcanostratigraphic unit at Yucca Mountain about 11.4 million years ago (Sawyer et al. 1994, Table 1 [DIRS 100075]). Formation of the caldera complex exhausted the late Miocene heat source, and the crust has been cooling steadily for the past 9 million years (inferred from Crowe et al. 1995, pp. 4-1 and 4-2 [DIRS 100110]). Additionally, Yucca Mountain is located in an area of moderate heat flow in the Southern Great Basin and lies south of the relatively high crustal heat flow regions in the Great Basin (Lachenbruch and Sass 1978, pp. 212 and 246 [DIRS 142990]). Furthermore, only small volumes (<0.5 km^3) of basaltic magma have been generated in the Yucca Mountain region during the Quaternary (Crowe et al. 1995, p. 5-5 [DIRS 100110]). The source depth of these magmas is approximately 60 km (Crowe et al. 1995, p. 5-2 and Figure 5.1 [DIRS 100110] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). These observations can be interpreted to indicate a waning volcanic setting (Crowe et al. 1995, pp. 4-1, 4-2, 5-5, and 5-15 [DIRS 100110]).

Silicic volcanism (magmatism) is an early-phase event in the development of crustal features. In the Yucca Mountain vicinity, silicic magmatism events ended approximately 11 million years ago and are not likely to reoccur during the compliance period, if at all (BSC 2003, Section 6.2 [DIRS 163769]). Hydrothermal activity is, usually, the 'cooling' stage in a silicic magma intrusion. The presence of silica, calcite, and clay vein deposits and mineral replacement assemblages indicate the presence of past hydrothermal activity as seen in the Calico Hills and along the south flank of Shoshone Mountain. Hydrothermal activity is conspicuous in the Calico Hills and along the south flank of Shoshone Mountain, but comparable hydrothermal activity has not been identified at Yucca Mountain. The Calico Hills is an intrusion-related dome, but Yucca Mountain is located outside the caldera margin, hence it was never near a hydrothermal source (BSC 2003, Figure 3 [DIRS 163769]). Deuteric, not hydrothermal, mineral alteration has occurred in the Yucca Mountain vicinity.

An increase in geothermal gradient sufficient to cause convective flow in the saturated zone would require a significant change in geologic conditions, and any significant change in regional strain rates and orientation at Yucca Mountain would likely be signaled by an increased heat flux (Lachenbruch and Sass 1978, p. 224 [DIRS 142990]) and by a prolonged period of seismicity. The existing geothermal gradient could, theoretically change rapidly, but only if a large volume of magma were emplaced high in the mid-to-upper crust (at approximately 5 km depth) (inferred from Lachenbruch and Sass 1978, pp. 224 and 244 [DIRS 142990]). This, hypothetically, could bring the Yucca Mountain area to a pre-eruptive state with attendant hot-spring activity. Such a scenario would require great extension rates and crustal mobility, a rapidly evolving mantle, and subcrustal conditions that involve either a mantle plume hot spot (Parsons et al. 1994, p. 83 [DIRS 106479]) or melting of weakened subducting slab (inferred from Bohannon and Parsons 1995, p. 957 [DIRS 101865]). However, such conditions are at odds with the current geologic and tectonic setting previously described.

Given the present and foreseeable tectonic state of Yucca Mountain (slow rate of extension, minimal rate of subsidence), the present source of basaltic-magma generation at depths of approximately 60 km, and the lack of conditions suitable for hydrothermal activities in the last two million years, it is concluded that a potentially significant increase in geothermal gradient would require several million years of evolution. Because of the time required for development, geothermal-gradient changes do not provide a mechanism sufficient to affect the repository performance within the next 10,000 years. Because there would be no affect on repository performance, there would be no significant change to the expected dose or release of radionuclides. Consequently, this FEP is *Excluded* from the TSPA-LA based on low consequence.

6.2.1.2 Fault Displacement Damages EBS Components (1.2.02.03.0A)

FEP Description: A fault intersects drifts within the repository. The fault undergoes movement. The EBS components experience related movement or displacement such that performance is degraded by such things as tilting of components, component-to-component contact, or drip shield separation. Or, it could be as significant as failure due to the shearing of drip shields and waste packages by virtue of the relative offset across the fault, or as extreme as exhumation to the surface.

Descriptor Phrases: Fault displacement (drip shield separation), Fault displacement (waste package shearing), Fault displacement (floor buckling damage to pallet), Fault displacement (floor buckling damage to invert), Fault displacement (exhumation)

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event being considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Included* (BSC 2003, Table 4 [DIRS 161812])

Screening Argument: Not Applicable

TSPA Disposition: Faulting is considered to be a potentially disruptive process with effects that include sudden relative rock/soil displacements across a fault surface (i.e., fault displacement). These effects are potentially relevant to the integrity of the repository and are *Included* in the TSPA-LA. Ground motions associated with fault displacements and rock fall are addressed under separate FEPs.

For this FEP, the discussion is limited to presenting the probable fault displacements leading to the relative offset of drifts (or tunnels). Consequences, and the manner of inclusion, are addressed in the model report *Seismic Consequence Abstraction* (BSC 2003, Sections 6.8.5 and 6.10 [DIRS 161812]). The following technical basis for inclusion involves a comparison of the fault displacement occurring with a 10^{-8} annual frequency (see Assumption 5.1 of this analysis report (ANL-WIS-MD-000005) to various elements of the repository design (i.e., waste package-to-drift wall spacing and set-back requirements). The potential for fault displacement damage from intra-block faults and features likely to exist within the repository are explicitly *Included* in the TSPA-LA. The repository design serves as the basis for the TSPA-LA model. Consequently, other fault displacements are considered to have been implicitly included because the displacements are accommodated by design features such as gaps between EBS elements, or in the case of the Solitario Canyon fault, by the use of set-back requirements.

The history of faulting and the nature of fault slip and its structural effects at Yucca Mountain are well known (CRWMS M&O 1998 [DIRS 103731]; and Whitney 1996 [DIRS 100188]). In situ stress measurements indicate that faults at Yucca Mountain are at the point of failure (Stock and Healey 1988, p. 92 [DIRS 101022]; Stock et al. 1985, p. 8705 [DIRS 101027]) suggesting that a fault displacement potential should be evaluated. The PSHA provides the results of the expert-elicitation process as it applies to probable fault displacements.

The PSHA (CRWMS M&O 1998, Figures 8.2 through 8.14, and p. 8-7 [DIRS 103731]) specifically examines displacements along block-bounding faults (Points 1 and 2), intrablock faults (Points 3 through 6 and 9) and for features likely to be found within the repository (Points 7 and 8) with various preexisting conditions, including the occurrence of features within the intact rock (Points 7d and 8d). These points were chosen to represent the range of conditions that may be encountered near or within the repository. Table 6-4 provides the median and mean fault displacements for the 10-8 annual-exceedance probability. Although the mean values for fault displacements at annual-exceedance probabilities of less than 10^{-6} are increasingly skewed due to uncertainty (compare median values to the mean values), the mean values shown in Table 6-4 represent a cautious projection of potential fault displacements and are used for the following evaluations discussed.

Table 6-4. Annualized Frequency of Exceedance and Displacements for Various Locations within the TSPA-LA Repository Footprint.

Location	Annual Frequency Associated with 20-cm displacement	Median Displacement (cm) for Postclosure	Mean Displacement (cm) for Postclosure
		Annual Frequency	
		10^{-8}	10^{-8}
1. Bow Ridge Fault	7×10^{-6}	200	600
2. Solitario Canyon Fault	2×10^{-5}	300	>1000
3. Drill Hole Wash Fault	9×10^{-7}	30	240
4. Ghost Dance Fault	7×10^{-7}	59	160
5. Sundance Fault	4×10^{-7}	9.9	~145
6. Unnamed fault west of Dune Wash	8×10^{-7}	20	210
7a. A hypothetical small fault with 2 m of offset, located about 100 m east of Solitario Canyon Fault	1×10^{-7}	2.1	~75
7b. A hypothetical shear with 10 cm of offset, located about 100 m east of Solitario Canyon fault	N/A	<0.1	9
7c. A hypothetical fracture, located about 100 m east of Solitario Canyon fault (no cumulative displacement)	N/A	<0.1	<1
7d. Intact rock, located about 100 m east of Solitario Canyon Fault	N/A	<0.1	<0.1

Table 6-4. Annualized Frequency of Exceedance and Displacements for Various Locations within the TSPA-LA Repository Footprint (Continued)

Location	Annual Frequency Associated with 20-cm displacement	Median Displacement (cm) for Postclosure	Mean Displacement (cm) for Postclosure
		Annual Frequency	
		10^{-8}	10^{-8}
8a. A hypothetical small fault with 2 m of offset, located between the Solitario Canyon fault and the Ghost Dance fault	1x 10^{-7}	2.1	~75
8b. A hypothetical shear with 10 cm of offset, located between the Solitario Canyon fault and the Ghost Dance fault	N/A	<0.1	9
8c. A hypothetical fracture, located between the Solitario Canyon fault and the Ghost Dance fault	N/A	<0.1	<1
8d. Intact rock, located between the Solitario Canyon fault and the Ghost Dance fault	N/A	<0.1	<0.1
9 Midway Valley, fracture with no cumulative displacement	7 x 10^{-7}	28	200

Source: Mean values were taken from the cited DTN: MO0004MWDRIFM3.002 [149092] from files

/displ/tot_haz/s1.frac_mean.gz; ./displ/tot_haz/s2.frac_mean.gz; ./displ/tot_haz/s3.frac_mean.gz; ./displ/tot_haz/s4.frac_mean.gz; ./displ/tot_haz/s5.frac_mean.gz; ./displ/tot_haz/s6.frac_mean.gz; ./displ/tot_haz/s7a.frac_mean.gz; ./displ/tot_haz/s7b.frac_mean.gz; ./displ/tot_haz/s7c.frac_mean.gz; ./displ/tot_haz/s7d.frac_mean.gz; ./displ/tot_haz/s8a.frac_mean.gz; ./displ/tot_haz/s8b.frac_mean.gz; ./displ/tot_haz/s8c.frac_mean.gz; ./displ/tot_haz/s8d.frac_mean.gz; ./displ/tot_haz/s9.frac_mean.gz.;

Notes: Zero displacement at Sites 7d and 8d at >10-8 annual frequency is documented in DTN: MO0004MWDRIFM3.002 [DIRS 149092]. See also CRWMS M&O 1998 (Section 8.2.1, [DIRS 103731]). Some displacement information was scaled from figures presented in the PSHA (CRWMS M&O 1998, Figures 8.2 through 8.14, and was stated in the text on p. 8-7 [DIRS 103731] and may be approximate. Median and mean values for 10-8 annual frequency were extrapolated from CRWMS M&O 1998, Figures 8-3 for Site 2, and median value was extrapolated for Figure 8-5 for displacement hazards at Site 4.

Inclusion of Block-Bounding Faults—The block-bounding faults include the Bow Ridge fault (Point 1) and the Solitario Canyon fault (Point 2). The Bow Ridge fault is located to the east of the waste emplacement area, whereas the Solitario Canyon fault parallels and forms part of the western repository footprint boundary. At a 10^{-8} annual-exceedance probability (see Assumption 5.1), the estimated mean displacements are 6 meters and >10 meters, respectively.

The use of setbacks is a project requirement for Type I block-bounding faults. The potential displacements from the block-bounding faults are implicitly included because the repository design that is being used as the basis for the TSPA-LA includes set-back requirements, and the repository design is part of the technical basis used to evaluate the repository performance.

In the case of the Bow Ridge fault, the north to northeast trending faults located east of the Ghost Dance fault do not intersect the repository footprint and are located sufficiently distant from the repository (see following paragraphs addressing fault/fracture relationships) such that set-back requirements are inherently satisfied, and explicit consideration within the TSPA-LA is not required. This also applies to the intra-block Ghost Dance fault located east of the repository, as it does not intersect the waste emplacement area. In the case of the Solitario Canyon fault, specific setback requirements have been instituted as part of the design documentation.

The following applicable criteria for fault setback have been developed based on engineering judgment and analyses based on pre-closure criteria. The design criteria for a setback is taken from *Project Design Criteria Document* (Minwalla 2003, Section 4.11.2 [DIRS 161362]) as:

> "Establish a minimum 60-m (200-ft) standoff between Type I faults and repository emplacement openings."

By way of corroboration and clarification, this is noted in 800-P0C-MGR0-00100-000-00E (BSC 2003, Sections 7.1.3 and 7.3.1 [DIRS 165572]), which is quoted as follows (with WP in the quote meaning waste package):

> "It is conservatively estimated that a 60-meter (197 foot) standoff from the trace of any Type I fault is adequate to reduce the impact of potential fault movement. …This standoff considers potential fractured ground in proximity of the Type I fault and uncertainty as to where the fault is located at depth. The use of a 60-meter (197-foot) standoff for a LA design is conservatively applied."

> "In the event that the standoff from repository openings to a Type I fault is waived following a site impact analysis, a standoff must be maintained between Type I faults and any WP. A standoff must be maintained between splays associated with Type I faults and any WP. Areas that contain Type I faults should be avoided but, if unavoidable, they must be allowed for in engineering design. It is conservatively estimated that a standoff from the edge of the Type I fault or fault zone by 15 meters (49-feet) is adequate to reduce the impact of potential fault movement. Using a 15-meter (49-foot) standoff to establish useable drift length for the LA design is conservatively applied."

For YMP, this means that no packages will be placed closer than 60 meters to the main trace of the Solitaro Canyon fault unless a specific site impact analysis is performed. Consequently, the potential for displacements between the fault and 60 meters need not be explicitly included for postclosure considerations as no waste packages or drip shield will be present in that interval. The footprint and location of the waste emplacement area, determined in part by the set-back requirements, serves as part of the basis for evaluating repository performance. Consequently, the effects of displacement from the Solitario Canyon fault are implicitly addressed in the TSPA-LA.

In support of setback requirements use, conclusions from Sweetkind et al. (1997, pp. 67 to 71 [DIRS 100183]) suggest that faulting and fracturing are spatially related. Spatial relationships based on the results of underground fault mapping have led to the definition/description of zones of influence around faults based on the observation that fracture frequency generally increases as faults are approached. The consideration of the zone of influence near faults is important because it helps define the potential for displacements in the drifts on either side of a fault/drift intersection, which determines in part, the number of waste packages that could potentially be affected.

The first conclusion from the study is that mapping results have shown that widths of zones of influence are generally quite narrow, ranging from less than 1 meter to about 7 meters from faults. The second conclusion is that the width of the zone of influence in the immediate vicinity of a fault generally correlates with the amount of cumulative fault offset. Therefore, faults having the largest potential future displacement are the most likely to influence the repository block. For instance, in the Solitario Canyon fault zone in the ECRB Cross Drift, the total displacement is approximately 260 meters, but the gouge and brecciated zones are limited to less than 20 meters (Mongano et al. 1999 pp. 59-65 [DIRS 149850]). Faults having tens of meters of cumulative offset (e.g., faults at ESF Stations 11+20, 67+88, and 70+58) have zones of influence that range up to 10 meters wide.

Intrablock faults, mentioned in the following discussion, having very small amounts of existing cumulative offset (1 to 5 m) have zones of influence that are 1 meter to 2 meters wide. The evaluation of the potential for damage from intrablock faults described takes into account the observations that gouge and brecciated zones are present only in limited proximity to fault planes.

<u>Inclusion of Intrablock Faults and Features Likely to Be Found in the Repository</u> — The intra-block faults are mapped features that intersect the repository footprint area. They include, but are not limited to, the Drill Hole Wash fault (Point 3), the Ghost Dance fault (Point 4), the Sundance Fault (Point 5), an unnamed fault west of Dune Wash (Point 6) and the Midway fault (Point 9). Because of the orientation and location of the Drill Hole Wash fault, the estimated displacements are used as an analog for possible displacement along the additional intrablock Pagany Wash fault and Sever Wash fault, which transect the northeast portion of the repository footprint. At a 10^{-8} annual-exceedance probability (see Assumption 5.1), the 85^{th} fractile and mean fault displacements for intrablock faults are, with one exception, less than or equal to 2 meters. The exception is for the mean fault displacement of the Drill Hole Wash fault, which is approximately 2.5 meters.

Additionally, features that are likely to be found within the repository are represented in the PSHA using a fixed location within the repository, but with hypothetical existing characteristics (Points 7 and 8). The PSHA (CRWMS M&O 1998, Figures 8.8 through 8.13 [DIRS 103731]) addresses such features within the waste-emplacement area by assessing the probability of displacement along existing small faults, shears, and fractures, as represented in the PSHA for Points 7a, 7b, 7c, 8a, 8b, and 8c and as explained in Table 6-4. The mean 10^{-8}

annual-exceedance probability for these small faults, shears, and fractures is slightly less than 1 meter, 10 cm, and <1 cm, respectively. The PSHA (CRWMS M&O 1998, p. 8-7 [DIRS 103731]) also examines the probability of displacement in the intact rock (Points 7d and 8d) at these hypothetical locations, and indicates that there is only a very unlikely probability (<10^{-8} annual-exceedance probability) that movement greater than 0.1 cm will occur in the intact rock. The potential for displacement in the intact rock is inferred analogous to the creation of new faults and fractures.

Based on the intrablock faults and the features likely to exist within the repository, the scale of displacements considered ranges from about 2.5 meters to <0.001m (for the intra-block faults and the features likely to be found in the repository, respectively). To determine whether this range of displacements is significant to repository performance, they are compared to the spatial gaps between various EBS components. The results of such a gap analysis are found in Tables 20 and 21 of the *Seismic Consequence Abstraction* (BSC 2003 [DIRS 161812]). The gap analysis is based on the drawings and design documents listed in Table 1 of that document.

The analysis shows that most all of the waste packages (with the exception of the naval and defense high level waste (DHLW) packages) would remain undamaged even for the 10^{-8} annual frequency fault displacement at locations 7a, b, c and 8a, b, c. This is because the maximum displacement for any of these sites (75 cm for Site 7a and 7b) is always less than the available clearances and maximum allowable displacements shown in the seismic consequence model report (BSC 2003, Tables 20 and 21 [DIRS 161812]). However, the waste packages containing Naval fuels or DHLW would potentially fail when placed over a small displacement fault (designated 7a and 8a). Several of the waste package designs also could potentially fail due to fault displacement for hazards near the 10^{-8} per year level if they are directly over any of the four known faults (Drill Hole Wash, Sundance, Pagany Wash, and Sever Wash) intersecting the emplacement drifts.

The actual response of the EBS components to a fault displacement scenario, however, is complicated. As a conservative simplification, the fault displacement is analyzed in TSPA-LA by considering: (1) the fault as perpendicular to the tunnel axis with the displacement being purely vertical, and (2) that the fault displacement occurs at a discrete point, creating a "knife-edge" discontinuity. As previously described, studies of the repository suggests that much of the strain will be mechanically dissipated within or near the fault planes. For example, the Dune Wash fault (as exposed in the ESF) exhibits a cumulative offset of 65 meters, but the zone of increased fracture frequency near the fault is only 6 meters to 7 meters wide (Sweetkind et al. 1997, Table 21 [DIRS 100183]). A second example is the Sundance fault in the ECRB Cross Drift. The Sundance fault has a presumed, though indeterminate, displacement of several meters. However, the footwall rock is intact at a distance of only 10 cm from the fault plane. The hanging wall of the Sundance fault is slightly more fractured, having an intensely fractured zone about 1 meter thick (Mongano et al. 1999, pp. 52-54 [DIRS 149850]).

The evaluation of potential damage due to fault displacement near fault zones is further evaluated and *Included* in the TSPA-LA analysis as described in Sections 6.8.5 and 6.10 of *Seismic Consequence Abstraction* (BSC 2003 [DIRS 161812]). In general, the expected number of damaged waste packages on four secondary faults is evaluated for displacements corresponding to a range of annual exceedance frequencies, based on the mean hazard curves for the Sundance

Fault, the Drill Hole Wash Fault, the Pagany Wash Fault, and the Sever Wash Fault. The evaluation considers the clearances between various types of waste packages and the drip shield, and on the expected numbers of waste packages that lie on these four faults. Furthermore, the potential for DLHW packages to be placed where existing, previously unknown features exist is also incorporated into the analysis on a probabilistic basis. Damage to the waste package is sampled from a uniform distribution with a lower bound of no damage and an upper bound given by the area of the waste package lid. The uniform distribution is a simple approximation to the upper and lower damage bounds in lieu of detailed structural response calculations. The upper bound is a reasonable estimate for a severely crimped waste package that loses its lid due to welds holding the lid in place cracking. The lower bound is a reasonable estimate for a waste package that is minimally damaged, either because fault displacement slightly exceeds the available clearance or because the package shear occurs at the opposite end of the waste package from the lid.

The FEP description also mentions the extreme case of fault displacements leading to waste exhumation. The probabilistically determined mean displacements (less than or equal to 10 meters for an individual event) are either implicitly or explicitly included in the TSPA-LA, as previously described, and define the potential for single-event movements to occur in a 10,000-year period and damage the waste packages. The potential for exhumation to occur due to fault movement is not credible given the existing cumulative displacement rate of 0.001-0.03 mm/yr (CRWMS M&O 2000, Table 6 [DIRS 142321]) or less than 0.3 meters in 10,000-years. The depth of the repository below the surface is on the order of 200 meters or greater. Generally speaking, the surface elevation of the repository decreases eastward. The elevation along the eastern edge of the repository, with the exception of topographic relief in drainages and washes, is on the order of 1250 to 1280 meters (4,100 to 4,200 ft). Drawing 800-IED-EBS0-00401-000-00C [DIRS 162289], in comparison to Figure 1 of BSC 2002 [DIRS 159124], indicates that the easternmost drifts are in the area of lowest ground surface elevations and include drifts 2-1E through 2-19E. Drawing 800-IED-EBS0-000402-000-000-00B [DIRS 161727] indicates that the endpoint elevations for these drifts varies from 1042 meters for Drift 2-1E, to as high as 1063 meters for Drift 2-19E. This suggests a difference in elevation (or depth to the repository) of 208 meters to 238 meters. A more detailed analysis can be had by scaling the end-points of the drifts from the grid presented in Drawing 800-IED-EBS0-00401-000-00C [DIRS 162289] and subtracting the corresponding end-drift elevations from the nearest topographic grid point provided in DTN: MO0002SPATOP00.001 [DIRS 152643]. The northernmost and southernmost drifts (Drifts 2-1E and 2-19E) were selected based on minimum and maximum drift elevations in the eastern part of the repository, and Figure 5 and DTN: MO0002SPATOP00.001 [DIRS 152643] were inspected to determine where the deepest draw and lowest elevation of the topographic grid occurred within the repository footprint (Drift 12-E) (see Table 6-5 in Section 6.2.2.4 of this report (ANL-WIS-MD-00005 REV 01). A minimum value of 211 meters was calculated and is corroborated by a value of 215 meters of overburden above the waste emplacement area as indicated in 800-P0C-MGR0-00100-000-00E (BSC 2003, Section 7.1.8 [DIRS 165572]). The calculated minimum value could be in error by as much as 10 meters, as it is based on only the three selected points. Regardless of the exact minimum value of overburden, the included fault displacements of 0.3 meter in 10,000-years are clearly insufficient to exhume waste to the ground surface within a 10,000-year period.

In summary, the potential for fault displacement to damage EBS components has been examined. In the case of block-bounding faults and faults existing outside of the waste emplacement area, the potential displacement is implicitly included in the design, and the repository footprint is used as the basis for the TSPA-LA evaluation. The potential for damage from intrablock faults and features likely to exist in the repository have been explicitly included in the TSPA-LA model.

Related FEPs:

FEPs that examine related but distinct effects and consequences

Tectonic activity—large scale (1.2.01.01.0A)
Seismic ground motion damages EBS components (1.2.03.02.0A)
Seismic-induced rockfall damages EBS components (1.2.03.02.0B)
Seismicity associated with igneous activity (1.2.03.03.0A)

FEPs that examine similar effects and consequences

Mechanical impact on waste package (2.1.03.07.0A)
Mechanical impact on drip shield (2.1.03.07.0B)
Mechanical degradation of pallet (2.1.06.05.0A)
Mechanical degradation of invert (2.1.06.05.0B)
Floor buckling (2.1.07.06.0A)

Related Documents: *Seismic Consequence Abstraction*
MDL-WIS-PA-000003 (BSC 2003 [DIRS 161812])

Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada
ANL-CRW-GS-000003 (CRWMS M&O 2000 [DIRS 142321])

Supplemental Discussion: None

6.2.1.3 Seismic Ground Motion Damages EBS Components (1.2.03.02.0A)

FEP Description: Seismic activity causes repeated vibration of the EBS components (drip shield, waste package, pallet, and invert). This could result in severe disruption of the drip shields and waste packages through vibration damage or contact between EBS components. Such damage mechanisms could lead to degraded performance.

Descriptor Phrases: Seismic ground motion (drip shield separation); Seismic ground motion (drip shield vibration); Seismic ground motion (drip shield stress corrosion cracking); Seismic ground motion (waste package vibration and dislodgement); Seismic ground motion (waste package stress corrosion cracking); Seismic ground motion (drip shield contacts waste package); Seismic ground motion (cladding damage); Seismic ground motion (invert damage); Seismic ground motion (ground support damage)

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Included* (BSC 2003, Table 4 [DIRS 161812])

Screening Argument: Not Applicable

TSPA Disposition: Ground motion associated with seismic activity has the potential to disrupt the integrity of components of the EBS or waste packages. These events could lead to impaired container performance and/or breaching, with subsequent radionuclide release. Seismic ground motion damage is included in the TSPA-LA using damage areas on EBS components based on vibratory ground motions at 5×10^{-4} per year, 10^{-6} per year, and 10^{-7} per year levels.

The ground motion hazard curves developed for the PSHA were extended to address ground motion during the postclosure period as documented in DTN: MO03061E9PSHA1.000 [DIRS 163721]. The seismic time histories contained in the following DTNs were developed starting with the results of the PSHA (CRWMS M&O 1998 [DIRS 103731]) and take into account the effect of the upper 300 meters of rock/soil at the site (site response). These repository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* (BSC 2003 [DIRS 166274]). The ground motion time histories were developed for 5×10^{-4}, 10^{-6} and 10^{-7} annual exceedance probabilities (see Assumption 5.1 of this report, ANL-WIS-MD-000005 REV. 01) and have been used in various seismic-related AMRs to provide inputs to support the postclosure analyses of damage to EBS components from seismic ground-motion, seismic-induced rockfall, and the effects related to seismic-induced drift collapse. The outputs include, but are not limited to:

MO0211AVTMH107.001. Acceleration, Velocity, and Displacement Spectrally Conditioned Time Histories for the Repository Level at 10^{-7} Annual Exceedance Frequency ([DIRS 161513])

MO0301TMHIS106.001. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at 10^{-6} Annual Exceedance Frequency ([DIRS 161868])

MO0211TMHIS104.002. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at $5x10^{-4}$ Annual Exceedance Frequency [DIRS 161540]).

The outputs are of particular interest because they are used by the *Drift Degradation Analysis* (BSC 2003 [DIRS 162711]) to determine rockfall and drift-collapse effects related to seismic-induced ground motion, which are each addressed in related FEPs.

Additionally the following outputs were used to determine ground motion damage to EBS components:

MO0212AVDSC106.000. Acceleration, Velocity, and Displacement Spectrally Conditioned Time Histories for the Repository Level at 10-6 Annual Exceedance Frequency [DIRS 164206]

MO0303DPGVB106.002. Design Peak Ground Velocity for the Repository Level (Point B) at 10-6 Annual Exceedance Probability [DIRS 162712]

MO0210PGVPB107.000. Design Peak Ground Velocity for the Repository Level (Point B) at 10-7 Annual Exceedance Probability [DIRS 162713].

The characterization of seismic damage incorporates these and other inputs to determine damage-related response surfaces, which is fully discussed in the model report *Seismic Consequences Abstraction* (BSC 2003 [DIRS 161812]). Of particular interest for this FEP are the peak ground velocity (PGV) values. The horizontal PGV values have been calculated for the 10^{-6} per year and 10^{-7} per year mean annual exceedance frequencies at the emplacement drifts (called Point B in the PSHA). The horizontal PGV value for the 10^{-6} per year ground motions is 2.44 m/s (MO0303DPGVB106.002 [DIRS 162712]). The horizontal PGV value for the 10^{-7} per year ground motions is 5.35 m/s (MO0210PGVPB107.000 [DIRS 162713].

Damage from seismic events is expressed as a failed area on the surfaces of the waste package, the drip shield, and the cladding. Section 6.5.1 of the cited model report addresses waste packages, Section 6.6.3 addresses drip shields, and Section 6.7 addresses fuel cladding. In general, the model report (BSC 2003 [DIRS 161812]) uses structural response calculations for the waste package and drip shield as the basis for predicting failed areas for advective flow and transport. The criteria for failure are based on a residual stress threshold of between 80 percent and 90 percent of the yield strength for Alloy 22, and of 50 percent of the yield strength for Titanium Grade 7. A summary of the damage abstraction from Sections 6.5.1 and 6.6.3 and 6.7 (BSC 2003 [DIRS 161812]), are given in the following paragraphs:

Structural analyses for the waste package and drip shield have been performed using a single set of vibratory ground motions (with two horizontal components and one vertical component) for an annual exceedance frequency of 5×10^{-4} per year. The results of these analyses demonstrate that the response of the waste package and drip shield are always in the elastic regime for the 5×10^{-4} per year ground motion, with no damage to the structures. For less frequent ground motions, however, failed areas occur in response to impact of the waste package on the emplacement pallet and to end-to-end impacts of adjacent waste packages.

Because damage to the waste package is always much less than 100 percent, the failed areas are abstracted as a uniform distribution with a lower bound of zero (0) and an upper bound that is a function of the PGV. The upper bound of the uniform distribution has been increased to ensure conservatism with respect to the lognormal distribution over a PGV range of 1 to 6 m/s. Damage to the cladding is also included in the seismic scenario class for TSPA-LA. Structural response calculations for end-to-end impacts of adjacent waste packages define the axial loads on fuel assemblies. These loads are compared to fuel rod failure criteria based on buckling for various

fuel pin designs. Comparison of axial loads with the failure criteria indicates that most, if not all, fuel pins will fail under vibratory ground motions at the 10^{-6} per year and the 10^{-7} per year levels. Cladding however, will not fail from the vibratory ground motion at the 5×10^{-4} per year level.
Related FEPs:

FEPs that examine related but distinct effects and consequence

Tectonic activity—large scale (1.2.01.01.0A)
Fault displacement damages EBS components (1.2.02.03.0A)
Rockfall (2.1.07.01.0A)
Drift collapse (2.1.07.02.0A)

FEPs that examine similar effects and consequences

Seismic-induced rockfall damages EBS components (1.2.03.02.0B)
Seismic-induced drift collapse damages EBS components (1.2.03.02.0C)
Seismic-induced drift collapse alters in-drift thermohydrology (1.2.03.02.0D)
Seismicity associated with igneous activity (1.2.03.03.0A)
Mechanical impact on waste package (2.1.03.07.0A)
Mechanical impact on drip shield (2.1.03.07.0B)
Mechanical degradation of pallet (2.1.06.05.0A)
Mechanical degradation of invert (2.1.06.05.0B)
Floor buckling (2.1.07.06.0A)

Related Documents: *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada*
MDL-MGR-GS-000003 (BSC 2003 [DIRS 166274])

Drift Degradation Analysis
ANL-EBS-MD-0000027 (BSC 2003 [DIRS 162711])

Seismic Consequence Abstraction
MDL-WIS-PA-000003 (BSC 2003 [DIRS 161812])

Supplemental Discussion: None

6.2.1.4 Seismic-induced Rockfall Damages EBS Components (1.2.03.02.0B)

FEP Description: Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced rockfall that could impact drip shields, waste packages, or other EBS components

Descriptor Phrases: Seismic-induced rockfall (drip shield damage); Seismic-induced rockfall (drip shield stress corrosion cracking); Seismic-induced rockfall (waste package damage); Seismic-induced rockfall (drip shield contacts waste package); Seismic-induced rockfall (waste

	package dislodgement); Seismic-induced rockfall (cladding damage); Seismic effects on rockfall [Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]
Screening Decision:	*Included* (BSC 2003, Table 4 [DIRS 161812])
Screening Argument:	Not Applicable
TSPA Disposition:	Because of the additional imposed stresses, seismic ground motion has the potential to dislodge blocks. This could result in additional damage to the drip shields through mechanical impact mechanisms, and possibly the waste packages (if the drip shields fail) via increased seepage through a damaged or separated drip shield and is *Included* in the TSPA-LA.

It is anticipated that rockfall occurring within lithophysal zones will result in relatively smaller rock fragments with insufficient mass and energy to permanently deform or damage the drip shields. Therefore, damage to the drip shield from rockfall in the lithophysal units is neglected for TSPA-LA. The following discussion addresses only the potential damage to drip shields resulting from the impact of relatively large rock blocks, more likely to occur in nonlithopysal zones. The mechanical response of the drip shield to an impact by large rock blocks from the nonlithophysal unit has the potential to damage the drip shield's ability to act as a flow barrier. The abstraction for the percent failed surface area mode is included as a function of peak ground velocity. An *en masse* fall of rock fragments, for FEPs purposes, constitutes drift collapse. Seismic-induced drift collapse is addressed as FEP 1.2.03.02.0C in Section 6.2.15 of this analysis report (ANL-WIS-MD-000005 REV 01).

The ground motion hazard curves developed for the PSHA (CRWMS M&O 1998 [DIRS 103731]) were extended to address ground motion during the postclosure period as documented in DTN: MO03061E9PSHA1.000 [DIRS 163721]. The seismic time histories contained in the following DTNs were developed starting with the results of the PSHA and take into account the effect of the upper 300 meters of rock/soil at the site (site response). The repository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* (BSC 2003 [DIRS 166274]). The ground motion time histories were developed for 5×10^{-4}, 10^{-6} and 10^{-7} annual exceedance probabilities (see Assumption 5.1 of this report, ANL-WIS-MD-000005 REV. 01) and have been used in various seismic-related AMRs to provide inputs to support postclosure analyses of damage to EBS components from seismic ground-motion, seismic-induced rockfall, and effects related to seismic-induced drift collapse. The outputs include, but are not limited to:

MO0211AVTMH107.001. Acceleration, Velocity, and Displacement Spectrally Conditioned Time Histories for the Repository Level at 10^{-7} Annual Exceedance Frequency ([DIRS 161513])

MO0301TMHIS106.001. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at 10^{-6} Annual Exceedance Frequency ([DIRS 161868])

MO0211TMHIS104.002. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at $5x10^{-4}$ Annual Exceedance Frequency ([DIRS 161540]).

These outputs are of particular interest because they are used by the *Drift Degradation Analysis* (BSC 2003 [DIRS 162711]) to determine rock block size, rockfall frequency, and drift-collapse effects related to seismic-induced ground motion, which are addressed in related FEPs. The outputs of that analysis are used to evaluate damage to EBS components from seismically induced rockfall, which is included in the seismic scenario class for TSPA-LA.

In general, vibratory ground motions can cause failure of the host rock around the emplacement drifts. The characterization of seismic damage is addressed using damage-related response surfaces and is fully discussed in the model report *Seismic Consequences Abstraction* (BSC 2003, Section 6.6 [DIRS 161812]). Damage to the drip shield from impact of individual rock blocks is determined by structural response calculations. The objective of these calculations is to determine the drip shield areas where the residual stress exceeds the threshold value (50 percent of yield strength) for Titanium Grade 7. The analysis evaluates damage based on six representative rock sizes impacting the drip shield from three different angles: (1) vertically downward onto the top of the drip shield; (2) at a 60° angle (with the horizontal) onto the transition region between the top and side of the drip shield; and (3) horizontally into the side wall.

For the 5×10^{-4} per year ground motion, tunnels in the lithophysal zones have no damage for higher values of rock compressive strength and exhibit only minor damage (but no collapse) at the lowest level of compressive strength (BSC 2003, Section 6.4.1.1 [DIRS 162711]). Rockfall in the lithophysal zone was also examined for less frequently occurring ground motions. In the lithophysal zones, average joint spacing is less than 1 meter, and at certain locations this spacing is much smaller, on the order of 0.1 meter (BSC 2003, Section 6.1.4.1 [DIRS 162711]). Based on the results of Table 12 of the seismic abstraction model report (BSC 2003, Section 6.6.1.2 [DIRS 161812]), consider a fragment that (for simplicity) is a cube 0.1-meter (4-in) on a side. The volume of this fragment is 0.001 m^3 and its mass is approximately 2 kg, assuming a tuff density of approximately 2,000 kg/m^3. The velocity of this fragment is 7.7 m/s for a 3-meter drop under gravitational acceleration, and the associated kinetic energy is 59 Joules. Table 12 shows that a 0.11 MT rock with 42 J of kinetic energy does not produce a failed area on the surface of the drip shield. A comparison of the mass and kinetic energy of the 0.1-meter fragment with the block in Table 12 indicates that there should be no damage from the impact of this fragment on the drip shield. A cubic fragment that is 0.3-meters (12-in) on a side has a mass of 54 kg and a kinetic energy of 1600 Joules. This fragment is approximately equivalent to the 0.15 MT (150 kg) rock having 902 Joules of kinetic energy noted in Table 12. This rock produces no damage for top and side impacts, and very small damage (0.02 percent) for the corner impact. Therefore, for the lithophysal unit, the small fragments have little capability to damage the drip shield, because the small mass and energy of the individual fragments cannot cause permanent deformation of the drip shield. Damage to the drip shield from rockfall in the lithophysal zone is neglected for TSPA-LA on this basis. Furthermore, in the lithophysal zones, the rock mass has very low compressive strength and is permeated with void spaces of varying size. This weak rock mass is expected to collapse into small fragments under the load imposed by a large vibratory ground motion. Consequently, rockfall in the lithophysal zone does not damage the waste package and cladding. The waste package and cladding are not damaged because the drip shield remains intact until a seismic event occurs, deflecting any rockfall away from the waste package.

Vibratory ground motions also have the potential to eject large, non-lithophysal rock blocks at high velocity. Rock blocks are ejected for the 10^{-6} per year and the 10^{-7} per year ground motion levels; relatively few blocks are ejected at the 5×10^{-4} per year ground motion level (see BSC 2003, Section 6.6.1 [DIRS 161812]). As given in Table 13 of BSC 2003 ([DIRS 161812]), the mean damage areas for ground motions with 10^{-6} and 10^{-7} annual frequency in the non-lithophysal are 1.7 percent and 3.4 percent. Maximum values are 32.2 percent and 63.6 percent, respectively. Clearly, the mechanical response of the drip shield to impact by a large rock block in the non-lithophysal zone has the potential to damage the drip shield and impair its function as a flow barrier.

The analysis uses the PGV as a basis for the damage abstraction, with PGV values being taken from:

> *MO0303DPGVB106.002. Design Peak Ground Velocity for the Repository Level (Point B) at 10-6 Annual Exceedance Probability* [DIRS 162712]

> *MO0210PGVPB107.000. Design Peak Ground Velocity for the Repository Level (Point B) at 10-7 Annual Exceedance Probability* [DIRS 162713].

The abstraction for the percent failed surface area mode as a function of PGV is based on a log-triangular distribution. The results of the calculations for PGVs of 2.44 m/s and 5.35 m/s (10^{-6} and 10^{-7} per year mean annual exceedance frequencies, respectively) have been supplemented by an additional point representing the 5×10^{-5} per year exceedance frequency with a PGV of 0.55 m/s (BSC 2003, Section 6.6.1.4 [DIRS 161812]). For this latter case, there is zero damage to the drip shield. Thus, the mode is taken to be the same as the lower bound (i.e., 0.001 percent), and the fraction of no-failure cases is taken to be 1.0. Furthermore, due to the length of the drip shield versus the drift length value used as a basis for the analysis, multiple block impacts are shared between multiple drip shields.

Related FEPs:

<u>*FEPs that examine related but distinct effects and consequence*</u>

Tectonic activity—large scale (1.2.01.01.0A)
Fault displacement damages EBS components (1.2.02.03.0A)
Seismicity associated with igneous activity (1.2.03.03.0A)
Hydrologic response to seismic activity (1.2.10.01.0A)

Rockfall (2.1.07.01.0A)
Drift collapse (2.1.07.02.0A)

FEPs that examine similar effects and consequences

Seismic-induced drift collapse damages EBS components (1.2.03.02.0C)
Seismic-induced drift collapse alters in-drift thermohydrology (1.2.03.02.0D)
Mechanical impact on waste package (2.1.03.07.0A)
Mechanical impact on drip shield (2.1.03.07.0B)
Mechanical degradation of pallet (2.1.06.05.0A)
Mechanical degradation of invert (2.1.06.05.0B)

Related Documents: *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada*
MDL-MGR-GS-000003 (BSC 2003 [DIRS 166274])

Drift Degradation Analysis
ANL-EBS-MD-0000027 (BSC 2003 [DIRS 162711])

Seismic Consequence Abstraction
MDL-WIS-PA-000003 (BSC 2003 [DIRS 161812])

Supplemental Discussion: None

6.2.1.5 Seismic-induced Drift Collapse Damages EBS Components (1.2.03.02.0C)

FEP Description: Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse that could impact drip shields, waste packages, or other EBS components. Possible effects include both dynamic and static loading.

Descriptor Phrases: Seismic-induced drift collapse (drip shield damage); Seismic-induced drift collapse (drip shield stress corrosion cracking); Seismic-induced drift collapse (waste package damage); Seismic-induced drift collapse (drip shield contacts waste package); Seismic-induced drift collapse (waste package dislodgement); Seismic-induced drift collapse (cladding damage); Seismic-induced drift collapse (invert damage); Seismic effects on drift collapse

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded—Low Consequence*

Screening Argument: The potential consequences of seismic-induced drift collapse require two preceding factors: 1) that drift collapse occurs, and 2) that the volume or amount of collapse is sufficient to cause structural failure of the drip shields. Drift degradation analysis covered in the following discussion, indicates that drift collapse in the non-lithophysal unit is not of concern. However, the analysis does indicate that seismic-induced rockfall in the non-lithophysal unit may be of concern due to the rock block size. The analysis also demonstrates that drifts in the lithophysal zones would collapse under the 10^{-6} per year (and by inference the larger, 10^{-7} per year) vibratory ground motions (BSC 2003, Section 6.4.1.1 [DIRS 162711]).

The ground motion hazard curves developed for the PSHA (CRWMS M&O 1998 [DIRS 103731]) were extended to address ground motion during the postclosure period as documented in DTN: MO03061E9PSHA1.000 [DIRS 163721]. The seismic time histories contained in the following DTNs were developed starting with the results of the PSHA and take into account the effect of the upper 300 meters of rock/soil at the site (site response). These repository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* (BSC 2003 [DIRS 166274]). These ground motion time histories were developed for 5×10^{-4}, 10^{-6} and 10^{-7} annual exceedance probabilities (see Assumption 5.1 of this report, ANL-WIS-MD-000005 REV. 01) and have been used in various seismic-related AMRs to provide inputs to support postclosure analyses of damage to EBS components from seismic ground-motion, seismic-induced rockfall, and effects related to seismic-induced drift collapse. The outputs include, but are not limited to:

MO0211AVTMH107.001. Acceleration, Velocity, and Displacement Spectrally Conditioned Time Histories for the Repository Level at 10^{-7} Annual Exceedance Frequency ([DIRS 161513])

MO0301TMHIS106.001. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at 10^{-6} Annual Exceedance Frequency ([DIRS 161868])

MO0211TMHIS104.002. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at $5x10^{-4}$ Annual Exceedance Frequency ([DIRS 161540]).

These outputs are of particular interest because they are used by the *Drift Degradation Analysis* (BSC 2003 [DIRS 162711]) to determine rockfall and drift-collapse effects related to seismic-induced ground motion, which are addressed in related FEPs. The drift degradation analysis for the non-lithophysal unit is presented in Table 33 of that document. The worst-case analysis indicates for ground motions occurring at a 10^{-7} annual frequency, the total volume of rockfall is 50.64 m^3 with a total of 46 blocks, for each km of drift. The maximum block size, without considering small-scale fractures, is 7.36 m^3 (BSC 2003, Table 31 [DIRS 162711]). The nominal diameter of the drift is 5.5 meters, so each meter of drift length constitutes a volume of

15.9 m^3. This indicates that drift collapse in the non-lithophysal unit is of no concern. However, the analysis does indicate that seismic-induced rockfall in the non-lithophysal unit may be of concern due to the rock block size. Seismic-induced rockfall damage is addressed as a separate FEP. By comparison, for the lithophysal unit, ground motions with an annual frequency of 10^{-6} cause complete collapse of the emplacement drifts (BSC 2003, Section 6.4.1.1 [DIRS 162711]).

For the 5×10^{-4} per year ground motion, tunnels in the lithophysal zones show no damage for higher values of rock compressive strength and exhibit only minor damage (but no collapse) at the lowest level of compressive strength (BSC 2003, Section 6.4.1.1 [DIRS 162711]). Drift degradation analysis also demonstrates that drifts in the lithophysal zones would collapse under the 10^{-6} per year (and by inference the larger, 10^{-7} per year) vibratory ground motions (BSC 2003, Section 6.4.1.1 [DIRS 162711]). Consequently, drift collapse in the lithophysal zones can impose a static load on the drip shield from the weight of the natural backfill that fills the drifts as a result of the collapse. The characterization of seismic damage from rockfall is addressed using damage-related response surfaces and is fully discussed in the model report *Seismic Consequences Abstraction* (BSC 2003, Sections 6.6.1 and 6.6.2 [DIRS 161812]). In the lithophysal zones, the static loads from a collapsed drift using continuum or discontinuum representations of the host rock are not expected to collapse the drip shield. This is predicated on the mean value of the rock mass pressure predicted for the drip shield. Damage to the drip shield from rockfall in the lithophysal zone is neglected for TSPA-LA on this basis. However, structural response calculations have not been performed for the most extreme pressures or for the nonuniform loading predicted by the rock mechanics codes.

TSPA Disposition: Not Applicable

Related FEPs

FEPs that examine related but distinct consequences and events

Tectonic activity—large scale (1.2.01.01.0A)
Mechanical impact on waste package (2.1.03.07.0A)
Mechanical impact on drip shield (2.1.03.07.0B)
Mechanical degradation of pallet (2.1.06.05.0A)
Mechanical degradation of invert (2.1.06.05.0B)
Effects of drip shield on flow (2.1.06.06.0A)
Rockfall (2.1.07.01.0A)
Drift collapse (2.1.07.02.0A)
Mechanical effects of excavation/construction in the near field (2.2.01.01.0A)
Thermally-induced stress changes in the near field (2.2.01.02.0A)
Rock properties of host rock and other units (2.2.03.02.0A)
Enhanced influx at the repository (2.1.08.02.0A)
Focusing of unsaturated flow (fingers, weeps) (2.2.07.04.0A)

FEPs that examine similar consequences and events

Seismic-induced rockfall damages EBS components (1.2.03.02.0B)
Seismic-induced drift collapse alters in-drift thermohydrology (1.2.03.02.0D)

Related Documents: *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada*
MDL-MGR-GS-000003 (BSC 2003 [DIRS 166274])

Drift Degradation Analysis
ANL-EBS-MD-000027 (BSC 2003 [DIRS 162711])

Seismic Consequence Abstraction
MDL-WIS-PA-000003 (BSC 2003 [DIRS 161812])

Supplemental Discussion: Degradation of underground openings as a function of time, including drift collapse, is a natural and expected occurrence for any subsurface excavation. Over time, changes to both the stress condition and the strength of the rock mass occur due to several different interacting factors.

With time and changes in the state of stress in the repository block due to stress relief, seismic activity, tectonic activity, or thermal loading and unloading, the rock mass surrounding the emplacement drifts will deteriorate. A triggering event may cause movement or collapse of the drift onto the drip shield and/or waste packages. The drip shield and/or waste package may undergo structural failure due to impact or loading and water may flow through the breach and transport radionuclides from the repository.

An analysis of the potential for drift collapse within the repository horizon is provided in the *Drift Degradation Analysis* (BSC 2003 [DIRS 162711]). This document provides an analysis of the amount of drift degradation in repository emplacement drifts anticipated for discrete events and time increments extending throughout the 10,000-year compliance period for postclosure performance. The earlier versions of the *Drift Degradation Analysis* (Revisions 0 and 1) relied primarily on the DRKBA numerical code, which provides for a probabilistic key block assessment based on realistic fracture patterns determined from field mapping in the ESF. However, the use of the DRKBA code to determine potential rockfall data at the repository horizon during the postclosure period had several limitations and exhibited areas for improvement. To resolve these limitations, additional numerical codes have been included that can explicitly apply seismic and thermal loads, providing significant improvements to the analysis of drift degradation and extending the validity of drift degradation models.

The revised analysis now incorporates diverse factors, including rock mass characterization to accommodate differences in lithophysal and non-lithophysal rock types and strength properties, seismic ground motion, thermal stresses, and time-dependent degradation of rock strength. The analysis now provides a model of the rock mass jointed configuration surrounding the emplacement drift cavity, and provides a statistical description of block sizes formed by fractures around the emplacement drifts for the lithologic units of the repository host horizon. The analysis also provides estimates of changes in drift profiles resulting from progressive deterioration of the emplacement drifts and provides an estimate of the time required for significant drift deterioration to occur. Specific analysis now include a thermomechanical assessment of the repository block at Yucca Mountain to determine thermal stress inputs to the drift degradation models and a fracture degradation assessment to account for long-term strength degradation. The analysis also includes a drift degradation structural model for non-lithophysal rock that includes thermal and seismic loading and a drift degradation lithophysal model that includes thermal and seismic loading. The results of this modeling and analysis activity provide rockfall data to support structural analyses of the ground support system, the drip shield, and waste package. This assessment provides strength degradation inputs to the drift degradation models. The drift degradation analysis also provides the changes in drift profile due to rockfall, which supports analyses of seepage into the emplacement drift during the period of compliance for postclosure performance.

6.2.1.6 Seismic-Induced Drift Collapse Alters In-drift Thermohydrology (1.2.03.02.0D)

FEP Description: Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse and/or rubble infill throughout part or all of the drifts. Drift collapse could impact flow pathways within the EBS, mechanisms for water contact with EBS components, and thermal properties within the EBS.

Descriptor Phrases: Flow and pathways in collapsed drift, Thermal effects of collapsed drift, Seismic-induced drift collapse (invert damage)

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Included* (BSC 2003, Table 4 [DIRS 161812])

Screening Argument: Not Applicable

TSPA Disposition: The potential consequences of drift collapse require two factors: 1) that drift collapse occurs, and 2) that the volume or amount of collapse is sufficient to changes the drift profile such that seepage into the drift and thermal properties are significantly affected. Changes to the seepage due to seismic-induced changes in the drift profile are *Included* in the TSPA-LA.

The ground motion hazard curves developed for the PSHA (CRWMS M&O 1998 [DIRS 103731]) were extended to address ground motion during the postclosure period as documented in DTN: MO03061E9PSHA1.000 [DIRS 163721]. The seismic time histories contained in the following DTNs were developed starting with the results of the PSHA and taking into account the effect of the upper 300 meters of rock/soil at the site (site response). Therepository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* (BSC 2003 [DIRS 166274]).

The ground motion time histories were developed for 5×10^{-4}, 10^{-6} and 10^{-7} annual exceedance probabilities (see Assumption 5.1 of this report, ANL-WIS-MD-000005 REV. 01) and have been used in various seismic-related AMRs to provide inputs to support postclosure analyses of damage to EBS components from seismic ground-motion, seismic-induced rockfall, and effects related to seismic-induced drift collapse. The outputs include, but are not limited to:

MO0211AVTMH107.001. Acceleration, Velocity, and Displacement Spectrally Conditioned Time Histories for the Repository Level at 10^{-7} Annual Exceedance Frequency ([DIRS 161513])

MO0301TMHIS106.001. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at 10^{-6} Annual Exceedance Frequency ([DIRS 161868])

MO0211TMHIS104.002. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at $5X10^{-4}$ Annual Exceedance Frequency ([DIRS 161540]).

These outputs are of particular interest because they are used by the *Drift Degradation Analysis* (BSC 2003 [DIRS 162711]) to determine rockfall and drift-collapse effects related to seismic-induced ground motion, which are addressed in related FEPs. As discussed for FEP 1.2.03.02.0C (Seismic-induced drift collapse damages EBS components), the drift collapse in the non-lithophysal unit is of no concern due to limited volume and block size. There is no change in the seepage abstraction in the non-lithophysal zones because the rockfall does not completely fill the tunnels at the ground motion levels of interest. The seepage abstraction currently includes an enhancement factor for limited collapse, and this enhancement factor is deemed adequate to address limited collapse in the non-lithophysal zone.

For the 5×10^{-4} per year ground motion, tunnels in the lithophysal zones have no damage for higher values of rock compressive strength and only minor damage (but no collapse) at the lowest level of compressive strength. However, for the lithophysal unit, ground motions with an annual frequency of 10^{-6} or less (see Assumption 5.1 of this report) cause complete collapse of the emplacement drifts (BSC 2003, Section 6.4.1.1 [DIRS 162711]). The collapse of drifts from high amplitude ground motion in the lithophysal zones can fill the drifts with rubble, altering the hydrologic and thermal environment around the EBS components. Changes in seepage are addressed by modifying the seepage flux (BSC 2003, Section 6.9 [DIRS 161812]) for the lithophysal zone.

This FEP is considered as *Included* in the TSPA-LA and seismic-induced rockfall and change in seepage associated with drift collapse are addressed in the TSPA-LA. Changes in the thermal properties due to seismic-induced drift collapse are addressed in the sharing FEP AMRs (see Section 1.2 of this report, ANL-WIS-MD-000005 REV 01).

Related FEPs

<u>*FEPs that examine related but distinct consequences and events*</u>

Tectonic activity—large scale (1.2.01.01.0A)
Mechanical impact on waste package (2.1.03.07.0A)

Mechanical impact on drip shield (2.1.03.07.0B)
Mechanical degradation of pallet (2.1.06.05.0A)
Mechanical degradation of invert (2.1.06.05.0B)
Effects of drip shield on flow (2.1.06.06.0A)
Rockfall (2.1.07.01.0A)
Drift collapse (2.1.07.02.0A)
Mechanical effects of excavation/construction in the near field (2.2.01.01.0A)
Thermally-induced stress changes in the near field (2.2.01.02.0A)
Rock properties of host rock and other units (2.2.03.02.0A)

FEPs that examine similar consequences and events

Seismic-induced rockfall damages EBS components (1.2.03.02.0B)
Seismic-induced drift collapse damages EBS components (1.2.03.02.0C)
Enhanced influx at the repository (2.1.08.02.0A)
Focusing of unsaturated flow (fingers, weeps) (2.2.07.04.0A)

Related Documents: *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* MDL-MGR-GS-000003 (BSC 2003 [DIRS 166274])

Drift Degradation Analysis ANL-EBS-MD-000027 (BSC 2003 [DIRS 162711])

Seismic Consequence Abstraction MDL-WIS-PA-000003 (BSC 2003 [DIRS 161812])

Supplemental Discussion: None

6.2.1.7 Seismicity Associated with Igneous Activity (1.2.03.03.0A)

FEP Description: Seismicity associated with future igneous activity in the Yucca Mountain region may affect repository performance.

Descriptor Phrases: Seismicity associated with igneous activity

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Included* (BSC 2003, Table 6.4.2 [DIRS 166274])

Screening Argument: Not Applicable

TSPA Disposition:	Seismicity associated with igneous activity was either specifically considered, or was considered within the background evaluation of ground motion, by expert elicitation teams in developing probabilistic ground motion hazards. It is implicitly *Included* in the TSPA-LA.

Ground motion associated with seismic events has the potential to disrupt the integrity of the EBS or waste package components. Repeated vibration of a container and/or container impact with other repository elements could potentially cause the container to be damaged. These events could lead to decreased performance and/or to radionuclide release.

At Yucca Mountain, earthquakes associated with igneous activity would be related to basaltic intrusion and volcanism. Volcanic eruption is commonly preceded and accompanied by swarms of earthquakes that indicate progressive rock-strength failure as magma migrates to the earth's surface (Smith et al. 1998, p. 158 [DIRS 118967]). That study specifically mentions that magma intrusion into the seismogenic crust tends to supplant sizable, large tectonic earthquakes with swarms of low to moderate magnitude earthquakes. Smith et al. (1998, Table 1 [DIRS 118967]) summarizes published accounts of observed seismicty that is clearly associated with dike intrusion and indicate that observational seismicity from volcanic rift zones worldwide indicates the mean maximum magnitude of dike-induced earthquakes is 3.8 ±0.8 and is generally less than 5 (Smith et al. 1998, Table 1 [DIRS 118967]). That study further list areas where magmatism has affected activity of the Basin and Range normal faults including, possibly, the Yucca Mountain area of southern Nevada, even though it is not a volcanic rift zone. That study also lists two approaches for estimating maximum magnitude of seismicity estimation based on ruptured surface area of fissures and faults, and the use of recorded seismicity during dike injection events. The first of these methods was considered in the PSHA.

As stated in *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000, Section 6.4.4 [DIRS 142321]), "The PSHA was computed by integrating recurrence curves for earthquakes of Mw 5.0 and greater. It is established practice that smaller earthquakes produce no damage to well-engineered structures regardless of the ground motion they generate." Seismicity related to volcanic processes, particularly basaltic volcanoes and dike injection, was explicitly modeled in the volcanic source zones by two of the six expert teams working on the PSHA (as summarized in CRWMS M&O 2000, Table 5 [DIRS 142321]). Igneous-related earthquakes were not modeled as a separate source zone by the four other PSHA expert teams because they presumed that the low magnitude and frequency of igneous-related seismicity were accounted for by the areal source zone evaluation used for the PSHA.

The repository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* (BSC 2003 [DIRS 166274]). The ground motion time histories were developed for 5×10^{-4}, 10^{-6} and 10^{-7} annual exceedance probabilities (see Assumption 5.1 of this report, ANL-WIS-MD-000005 REV. 01) and have been used in various seismic-related AMRs to provide inputs to support postclosure analyses of damage to EBS components from seismic ground-motion, seismic-induced rockfall, and effects related to seismic-induced drift collapse. The outputs include, but are not limited to:

MO0211AVTMH107.001. Acceleration, Velocity, and Displacement Spectrally Conditioned Time Histories for the Repository Level at 10^{-7} Annual Exceedance Frequency ([DIRS 161513])

MO0301TMHIS106.001. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at 10^{-6} Annual Exceedance Frequency ([DIRS 161868])

MO0211TMHIS104.002. Acceleration, Velocity, and Displacement Time Histories for the Repository Level at $5x10^{-4}$ Annual Exceedance Frequency ([DIRS 161540]).

Because seismicity associated with igneous activity is included in the PSHA results, through volcanic source zones or areal source zones, all seismic inputs developed to support postclosure analyses account for the volcanic component of seismic hazard. Thus, it is inappropriate to represent igneous-related seismicity in the TSPA-LA by a parameter or submodel independent of the PSHA results. It does not represent a separate mechanism for changing the properties of the host rock or for damaging the waste packages. Furthermore, the low-magnitude events associated with igneous activity do not represent a credible damage mechanism that could contribute to enhanced failure potential of intact waste packages during the 10,000-year performance period. Waste package damage due to a related igneous-intrusion is addressed separately in FEP 1.2.04.04.0A (Igneous intrusion interacts with EBS components), wherein waste packages in intersected drifts are assumed to have failed due to the extreme conditions potentially existing in the intersected drifts. Addition of a low-magnitude seismic component following failure of waste packages due to intrusion of the drifts would be inconsequential to dose.

Related FEPs:

FEPs that examine related but distinct effects and consequence

Fault displacement damages EBS components (1.2.02.03.0A)
Seismic-induced rockfall damages EBS components (1.2.03.02.0B)
Igneous intrusion into repository (1.2.04.03.0A)
Igneous intrusion interacts with EBS components (1.2.04.04.0A)
Hydrologic response to seismic activity (1.2.10.01.0A)

FEPs that examine similar effects and consequences

Seismic ground motion damages EBS components (1.2.03.02.0A)

Related Documents:

Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada
ANL-CRW-GS-000003 (CRWMS M&O 2000 [DIRS 142321])

Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada
MDL-MGR-GS-000003 (BSC 2003 [DIRS 166274])

Supplemental Discussion: None

6.2.1.8 Hydrologic Response to Seismic Activity (1.2.10.01.0A)

FEP Description: Seismic activity, associated with fault movement, may create new or enhanced flow pathways and/or connections between stratigraphic units, or it may change the stress (and therefore fluid pressure) within the rock. These responses have the potential to significantly change the surface- and groundwater-flow directions, water level, water chemistry, and temperature.

Descriptor Phrases: Water table elevation; Saturated flow and pathways in the SZ; Unsaturated flow and pathways in the UZ.

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded*—Low Consequence

Screening Argument: This FEP specifically addresses the effects of seismic activity on UZ and SZ flow and transport at the mountain scale and on drift seepage, and addresses the possibility of a water-table rise in response to seismic activity (e.g., seismic pumping). However, the changes in flow properties is insignificant at the mountain scale, and the potential for a rise in water levels is insignificant with regard to reaching the repository level and is transient in nature. The FEP is therefore, *Excluded.*

Seismic activity is the result of sudden fault slip, and can cause changes in rock stresses or changes in flow through the drifts. The change in the state of stress, in turn, has the potential to affect the groundwater flow and the transport properties of the UZ and or SZ. Changes in flow through the drifts have the potential to increase degradation of EBS components and waste packages, leading to a release of radionuclides. Regardless, the effects of seismic activity in the UZ would result in changes to the hydrologic characteristics of fractures, as expressed through the UZ model parameter of fracture aperture, or would be transient.

The effects of fracture systems changes due to geologic effects on mountain-scale flow and radionuclide transport have been investigated using a sensitivity approach in *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000 [DIRS 151953]). The effects of fracture aperture changes are examined because several fracture properties (permeability, capillary pressure, and porosity) are functions of fracture aperture. The results indicate that changes in fracture aperture confined to fault zones show virtually no effect on transport behavior in the UZ, and increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than other uncertainties related to infiltration (CRWMS M&O 2000, Section 7 [DIRS 151953]).

Muir-Wood and King (1993, pp. 22054, 22059, and 22060 [DIRS 124023]) assert that the most significant changes, primarily measured in terms of stream discharges, are related to normal-fault earthquakes. The mechanism for changing surface-water-flow directions is not readily apparent, unless it is related to the relocation of recharge and discharge structures, which is in turn related to changes in water levels. Earthquakes noticeably effect changes in groundwater levels, sometimes at distances far removed from the epicenter. Gauthier et al. (1996, p. 164 [DIRS 100447]) indicate that for Yucca Mountain, the greatest strain-induced changes in water-table elevation occur with strike-slip faults. Such changes, if permanent, have the potential to alter groundwater-flow directions. The mechanisms for affecting water chemistry and temperature are undefined, but they are presumed linked to a change in groundwater levels and associated changes in geochemical conditions. However, water-level changes usually are transient, although the reversion to pre-earthquake levels may occur over several months.

O'Brien (1993 [DIRS 101276]) analyzed observed water level fluctuations at Yucca Mountain due to earthquakes in the region. Fluctuations range from 90 cm related to a 7.5 magnitude earthquake near Landers CA, to 20 cm for a second earthquake of 6.6 magnitude near Big Bear Lake, CA. The Landers and Big Bear Lake earthquakes are located 293 km and 296 km, respectively, from Yucca Mountain (O'Brien 1993 [DIRS 101276] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). More notably, a 5.6 magnitude earthquake at Little Skull Mountain (approximately 23 km from Yucca Mountain) resulted in a maximum fluctuation of 40 cm, with water levels in another well declining approximately 50 cm over the three days following the earthquake. Water levels in that well returned to pre-quake levels over a period of about 6 months.

Alternative perspectives on seismic pumping and water-level changes are discussed in the Final Environmental Impact Statement (DOE 2002, p. 3-59 [DIRS 155970]), which cites to the work by the National Research Council (1992 [DIRS 105162] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). The panel reviewed the alternative conceptual model and concluded that it was infeasible. The panel went on to state that seismic pumping at most would have elevated the water levels a few tens of meters.

By way of corroboration, Gauthier et al. (1996, p. 163-164 [DIRS 100447]) analyzed the potential effects of seismic activity on contaminant transport in the SZ due to changes in water-table elevation. Their simulations for TSPA-VA of the timing, amplitude, and duration of water-table rise indicated a maximum rise of 50 meters within an hour of a simulated seismic event. The simulated system returned to steady-state conditions within six months. Gauthier et al. (1996, pp. 163–164 [DIRS 100447]) conclude that:

> "In general, seismically induced water-table excursions caused by poroelastic coupling would not influence the models presently being used to determine long-term performance of a repository at Yucca Mountain; therefore, we excluded them from the total-system simulations."

Given the changes in water levels in the time following discrete seismic events as reported by the USGS (O'Brien, 1993 [DIRS 101276] as referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880] and used as direct input) it would appear that the conclusion by Gauthier et al. remains valid.

Sensitivity modeling indicates that changes to faults and fracture properties due to changes in stress and strain are inconsequential to groundwater flow at the mountain scale. Therefore, the FEP is *Excluded* from the TSPA-LA based on low consequence. Additionally, because water-table changes caused by seismic activity do not reach the repository level and are transient, groundwater flow and radionuclide transport are not significantly affected. The hydrologic response to seismic activity, therefore, does not provide a mechanism to significantly affect dose.

TSPA Disposition: Not Applicable

Related FEPs:

<u>FEPs that examine related but distinct effects and consequences:</u>

Tectonic activity — large scale (1.2.01.01.0A)
Seismic-induced rockfall damages EBS components (1.2.03.02.0B)
Seismicity associated with igneous activity (1.2.03.03.0A)
Hydrologic response to igneous activity (1.2.10.02.0A)

<u>FEPs that examine similar effects and consequences:</u>

Water-table rise (1.3.07.02.0A)
Earth tides (1.5.03.02.0A)
Seismic activity changes porosity and permeability of rock (2.2.06.01.0A)
Seismic activity changes porosity and permeability of faults (2.2.06.02.0A)
Seismic activity changes porosity and permeability of fractures (2.2.06.02.0B)
Seismic activity alters perched water zones (2.2.06.03.0A)

Related Documents: *Fault Displacement Effects on Transport in the Unsaturated Zone* ANL-NBS-HS-000020 (CRWMS M&O 2000 [DIRS 151953]

Supplemental Discussion: None

6.2.1.9 Seismic Activity Changes Porosity and Permeability of Rock (2.2.06.01.0A)

FEP Description: Seismic activity (fault displacement or vibratory ground motion) has a potential to change rock stresses and result in strains that affect flow properties in rock outside the excavation-disturbed zone. It could result in strains that alter the permeability in the rock matrix. These effects may decrease the transport times for potentially released radionuclides.

Descriptor Phrases: Seismic activity (rock properties in the UZ); Seismic activity (rock properties in the SZ)

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded*—Low Consequence

Screening Argument: Future seismic activity could redistribute strain within the system. Redistribution of strain could open new fractures and close some existing fractures, as presumed by Gauthier et al. (1996, p. 163 [DIRS 100447]) and the strain likely is transferred, at least in part, to the rock matrix. Therefore, the issue is consequence rather than probability.

A sensitivity analysis for UZ flow properties, discussed in the following paragraphs, was performed and demonstrated that the consequence in the UZ would be negligible. Additionally, the net effect in the SZ would be a temporary rise and/or decline in water levels (an SZ effect) and is addressed in FEP 1.2.10.01.0A (Hydrologic response to seismic activity). That FEP is *Excluded* based on low consequence of a temporary water level rise (or decline) on the order of a few tens of meters.

Available analysis for the UZ, as discussed in the following paragraphs, considered the potential effects on the rock matrix and fractures. The effects of changes to matrix/fracture systems in the UZ on mountain-scale flow and radionuclide transport have been investigated using a sensitivity approach (see *Fault Displacement Effects on Transport in the Unsaturated* Zone, CRWMS M&O 2000 [DIRS 151953]). The UZ sensitivity analyses were performed with the nominal UZ three-dimensional flow model and used several conservative choices that, together, provide bounding cases for determining whether changes in fractures would significantly impact repository performance. The analyses were performed using a dual-permeability, active-fracture flow model, and were based on fracture apertures changes that could be the result of strain conditions or other factors. Given a change in fracture aperture, other hydrologic properties of fractures (permeability, capillary pressure, and porosity) were estimated using theoretical models. The sensitivity of a fracture aperture to mechanical strain is due to the small porosity of the fracture continuum. The fracture porosity is much less than the matrix (i.e., rock) porosity at Yucca Mountain (see CRWMS M&O 2000 Assumption 5.2 [DIRS 151953]). The matrix (i.e., rock), on the other hand, has much greater porosity than the fractures in general, and its properties are not expected to be as sensitive to mechanical strain.

Based on the results of the UZ sensitivity analyses (CRWMS M&O 2000 [DIRS 151953]), changes in fracture aperture confined to fault zones showed virtually no effect on transport behavior in the UZ. Increased fracture aperture applied over the entire UZ domain resulted in effects that are no more significant than other uncertainties related to infiltration, which are dominated by climate change effects (CRWMS M&O 2000, Section 7 [DIRS 151953]).

Regardless of the fracture apertures used in the sensitivity study, the principle factor influencing flux through the UZ is infiltration at the land surface, which is linked directly to climatic conditions. The TSPA-LA includes a span of climatic conditions ranging from present conditions to wetter conditions associated with glacial periods. Consequently, the effects on infiltration stemming from changes in fracture aperture will be insignificant because of the dominance of parameters related to climate change. The evaluation of changes to fracture systems presented in CRWMS M&O (2000 [DIRS 151953]) relies upon information and assumptions related to the perched water table response and thermal hydrologic processes; these effects are expected to be minimal.

The SZ model (*SZ Flow and Transport Model Abstraction* (BSC 2003, Section 6.5.2 [DIRS 164870]) uses the flowing intervals concept, based on site data. indicating that only some of the fractures within the saturated zone contribute to the flow. Additionally, the SZ model implicitly includes fracture zones in the nominal case by considering the horizontal anisotropy in permeability located in the fractured volcanic units downgradient of the repository, with the SZ model producing 200 flow fields.

The SZ model (BSC 2003, Section 6.5.2 [DIRS 164870]) likely underestimates the effect of matrix-diffusion processes in the SZ transport model because of possible overestimated flowing-interval spacing (*Probability Distribution for Flowing Interval Spacing,* BSC 2001, Section 1.0 [DIRS 156965]). The overestimation occurs because the number of fractures contributing to a flowing interval cannot be determined from the available data. Because each flowing interval likely has more than one fracture contributing to it, the true flowing-interval spacing could be less than the spacing determined from the probability distribution. The determination of flowing-interval spacing potentially affects matrix-diffusion processes.

The SZ model (BSC 2003, Section 6.5.2 [DIRS 164870]) does not explicitly address changes to fracture properties due to changes in stress. However, because of the existing uncertainty considerations for the flow field, and because of the conservative choices for flowing-interval spacing used for the analysis, the effect of increasing or decreasing matrix and fracture porosity and permeability, and/or the creation of new fractures in the SZ, would be of no significance to flow-and-transport characteristics. Because SZ flow characteristics are not significantly changed, dose is not significantly changed.

In summary, based on the results of the UZ sensitivity analyses (CRWMS M&O 2000 [DIRS 151953]), changes in fracture aperture confined to fault zones show virtually no effect on transport behavior in the UZ. Increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than other uncertainties related to infiltration (CRWMS M&O 2000, Section 7 [DIRS 151953]). Because of the existing uncertainty considerations for the flow field and the conservative choices for flowing-interval spacing used for the SZ analysis (BSC 2003 [DIRS 164870]), the effect of opening or closing fractures and/or the creation of new fractures in the SZ would be of no significance to the flow-and-transport characteristics. Because flow characteristics are not significantly changed, dose is not significantly changed. Furthermore, the presence and durability of the drip shield will mitigate any increased flux during the repository performance period (10,000 years). Consequently, this FEP is *Excluded* from the TSPA-LA based on low consequence.

TSPA Disposition: Not Applicable

Related FEPs:

<u>*FEPs that examine related but distinct effects and consequences*</u>

Tectonic activity—large scale (1.2.01.01.0A)
Metamorphism (1.2.05.00.0A)
Diagenesis (1.2.08.00.0A)
Earth tides (1.5.03.02.0A)

<u>*FEPs that examine similar effects and consequences*</u>

Hydrologic response to seismic activity (1.2.10.01.0A)
Seismic activity changes porosity and permeability of faults (2.2.06.02.0A)
Seismic activity changes porosity and permeability of fractures (2.2.06.02.0B)
Seismic activity alters perched water zones (2.2.06.03.0A)
Matrix diffusion in the SZ (2.2.08.08.0A)
Matrix diffusion in the UZ (2.2.08.08.0B)

Related Documents: *Fault Displacement Effects on Transport in the Unsaturated Zone* ANL-NBS-HS-000020 (CRWMS M&O 2000 [DIRS 151953]

SZ Flow and Transport Model Abstraction MDL-NBS-HS-0000210 (BSC 2003 [DIRS 164870]

Supplemental Discussion: None

6.2.1.10 Seismic Activity Changes Porosity and Permeability of Faults (2.2.06.02.0A)

FEP Description: Seismic activity (fault displacement or vibratory ground motion) has a potential to produce jointed-rock motion and change stress and strains that alter the permeability along faults. This could result in reactivation of preexisting faults or generate new faults and significantly change the flow and transport paths, alter or short-circuit the flow paths and flow distributions close to the repository, and create new pathways through the repository. These effects may decrease the transport times for potentially released radionuclides.

Descriptor Phrases: Seismic activity (faults in the UZ), Seismic activity (faults in the SZ)

[Note: This is a shared FEP. This scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded*—Low Consequence

Screening Argument: Future seismic activity could redistribute strain within the system. Redistribution of strain could open new fractures and close some existing fractures, as presumed by Gauthier et al. (1996, p. 163 [DIRS 100447]). It is likely that at least some of this redistribution would occur within the faults zones.

A sensitivity analysis for UZ fracture apertures in fault zones, discussed in the following paragraphs, was performed and demonstrated that the consequence of this FEP would be negligible. Furthermore, regardless of the strain distribution, the net effect of seismic activity in the SZ is the temporary rise and/or decline in water levels associated with seismic events as addressed in FEP 1.2.10.01.0A (Hydrologic response to seismic activity). That FEP was *Excluded* based on low consequence of a temporary water level rise (or decline) on the order of a few tens of meters.

Two conclusions from Sweetkind et al. (1997, pp. 67 to 71 [DIRS 100183]) suggest that faulting and fracturing are spatially related. Spatial relationships based on the results of underground fault mapping of faults have led to the definition/description of zones of influence around faults based on the observation that fracture frequency generally increases as faults are approached. Mapping results have shown that widths of zones of influence are in general quite narrow, ranging from less than 1 meter to about 7 meters from the faults. The second conclusion is that the width of the zone of influence in the immediate vicinity of a fault generally correlates with the amount of cumulative fault offset. Therefore, faults having the largest potential future displacement are the most likely to influence the repository block. Faults having tens of meters of cumulative offset (e.g., faults at ESF Stations 11+20, 67+88, and 70+58) have zones of influence that range up to 10 meters wide. Intrablock faults having very small amounts of cumulative offset (1 m to 5 m) have zones of influence that are 1 to 2 meters wide.

Consequently, the presence of gouge and brecciated zones only in limited proximity to fault planes suggests that much of the strain will be mechanically dissipated within or near the fault planes. For instance, in the Solitario Canyon fault zone in the ECRB Cross Drift, the total displacement is approximately 260 meters, but the gouge and brecciated zones are limited to less than 20 meters from the fault trace (Mongano et al. 1999, pp. 59-65 [DIRS 149850]). Similarly, the Dune Wash fault exposed in the ESF exhibits a cumulative offset of 65 meters, but the zone of increased fracture frequency in the vicinity of the fault is only 6 meters to 7 meters wide (Sweetkind et al. 1997, Table 21 [DIRS 100183]). A third example is the Sundance fault in the ECRB Cross Drift. The Sundance fault has a presumed, though indeterminate, displacement of several meters. However, the footwall rock is intact at a distance of only 10 cm from the fault plane. The hanging wall of the Sundance fault is slightly more fractured, having an intensely fractured zone about 1 meter thick (Mongano et al. 1999, pp. 52–54 [DIRS 149850]).

Another aspect of faulting that could be important to repository performance is the displacement on existing faults, particularly within the repository block, or the formation of new faults.

Section 6.2.1.2 and Table 6-4 of this report (ANL-WIS-MD-000005 REV 01) provide a discussion of probabilistic fault displacements. With regard to the formation of new faults, the PSHA (CRWMS M&O 1998, p. 8-7 [DIRS 103731] and DTN: MO0004MWDRIFM3.002 [DIRS 149092], referring to intact rock at Points 7d and 8d) indicates that mean displacements in the intact rock are less than 0.1 cm for a 10^{-8} annual-exceedance probability (see Assumption 5.1 of this report, ANL-WIS-MD-000005 REV. 01). The development of new faults and fractures is inferred from the PSHA to be of low probability and is, therefore, not further considered within this FEP.

Most of the large displacements are expected to occur along existing block-bounding faults. The largest mean predicted displacement at 10^{-8} is associated with the Solitario Canyon and the mean displacement is estimated to be on the order of 10 meters. The median predicted displacement is calculated, however, to be on the order of only a few meters. (See FEP 1.2.02.03.0A (Fault displacement damages EBS components) for a table of estimated displacements). The effects of this range of displacements are addressed by the range of aperture conditions presented in *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000, Section 6.2.2.3 [DIRS 151953]), as discussed in the following paragraphs.

The effects of changes to fracture systems in the UZ fault zones have been investigated using a sensitivity approach (CRWMS M&O 2000 [DIRS 151953]). The sensitivity study was performed with the nominal UZ three-dimensional flow model and uses several conservative approaches that together provided bounding cases for determining whether changes in fractures will significantly impact repository performance. The analysis was performed using a dual-permeability, active-fracture flow model, and was based on fracture apertures changes that could result from changes in strain conditions or other factors. Given a change in fracture aperture, other fracture hydrologic properties (permeability, capillary pressure, and porosity) were estimated using theoretical models CRWMS M&O 2000 ([DIRS 151953]).

The sensitivity study (CRWMS M&O 2000 [DIRS 151953]) included two bounding cases: (1) that changes in fracture properties occur over the entire UZ domain (fault zones and fractured rock), or (2) that the effects of fault displacement are limited to fracture-property changes in fault zones. These were modeling cases chosen to bound a presumed range of fracture-aperture changes resulting from fault movement. No direct observations for Yucca Mountain relate stress caused by fault displacement to strain and the resultant changes in fracture aperture. The bounding cases were used to simulate a response beyond that of the expected geologic response. The second bounding case (effects of fault displacement limited to fault zones) is applicable to this discussion and is justified based on conclusions by Sweetkind et al. (1997, pp. 67 to 71 [DIRS 100183]) and field observations by Mongano et al. (1999 [DIRS 149850]), previously described.

A potentially conservatism for the sensitivity analysis lies in the estimated fracture aperture for the bounding case. A maximum, ten-fold increase in fracture aperture is selected as a modeler's upper-bounding value and was justified in CRWMS M&O 2000 ([DIRS 151953]). The justification cites distance-strain relationships derived from models for a 1-meter displacement along a strike-slip fault (used as an analogue, though not directly representative of normal-fault response) at Yucca Mountain and for a 1-meter displacement on a theoretically normal fault. The changes in fracture apertures for the sensitivity analysis were derived presuming a 10-meter fault movement along the Solitario Canyon and multiplying the strains cited in the justification. This corresponds to the projected mean value at 10^{-8} annual frequency (see Assumption 5.1 of this report, ANL-WIS-MD-000005 REV 01) and serves as the basis for FEPs screening. The potential for conservatism is mentioned primarily because the presumed 10-meter displacement, although a mean value, is conservative when compared to probabilistically-determined (median and 85th fractile) and observed fault displacements. The results of the PSHA (CRWMS M&O 1998, Figure 8-3 [DIRS 103731]) indicate that, for the Solitario Canyon fault, there is a large uncertainty range in the potential displacements from 3 meters (the median value) to approximately 9 meters (the 85th fractile value) at the 10^{-8} annual-exceedance probability. By contrast, the maximum measured single-event Quaternary displacement (i.e., during the past 1.6 million years) on the Solitario Canyon fault is only 1.3 meters (Ramelli et al. 1996, Table 4.7.3 [DIRS 101106]).

The results of the sensitivity study (CRWMS M&O 2000 [DIRS 151953]) has shown that fracture aperture changes confined to fault zones resulted in virtually no effect on transport behavior in the UZ (CRWMS M&O 2000, Section 7 [DIRS 151953]). Because neither the flow nor the transport are significantly affected by fracture aperture changes in fault zones, changes in the stress state of fractures in faults do not provide a mechanism to significantly affect dose. Because dose is not significantly affected, the effects of faults and changes on the flow-properties of faults are *Excluded* based on low consequence. However, the evaluation of changes to fracture systems presented in CRWMS M&O (2000 [DIRS 151953]) relied upon information and assumptions related to the perched water table response and thermal hydrologic processes, but effects are expected to be minimal and are being evaluated.

By way of corroboration, an early analysis of the effect of a fault on flow in the SZ was conducted and documented in Chapter 10 of the TSPA for the Viability Assessment (CRWMS M&O 1998, Section 10.5.3 [DIRS 100369]). The corroborative analysis suggested that there would be negligible impact on performance, even though fault hydraulic conductivities were varied over five orders of magnitude for the modeling effort.

Also, by way of corroboration, Gauthier et al. (1996, pp. 163–164 [DIRS 100447]) analyzed the potential effects of seismic activity on contaminant transport in the SZ due to changes in water-table elevation based on TSPA-VA modeling. Their analysis indicates that the greatest strain-induced changes in water-table elevation occur with strike-slip faults. Simulations of the timing, amplitude and duration of a water-table rise indicate a maximum rise of 50 meters within an hour of a simulated event. The simulated system returns to steady-state conditions within six months. Gauthier et al. (1996, pp. 163 and 164 [DIRS 100447]) concluded that:

> "In general, seismically induced water-table excursions caused by poroelastic coupling would not influence the models presently being used to determine long-term performance of a repository at Yucca Mountain; therefore, we excluded them from the total-system simulations."

Given the response of regional water levels to seismic events, as discussed in FEP 1.2.10.01.0A, the conclusion by Gauthier for TSPA-VA still appears valid.

In summary, effects in the UZ would be transient or would result in changes to the hydrologic characteristics of fractures, as expressed through the parameter of fracture aperture. The effects of changes to fracture systems due to geologic effects on mountain-scale flow and radionuclide transport have been investigated using a sensitivity approach (CRWMS M&O 2000 [DIRS 151953]). The results indicate that changes in fracture aperture confined to fault zones show virtually no effect on transport behavior in the UZ, and increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than other uncertainties related to infiltration (CRWMS M&O 2000, Section 7 [DIRS 151953]). Effects in the SZ would be transient. Therefore, this FEP is of low consequence and is *Excluded* from the TSPA-LA.

TSPA Disposition: Not Applicable

Related FEPs:

FEPs that examine related but distinct effects and consequences

Tectonic activity—large scale (1.2.01.01.0A)
Metamorphism (1.2.05.00.0A)
Earth tides (1.5.05.02.0A)
Diagenesis (1.2.08.00.0A)

FEPs that examine similar effects and consequences

Hydrologic response to seismic activity (1.2.10.01.0A)
Seismic activity changes porosity and permeability of rock (2.2.06.01.0A)
Seismic activity changes porosity and permeability of fractures (2.2.06.02.0B)
Seismic activity alters perched water zones (2.2.06.03.0A)

Related Documents: *Fault Displacement Effects on Transport in the Unsaturated Zone* ANL-NBS-HS-000020 (CRWMS M&O 2000 [DIRS 151953])

Supplemental Discussion: The Screening Argument above embodies the results of analyses that examined the consequence to dose and the geologic realities of faulting. Additional data on the fault-and-fracture relationships are available to support the conclusions drawn above and provide additional support to the preceding argument.

The conclusions drawn were based on site data that are the source for the development of a suite of parameters used to characterize fractures. To provide additional context for the preceding argument, examples of the types and sources of data available are provided in the following paragraphs.

An analysis of fracture apertures is available from the ECRB Cross Drift Study (Mongano et al. 1999, p. 79 and Figure 16 [DIRS 149850]). The largest aperture recorded was 520 mm. Approximately 67 percent of the observed fractures exhibited “zero” aperture. Of the greater than 1800 fractures measured, only 40 apertures, or about 2 to 3 percent, were measured as greater than 20 mm. The remaining apertures were 20 mm or less.

The relationship of fractures smaller than 1 meter in length to faults was evaluated by visual examination of every fault in the ESF (Sweetkind et al. 1997, p. 68 [DIRS 100183]) that could be correlated with a fault mapped at the land surface (Day et al. 1998 [DIRS 100027]). Four principal conclusions listed below provide further evidence that the amplitude and distribution of the effects of changes in fracture aperture is likely conservative. Based on observations in the ESF (Sweetkind et al. 1997, pp. 67–71 [DIRS 100183]), the four principal conclusions regarding fault-to-fracture relationships are:

1) The width of the zone of influence on fracture frequency in the immediate vicinity of a fault is, in general, quite narrow, ranging from less than 1 meter to about 7 meters from a fault.

2) The width of the zone of influence in the immediate vicinity of a fault generally correlates with the amount of cumulative fault offset. Therefore, faults with the largest potential future displacement are the most likely to influence the repository block. Faults with tens of meters of cumulative offset (e.g., faults at ESF Stations 11+20, 67+88, and 70+58) have zones of influence up to 10 meters wide. The limited available data from block-bounding faults are not definitive regarding the nature of attendant fracturing. Intrablock faults with very small amounts of cumulative offset (1 to 5 m) have zones of influence that are 1 to 2 meters wide.

3) The width of the zone of influence around a fault does not appear to be related to depth, at least within the ESF. The width of the zones of influence is similar for small faults observed along the North Ramp, where overburden is 50 to 60 meters thick, as it is for small faults observed elsewhere in the ESF, where overburden thickness is two to three times greater than at the North Ramp. However, upward-splaying faults can result in apparent broad zones of influence at land surface because of the overlap of fractured zones surrounding individual fault splays.

4) The amount of deformation associated with faults appears, in part, to be dependent upon which lithologic units are faulted. In the ESF, overall variability in the frequency of fractures 1-meter long or longer is primarily a function of lithology, not proximity to faults (Sweetkind et al. 1997, p. 66 [DIRS 100183]). Each lithostratigraphic unit at Yucca Mountain has characteristic fracture attributes, including predominant orientations, spacing, trace length, and joint type that are lithologically controlled (Sweetkind et al. 1997, p. 74 [DIRS 100183]); and it is inferred that each is unique in its ability to deform by distributed slip. The result is stratigraphic control of structural geometry—what may be a discrete break in one lithostratigraphic unit, may be a broad zone of distributed deformation in another. Consequently, the modeling case of "mountain-scale" distribution of changes in fracture aperture changes is considered conservative.

6.2.1.11 Seismic Activity Changes Porosity and Permeability of Fractures (2.2.06.02.0B)

FEP Description: Seismic activity (fault displacement or vibratory ground motion) has a potential to change stress and strains that alter the permeability along fractures. This could result in reactivation of preexisting fractures or generation of new fractures. Generation of new fractures and reactivation of preexisting fractures may significantly change the flow and transport paths, alter or short-circuit the flow paths and flow distributions close to the repository and create new pathways through the repository. These effects may decrease the transport times for potentially released radionuclides.

Descriptor Phrases: Seismic activity (fractures in the UZ), Seismic activity (fractures in the SZ)

[Note: This is a shared FEP. This scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded*—Low Consequence

Screening Argument: The tectonic strain rate controlling the seismic and fault-displacement events leading to the small-scale displacements was evaluated as an uncertain parameter in the PSHA, and the uncertainty in the tectonic rate is, thereby, reflected in the PSHA results (see the FEP 1.2.01.01.0A Tectonic activity—large scale). A sensitivity analysis, discussed below, was performed and demonstrated that the consequence would be negligible.

Strain is more likely to affect existing features rather than to create new fractures as evidenced by field observation of reactivation features and the geologic history of Yucca Mountain. Although it does not directly address the reactivation of fractures or the creation of fractures, the PSHA (CRWMS M&O 1998 [DIRS 103731]) examines the probability of movement along existing fractures with no measurable cumulative displacement and the development of small-scale displacements in the intact rock. The results are used to infer that the reactivation of fractures and the development of new fractures are of low probability and are, therefore, not further considered within this FEP. This inference concerning small-displacement probabilities to fracture probabilities is possible because of the definition of "fractures".

According to the NRC (1999, p. 55 [DIRS 135621]), fractures are characterized by motion perpendicular to the fracture walls (extension fractures), by motion parallel to the fracture walls (shear fractures), or by very small displacement normal to their surfaces, and little or no displacement parallel to their surfaces (joints). The range of displacements extends upward to amplitudes that characterize faults, which typically originate as shear fractures capable of fracturing across discontinuities. According to Bates and Jackson (1987, p. 257 [DIRS 164050]), fracture "is a general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fracture includes cracks, joints, and faults." Consequently, fractures involve a range from no displacement, up to and including, small-scale movement.

Tectonically induced strain can be accommodated in several ways, including the formation of new fractures and/or movement on existing fractures.

The PSHA (CRWMS M&O 1998, p. 8-7 referring to intact rock, or condition "d" at hypothetical Points 7 and 8 within the repository block [DIRS 103731]) indicates that the probability of a movement (i.e., minimal displacement) developing in the intact rock has less than a 10^{-8} annual-exceedance probability (see Assumption 5.1 of this analysis report, ANL-WIS-MD-000005 REV. 01). By inference, this corresponds to the development of new fractures. The PSHA (CRWMS M&O 1998, Figures 8.10 and 8.13 for points 7c and 8c [DIRS 103731]) indicates that fractures within the current repository area having no measured displacements can be expected to experience on the order of 0.1 to 1 cm of displacement at a 10^{-8} annual-exceedance probability. By inference, this corresponds to the annualized probability for reactivation of fractures. These small-scale displacements along existing fractures and in the intact rock examined in the PSHA, at some undefined scale of movement, begin to fall within the range of the definition of fractures, as previously described. By inference from the PSHA, the development of new fractures due to seismic activity and associated fault displacement is inferred to be of low probability. It can also be inferred that movement along existing fractures is more likely than the development of new fractures, an inference that is directly supported by field observations and consideration of the geologic history of Yucca Mountain.

Field observations indicate that the rock at Yucca Mountain is highly fractured and that existing fractures and joints have been subject to reactivation. Evidence for reactivation of joints includes the presence of thin breccia zones along cooling joints and observable slip lineations along joint surfaces (Sweetkind et al. 1996 [DIRS 106957]). Cooling joints formed originally as tensional openings, have only face separation, not shear. However, thin selvages of tectonic breccia commonly are present along the trace of cooling joints, indicating later slip. Based on these field observations, the fracture network appears to act as a significant pre-existing weakness in the rock mass that can accommodate extensional strain through distributed slip along many reactivated joints. Coupled with the results of the PSHA for movement in the intact rock, it would appear that changes in strain are more likely to be accommodated along existing fractures rather than to initiate new fractures.

Fractures also, theoretically, could be created by mechanisms not directly related to seismicity or fault displacements, as examined in the PSHA, including changes in the stress field related solely to tectonism, without attendant seismicity or fault displacement. However, based on the geologic history of Yucca Mountain, tectonic changes, and hence changes in the stress field leading to fracture development, would occur at low rates (CRWMS M&O 2000, Section 6.3.1 [DIRS 142321]). Savage et al. (1999 [DIRS 118952]) present an evaluation of the strain-accumulation rate at Yucca Mountain, Nevada, for the period from 1983 to 1998, and address alternative interpretations by Wernicke et al. (1998 [DIRS 103485]) that suggest greater strain-accumulation rates. Regardless of the existing strain-accumulation rate, the existing fracture characteristics at Yucca Mountain have developed over an extended period and over a varying range of stress-and-strain conditions. For example, the development of Yucca Mountain itself (including deposition of the tuff layers, block faulting, and subsequent development of cooling joints and fractures) occurred over a period of 2.5 to 3 million years (inferred from Fridrich 1999, pp. 184–189 [DIRS 118942]; and Sawyer et al. 1994, pp. 1305 and 1312 [DIRS 100075]). The rate of regional tectonism has decreased greatly since late Miocene (inferred from Fridrich et al. 1998, pp. 1 and 2 [DIRS 164051]). The stress conditions associated with these earlier processes vary considerably from existing conditions. Consequently, unless stress vectors acting on Yucca Mountain were to deviate markedly and rapidly from those acting (either locally or regionally) within the past few million years, the shear strength of intact rock will not be exceeded (i.e., new fracturing will not be initiated) due to the presence of existing fracture sets favorably oriented to accommodate increased stresses and strains.

The effects of changes to fracture systems in the UZ fault zones have been investigated using a sensitivity approach (*Fault Displacement Effects on Transport in the Unsaturated Zone* CRWMS M&O 2000 [DIRS 151953]). The sensitivity study was performed with the nominal UZ three-dimensional flow model using several conservative approaches that, together, provide bounding cases for determining whether changes in fractures would significantly impact repository performance. The analysis was performed using a dual-permeability, active-fracture flow model, and was based on the fracture apertures changes resulting from changes in strain conditions or other factors. Given a change in fracture aperture, other fracture hydrologic properties (permeability, capillary pressure, and porosity) were estimated using theoretical models.

The sensitivity study (CRWMS M&O 2000 [DIRS 151953]) included two bounding cases: 1) that changes in fracture properties occur over the entire UZ domain (fault zones and fractured rock), or 2) that the effects of fault displacement are limited to fracture-property changes in fault zones. These were modeling cases chosen to bound a presumed range of fracture-aperture changes resulting from fault movement. There are no direct observations for Yucca Mountain that relate stress caused by fault displacement to strain and resultant changes in fracture aperture. The bounding cases were used to simulate a response beyond that of the expected geologic response.

A maximum, ten-fold increase in fracture aperture was selected as a modeler's upper-bounding value and was justified in CRWMS M&O (2000 [DIRS 151953]). The justification cites distance-strain relationships derived from models for a 1-meter displacement along a strike-slip fault (used as an analogue, though not directly representative of normal-fault response) at Yucca Mountain and for a 1-meter displacement on a theoretical normal fault. The changes in fracture apertures for the sensitivity analysis were derived presuming a 10-meter fault movement along the Solitario Canyon and multiplying the strains cited in the justification. The potential for being conservative is mentioned primarily because the presumed 10-meter displacement, although a mean value, is conservative when compared to probabilistically-determined (median and 85th fractile) and observed fault displacements. The results of the PSHA (CRWMS M&O 1998, Figure 8-3 [DIRS 103731] and DTN: MO0004MWDRIFM3.002 [DIRS 149092]) indicate that for the Solitario Canyon fault, there is a large uncertainty range in the potential displacements from 3 meters (the median value) to approximately 9 meters (the 85th fractile value) at the 10^{-8} annual-exceedance probability (See Assumption 5.1 of this report, ANL-WIS-MD-000005 REV 01). By contrast, the maximum measured single-event Quaternary displacement (i.e., during the past 1.6 million years) on the Solitario Canyon fault is only 1.3 meters (Ramelli et al. 1996, Table 4.7.3 [DIRS 101106]).

The results of the sensitivity study (CRWMS M&O 2000 [DIRS 151953]) has shown that changes in fracture aperture confined to fault zones resulted in virtually no effect on transport behavior in the UZ, and that increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than other uncertainties related to infiltration (CRWMS M&O 2000, Section 7 [DIRS 151953]).

Because neither flow nor transport is significantly affected by changes in fracture aperture, dose is not significantly affected. The effects of faults and changes on the flow-properties of faults are *Excluded* based on low consequence. However, the evaluation of changes to fracture systems presented in CRWMS M&O (2000 [DIRS 151953]) relies upon information and assumptions related to the response of the perched water table response and thermal hydrologic processes, but the effects are expected to be minimal.

In summary, effects in the UZ either would be transient or would result in changes to the hydrologic characteristics of fractures, as expressed through the parameter of fracture aperture. The effects of changes to fracture systems due to geologic effects on mountain-scale flow and radionuclide transport have been investigated using a sensitivity approach (CRWMS M&O 2000 [DIRS 151953]) and indicate that changes in fracture aperture confined to fault zones show virtually no effect on transport behavior in the UZ, and increased fracture aperture applied over the entire UZ domain results in effects that are no more significant than other uncertainties related to infiltration (CRWMS M&O 2000, Section 7 [DIRS 151953]). Therefore, this FEP is of low consequence and is *Excluded* from the TSPA-LA.

TSPA Disposition: Not Applicable

Related FEPs:

FEPs that examine related but distinct effects and consequences

Tectonic activity—large scale (1.2.01.01.0A)
Metamorphism (1.2.05.00.0A)
Diagenesis (1.2.08.00.0A)
Earth tides (1.5.05.02.0A)

FEPs that examine similar effects and consequences

Hydrologic response to seismic activity (1.2.10.01.0A)
Seismic activity changes porosity and permeability of rock (2.2.06.01.0A)
Seismic activity changes porosity and permeability of faults (2.2.06.02.0A)
Seismic activity alters perched water zones (2.2.06.03.0A)
Fracture flow in the UZ (2.2.07.08.0A)
Water- conducting features in the SZ (2.2.07.13.0A)

Related Documents: *Fault Displacement Effects on Transport in the Unsaturated Zone* ANL-NBS-HS-000020 (CRWMS M&O 2000 [DIRS 151953])

Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada ANL-CRW-GS-000003 (CRWMS M&O 2000 [DIRS 142321])

Supplemental Discussion: None

6.2.1.12 Seismic Activity Alters Perched Water Zones (2.2.06.03.0A)

FEP Description: Strain caused by stress changes from tectonic or seismic events alters the rock permeabilities that allow formation and persistence of perched water zones.

Descriptor Phrases: Seismic activity (alters perched water)

[Note: This is a shared FEP. The scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded*—Low Consequence

Screening Argument: This a shared FEP and the technical basis is fully addressed in the related FEP AMR cited therein. Only a partial conceptual volumetric argument is presented, as follows.

Changes in stress due to all causes have the potential to result in strains that affect groundwater flow-and-transport properties, leading to increased or decreased dose. It seems that a change in stress could, in itself, adequately seal a zone such that perched water develops. However, the generation of a perched water zone above the repository due to seismic activity, could potentially affect the flow of water to waste emplacement drifts. This potential effect is indirectly addressed by using focused flow in the seepage model abstraction.

Below the repository, the potential to release perched water because of stress changes and fracture openings due to seismic activity is considered. Hypothetically, such changes have the potential to result in a relatively sharp "pulse" of radionuclides, if the perched water contains radionuclides, and if the perched water is allowed to drain.

This FEP was previously addressed for TSPA-SR based on perched zone water volume calculations provided in Attachment X of BSC 2001 [DIRS 154826]. The TSPA-SR analysis indicated that the existing volume of perched zone water is insignificant because it represents only a few years of flux through the system. However, because of the repository footprint change for TSPA-LA, the calculation was updated in Attachment I of BSC 2003 [DIRS 164873], which serves as the technical basis for the FEP exclusion. Although the calculated values vary from those for TSPA-SR due to the change in the repository footprint, the approach used to exclude the FEP, and the finding of insignificance have not changed between TSAP-SR and TSPA-LA. This is because much of the TSPA-LA footprint overlaps with the TSPA-SR footprint, and the total area of the repository is roughly equivalent.

As shown by both the TSPA-SR and the TSPA-LA calculations, the relatively small amount of water *in the fracture domain* below the repository, and the radionuclides that could be contained in this water, are not expected to cause a significant "pulse" in radionuclide mass flux at the water table. For TSPA-LA, the unsaturated zone flow model shows that the volume of perched water in the high-permeability fracture domain below the repository ranges from about 466 m^3 to 1,190 m^3. This volume may be compared with the water flux entering the repository footprint (i.e., that average infiltration rate times the area of the repository footprint). The infiltration volume ranges from 2000 to 192,000 m^3/yr. As shown in Attachment I, the perched water volume is seen to represent about 0.006 to 0.2 years of water flux. Thus, the perched water volume in high-permeability fractures is small compared to the water flux through the repository horizon for one year, and the FEP is *Excluded* based on low consequence. Even if released instantaneously by a seismic event, the release of perched water would have no significant consequence on exposure or release of radionuclides to the accessible environment. Therefore, this FEP is *Excluded* from the TSPA-LA based on low consequence.

TSPA Disposition: Not Applicable

Related FEPs:

FEPs that examine related but distinct effects and consequences

Tectonic activity—large scale (1.2.01.01.0A)

FEPs that examine similar effects and consequences

Hydrologic response to seismic activity (1.2.10.01.0A)
Seismic activity changes porosity and permeability of rock (2.2.06.01.0A)
Seismic activity changes porosity and permeability of faults (2.2.06.02.0A)
Seismic activity changes porosity and permeability of factures (2.2.06.02.0B)
Perched water develops (2.2.07.07.0A)

Related Documents: None

Supplemental Discussion: None

6.2.2 Igneous-Related FEPs

The following subsections provide the screening decision and technical basis for inclusion and exclusion of the following igneous-related FEPs.

1.2.04.02.0A	Igneous activity changes rock properties (Section 6.2.2.1)
1.2.04.03.0A	Igneous intrusion into repository (Section 6.2.2.2)
1.2.04.04.0A	Igneous intrusion interacts with EBS components (Section 6.2.2.3)
1.2.04.05.0A	Magma or pyroclastic base surge transports waste (Section 6.2.2.4)
1.2.04.06.0A	Eruptive conduit to surface intersects repository (Section 6.2.2.5)
1.2.04.07.0A	Ashfall (Section 6.2.2.6)
1.2.04.07.0C	Ash redistribution via soil and sediment transport (Section 6.2.2.7)
1.2.10.02.0A	Hydrologic response to igneous activity (Section 6.2.2.8)

6.2.2.1 Igneous Activity Changes Rock Properties (1.2.04.02.0A)

FEP Description: Igneous activity near the underground facility causes extreme changes in rock stress and the thermal regime, and may lead to rock deformation including activation, creation, and sealing of faults and fractures. This may cause changes in the rock hydrologic and mineralogic properties. Permeabilities of dikes and sills and the heated regions immediately around them can differ from those of country rock. Mineral alterations can also change the chemical response of the host rock to contaminants.

Descriptor Phrases: Igneous activity (rock properties in the UZ), Igneous activity (rock properties in the SZ)

[Note: This is a shared FEP. This scope and intent of this report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded*—Low Consequence

Screening Argument: With regard to extreme changes in hydrologic properties, sills and dikes initially intrude into the country rock as molten material and then cool. Cooling joints are formed and resulting permeabilities may be greater than, equivalent to, or less than the surrounding country rock. However, the scale of these effects is limited to a few meters around the dike and changes in properties are, therefore, of low consequence.

An appropriate analog for understanding the components of a volcanic event is the Paiute Ridge intrusive/extrusive center (Byers and Barnes 1967 [DIRS 101859]) on the northeastern margin of the Nevada Test Site. Paiute Ridge is a small-volume Miocene volcanic center comparable in volume and composition to Quaternary volcanoes near Yucca Mountain (CRWMS M&O 1998 p. 5-29 [DIRS 105347]). Paleomagnetic, geochronologic, and geochemical data indicate that the entire intrusive/extrusive complex formed during a brief magmatic pulse and, thus, represents a single volcanic event (Ratcliff et al. 1994 [DIRS 106634]; and CRWMS M&O 1998, p. 5-29 [DIRS 105347]). The vents and associated dike system formed within a north-northwest-trending extensional graben provide excellent exposures of a variety of system depths including remnants of surface lava flows, volcanic conduits, and dikes and sills intruded into tuff country rock at depths of up to 300 meters (CRWMS M&O 1998, pp. 5-27 through 5-41 [DIRS 105347]). There is evidence of shallow structural control of dike emplacement at Paiute Ridge, including dike emplacement along fault planes (Byers and Barnes 1967 [DIRS 101859]; and CRWMS M&O 1998, pp. 5-27 and 5-28, [DIRS 105347]). Dike lengths at Paiute Ridge range from <1 km to 5 km (CRWMS M&O 1998, p. 5-31 [DIRS 105347]), comparable to the range estimated for post-Miocene volcanism near Yucca Mountain.

Carter-Krogh and Valentine (1996, pp. 7 and 8 [DIRS 160928] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) described the margins of the Paiute Ridge dike complex and the interaction of dikes and faults. The description is as follows:

> "PR dike contains ubiquitous near-vertical joints that result in a pervasive platy texture with plates parallel to the dike-host contact. Conversely, with the exception of local cooling joints in fused wall rock (extending 10-20 cm into the wall rock, perpendicular to the dike margin), joints are never visible in the host rock along the length of the dike. The contact between basalt and the tuff host rock is consistently smooth and shows no brecciation. Along strike at this contact, the tuff host rock is fused or welded to varying degrees: in places the tuff is completely welded and forms black vitrophyre that grades rapidly away from the contact, over a distance of ca 20–100 cm, into nonwelded tuff that is apparently unaffected by the dike. In other places the tuff is only partly welded at the contact and black fiamme are elongated parallel to the contact. We infer that this "contact welding" is the combined result of heat from the dike and compressive stress exerted by the flowing magma on the wall rocks. Welded host rock commonly contains vesicles that are elongated vertically and parallel to the margin. In some places, welded tuff coats the basalt and displays rills or elongate smooth ridges (flutes). Most rills plunge nearly vertically, however, a sub-horizontal rill is present in the central part of the dike. At the dike tip, exposed at Slanted Buttes, scoria patches crop out near the dike-host contact."
>
> The two eastern dikes, M and E … show geometries and textures similar to those of PR; however, M dike is much shorter and does not feed a sill, and E dike was emplaced closest to the paleosurface and feeds two sills. M dike … visibly occupies a normal fault, oriented N40° W, 61° E, … Its host rocks are only Tertiary tuffs, which show no brecciation or jointing near the dike contact … Texture within the dike is characterized by a vertical platy fabric that parallels the dike margins. E dike is the eastern-most dike studied within the graben. … Near the neck, the dike visibly occupies a NNW-trending, steeply E-dipping normal fault that displaces bedded tuffs 3.5 m and does not cut the dike …The texture of E dike is characterized by the pervasive vertical platy fabric common to M and PR dikes. Adjacent host tuffs are not jointed nor brecciated, except for local vertical jointing of the Rainier Mesa tuff, which is intruded by the dike at its shallowest level. The contact of the dike and host tuff is preserved in places and varies from partly to completely welded in the same manner as described above for the PR dike. Where complete welding has occurred, vesicles are vertical and parallel the dike margin. Contact welding of the host tuffs formed oblate fiamme that parallel the dike-host contact. Visible thermal effects on the wall rocks disappear within one meter of the dike margin."

This suggests that zones of change in rock properties (i.e., formation of vitrophyres and/or various degrees of welding of the host rock) are limited to between a few tens of centimeters to, at most, a meter perpendicular to the dike. Other features such as the platy texture along the dike margins and vesicles in the welded tuff are oriented parallel to the dike margins. This suggests that the primary direction of increased or decreased permeability (if any) is parallel with the dike margins. The description also indicates the interaction of faults and dikes and alludes to the segmented, discontinuous, *en echelon* structures observed for the dike complex.

Most researchers conclude that once dikes feeding volcanoes enter the shallow upper crust, their location and orientation is influenced by the orientation of the local stress field and the presence of faults that may locally control vent location and alignment. The evidence cited for these two conclusions includes several northeast-oriented vent alignments in the YMR and the association of eruptive centers with known or inferred faults (Smith et al. 1990, p. 83 [DIRS 101019]; CRWMS M&O 1996, Appendix E, p. AM-4 [DIRS 100116]; Connor et al. 1996, p.78 [DIRS 135969]; Reamer 1999, Section 4.1.3.3.3 [DIRS 119693]).

The results of the PVHA are summarized in the analysis report C*haracterize Framework for Igneous Activity at Yucca Mountain*, *Nevada* (BSC 2003 [DIRS 163769]), and the analysis report presents probability distributions for the length and orientation of volcanic dikes within the repository footprint. The individual PVHA expert dike length distributions can be aggregated to derive a PHVA aggregate dike length distribution. The aggregate dike-length distribution derived from the PVHA has 5th-percentile, mean, and 95th-percentile values of 0.6, 4.0, and 10.1 km, respectively, and the most commonly assigned dike orientation centers on N30^{o}E (BSC 2003, Section 6.3.2 [DIRS 163769]). The analysis, based on the results of the PVHA, also assigns the highest probabilities of dike orientation to azimuths of between 20 and 40 degrees (BSC 2003, Table 18 [DIRS 163769]).

The anisotropic transmissivity in the SZ observed in the Yucca Mountain region has a maximum principal transmissivity direction of approximately N15E (BSC 2003, Section 6.5.2.10 [DIRS 164870]), which is consistent with the fault and fracture orientation and a corroborative analysis by Ferrill et al. (1999, p. 1 [DIRS 118941], which indicates N30E. Based on the PVHA results, future dikes most likely will trend in a north-to-northeast orientation, although this may be altered by the presence of existing faults, or localized changes in the stress field with the orientation being perpendicular to the least compressive stress. A north-to-northeast orientation parallels or sub-parallels the faults, and fractures active in the present-day *in situ* stress field. Dike features, such as the platy texture and welded surfaces that could affect the permeability, will presumably parallel the dike orientation and be aligned in a north-to-northeast orientation.

This parallel to subparallel orientation of dikes and maximum principal transmissivity, coupled with the expected limited affected volume of material around the dikes, indicates that dikes, even if differing in permeability, will not significantly affect groundwater flow patterns at the mountain scale. By way of corroboration, an early analysis of the effect of a dike on flow in the SZ was conducted and documented in Chapter 10 of the TSPA for the Viability Assessment (CRWMS M&O 1998, Section 10.4.4 [DIRS 100369]). The corroborative analysis suggested that there would be negligible impact for a dike oriented north to northeast. The analysis included a variety of dike lengths and locations respective to the repository area. Additionally, the occurrence of such a change is conditional on a low probability event of an igneous intrusion.

CRWMS M&O (1998, p. 5-56 [DIRS 105347]) mentions the possibility of perched water forming near low-permeability intrusive bodies, and there is concern regarding the potential for a dike to provide a barrier to flow and/or cause impoundments. Because of the parallel to subparallel orientation of dikes with the existing orientation of the anisotropic maximum horizontal permeability in the SZ, a dike would not form a barrier or impoundment that would have any significant effect on flow in the SZ. In the UZ, the primary direction of groundwater flow is vertically through the fractures, although some horizontal flow component exists in the matrix. Because the joints on a dike margin would be near-vertical, it would seem that the formation of a significant perched water zone is problematic without the formation of a sill. The potential for sill formation is addressed in the FEP 1.2.04.03.0A (Igneous intrusion into repository). The formation of a perched water zone is addressed in the FEP 2.2.07.07.0A (Perched water develops) and has been *Included* in the TSPA-LA. Even if a perched water zone were to form and then drain, there would be only a minimal impact, as explained in FEP 2.2.06.03.0A (Seismic activity alters perched water zone).

Change in fault and fracture properties (i.e., activation, creation, and sealing of faults and fractures) is judged to be of negligible impact on three bases. First, the orientation of the faults and fractures is generally parallel-to-subparallel to the maximum principal transmissivity in the SZ, so alteration of the faults or fractures would presumably have minimal effect. Additionally, the effect of changes in aperture (i.e., the mathematical equivalent of sealing or reactivation) was examined in *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000, Section 7 [DIRS 151953]) and found to have negligible impact, and changes in fault properties were excluded from further consideration in TSPA-LA on that basis. Lastly, the potential for volcanic-generated seismic events was considered within the context of the PSHA and included implicitly in the probabilistic assessment of seismic ground motion hazards (see FEP 1.2.03.03.0A (Seismicity associated with igneous activity)). The seismic source characterization was also used as the basis for the earthquake approach for determining probabilistic fault displacements. Thus, displacements from igneous events have been implicitly included in evaluation of probabilistic fault displacement (i.e., reactivation and creation of new faults) and further consideration is unwarranted.

With regard to extreme changes in mineralogy, it is possible that the thermal and geochemical influence of igneous activity could affect the rock mineralogy surrounding the igneous intrusion. However, igneous intrusions at natural-analogue sites are generally confined to relatively thin zones of rock ranging from a few to a few hundred meters (CRWMS M&O 1998, pp. 5-42 and 5-57 [DIRS 105347] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). In particular, natural-analogue studies at the Nevada Test Site show that alteration is limited to a zone less than 10 meters away from the intrusion/host rock contact (CRWMS M&O 1998, pp. 5-41, 5-71, and 5-72 [DIRS 105347] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). CRWMS M&O (1998, p. 5-42 [DIRS 105347] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) further states that, "Based on natural-analogue sites, there is no indication for extensive hydrothermal circulation and alteration, brecciation and deformation related to magmatic intrusion, and vapor phase recrystallization during the magmatic intrusion into the vitric and zeolitized tuffs." Because the alteration zone around dikes is limited to the immediate proximity of the dike, then, at the scale of the repository, changes in mineralogy are of low consequence.

In summary, each concern posed in the FEP description has been evaluated based on site data or natural analogues. The subparallel orientation of dikes to transmissivity, coupled with the expected limited affected volume, indicates that dikes, even if differing in permeability, will not significantly affect groundwater flow patterns. Because the joints on the dike margin are near vertical, it would seem that the formation of a significant perched water zone is problematic. Furthermore, natural-analogue studies show that alteration is limited to a zone less than 10 meters away from the contact at the Nevada Test Site natural-analogue sites. Consequently, changes in rock properties due to igneous activity do not provide a mechanism to significantly affect exposure or release of radionuclides to the accessible environment. Therefore, the FEP is *Excluded* from the TSPA-LA based on low consequence.

TSPA Disposition: Not Applicable

Related FEPs:

FEPs that examine related but distinct effects and consequences

Igneous intrusion into repository (1.2.04.03.0A)
Diagenesis (1.2.08.00.0A)
Diapirism (1.2.09.01.0A)
Rind (chemically altered zone) forms in the near field (2.1.09.12.0A)
Rock properties of host rock and other units (2.2.03.02.0A)
Perched water develops (2.2.07.07.0A)
Fracture flow in the UZ (2.2.07.08.0A)
Groundwater conducting features in the SZ (2.2.07.13.0A)
Geochemical interactions and evolution in the SZ (2.2.08.03.0A)
Geochemical interactions and evolution in the UZ (2.2.08.03.0B)

FEPs that examine similar effects and consequences

Metamorphism (1.2.05.00.0A)
Hydrothermal activity (1.2.06.00.0A)
Thermally-induced stress changes in the near field (2.2.01.02.0A)
Thermomechanical stresses alter characteristics of fractures near repository (2.2.10.04.0A)
Thermomechanical stresses alter characteristics of faults near repository (2.2.10.04.0B)
Thermomechanical stresses alter characteristics of rocks above and below the Repository (2.2.10.05.0A)

Related Documents: None

Supplemental Discussion: None

6.2.2.2 Igneous Intrusion Into Repository (1.2.04.03.0A)

FEP Description: Magma from an igneous intrusion flows into the drifts and extends over a large portion of the repository site, forming a sill, dike, or dike swarm depending on the stress conditions. This could involve multiple drifts. The sill could be limited to the drifts or a continuous sill could form along the plane of the repository, bridging between adjacent drifts.

Descriptor Phrases: Dike or sill intersects one or more drifts, Magma or pyroclastic material intersects waste packages, In-drift flow and pathways through intrusive dike or sill

Screening Decision: *Included* (BSC 2003, Table 9 [DIRS 163769]; BSC 2003, Table 5 [DIRS 161838]; BSC 2003, Table 4 [DIRS 165923])

Screening Argument: Not Applicable

TSPA Disposition: The primary focus of this FEP is magmatic intrusion directly into the repository. The following FEP discussion addresses the potential for such an intrusion and the resulting in drift conditions and waste package damage, which are *Included* within the TSPA-LA. Related FEPs discuss changes in hydrology and rock properties.

Based on the results of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003, Table 22 [DIRS 163769]), the computed mean annual frequency of intersection of the repository footprint by a dike is 1.7×10^{-8} for the LA footprint compared to 1.5×10^{-8} obtained in the PVHA (CRWMS M&O 1996, p. 4-10 [DIRS 100116]) (see Assumption 5.1 of this analysis report, ANL-WIS-MD-000005 REV. 01). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBSO-00401-000-00C (BSC 2003 [DIRS 161727] and [DIRS 162289]). The computed 5th and 95th percentiles of the uncertainty distribution for frequency of intersection are 7.4×10^{-10} and 5.5×10^{-8}, respectively, as compared to 5.4×10^{-10} and 4.9×10^{-8} obtained in the PVHA (CRWMS M&O 1996, p. 4-10 [DIRS 100116]). The mean probability is used in the TSPA-LA to weight conditional dose calculations.

Igneous intrusion into the repository (i.e., igneous activity) as provided in the FEP description has the potential to effect both the hydrologic and geochemical characteristics of the site, and due to extreme changes the in-drift environment, could damage EBS components and the waste packages. Combined, this could result in the release of radionuclides and affect the radiological exposure of the RMEI.

Because the probability of igneous intrusion is slightly greater than the FEP screening probability threshold, and because waste package damage cannot be constrained due to the thermal, mechanical, and geochemical environment associated with an intrusion into an emplacement drift, igneous intrusion into the repository is *Included* within the TSPA-LA. The environmental conditions and their effect on waste packages are discussed in the FEP 1.2.04.04.0A (Igneous intrusion interacts with EBS components).

The TSPA-LA approach for addressing igneous intrusion is outlined in the document *Total System Performance Assessment-License Application Method and Approach* (BSC 2002, Section 8.1.2 [DIRS 160146]). The two igneous events (with individual probabilities and consequences) being modeled by the TSPA-LA are: 1) an igneous intrusion groundwater transport modeling case featuring the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to the repository level where it intersects drifts; and 2) a volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. As a consequence of the first event, which is non-eruptive, waste from breached packages may provide a source of radionuclides when groundwater moves through the damaged packages at some time in the future (igneous intrusion groundwater transport modeling case). The potential consequence of the second event (volcanic eruption modeling case) is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the RMEI. Based on the current design, the location is assumed approximately 18 km south of the repository (10 CFR 63.312 and 10 CFR 63.302, 66 FR 55732 [DIRS 156671]).

An appropriate analog for understanding the components of a volcanic event is the Paiute Ridge intrusive/extrusive center (Byers and Barnes 1967 [DIRS 101859]) on the northeastern margin of the Nevada Test Site. Paiute Ridge is a small-volume Miocene volcanic center comparable in volume and composition to Quaternary volcanoes near Yucca Mountain (CRWMS M&O 1998, p. 5-29 [DIRS 105347]). Paleomagnetic, geochronologic, and geochemical data indicate that the entire intrusive/extrusive complex formed during a brief magmatic pulse and, thus, represents a single volcanic event (Ratcliff et al. 1994 [DIRS 106634]; and CRWMS M&O 1998, p. 5-29 [DIRS 105347]). The vents and associated dike system formed within a north-northwest-trending extensional graben provide excellent exposures of a variety of system depths including remnants of surface lava flows, volcanic conduits, and dikes and sills intruded into tuff country rock at depths of up to 300 meters (CRWMS M&O 1998, pp. 5-27 through 5-41 [DIRS 105347]). There is evidence of shallow structural control of dike emplacement at Paiute Ridge, including dike emplacement along fault planes (Byers and Barnes 1967 [DIRS 101859]; and CRWMS M&O 1998, pp. 5-27 and5-28, [DIRS 105347]). Dike lengths at Paiute Ridge range from <1 km to 5 km (CRWMS M&O 1998, p. 5-31 [DIRS 105347]), comparable to the range estimated for post-Miocene volcanism near Yucca Mountain.

The technical basis for the inclusion of this FEP is partially provided in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [DIRS 163769]). The analysis report documents the probability of a basaltic dike intersecting the repository footprint, the number of eruptive centers (conduits) within the repository footprint, and the length and azimuth of intersecting dikes within the repository footprint. The developed values represent full distributions, which are then used to generate a cumulative distribution function (CDF) of less than 100 points for the primary and contingency block values.

The results of the probability analysis are used in the analyses of the number of waste packages hit during an igneous intrusion and affected by conduit formation. The distribution (CDF) of the number of waste packages hit is then used by the TSPA-LA model to determine the amount of waste released via an eruptive event and to determine the number of waste packages affected and the volume of waste subject to release via the groundwater pathway. For the igneous intrusion groundwater transport modeling case, all waste packages in intersected drifts are assumed to provide no further protection, and waste is available for release via normative groundwater flow and transport process. For the volcanic eruption modeling case, waste packages within the conduit diameter are assumed to release the waste to the surface via the conduit and an eruptive event. Because the CDF for the number of waste packages hit is dependent on the underlying inputs, the underlying inputs and related FEPs are considered included implicitly in the TSPA-LA model. Parameters developed in BSC 2003 (Sections 6.5.3.2 and 7.2 [DIRS 163769]) that are a direct output to the analysis report *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2003 [DIRS 161851]), and that are implicitly included in the TSPA-LA, include the following:

- Conditional joint probability distributions for length and azimuth of an intersecting dike within the repository LA footprint—used to determine the distribution of dike azimuth angles, as basis for selection of 30-degree representation

- Composite conditional probability distribution of the number of eruptive centers within the repository LA footprint—used to determine the aggregate probability for number of conduits intersecting repository.

Developed parameters from BSC 2003 (Section 7.2, [DIRS 163769]) that are direct outputs to and explicitly included in the TSPA-LA include the following:

- A discrete probability distribution for the annual frequency of intersection of the proposed repository emplacement area footprint by a dike or dike system

- A discrete probability distribution for the annual frequency of disruption of the proposed repository emplacement area footprint by one or more eruptive centers.

The thermal, mechanical, and geochemical environments associated with an intrusion into an emplacement drift are governed in part by the properties of the magma and in part by the physical processes of volcanic intrusion. The analysis report *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003, Section 6 [DIRS 161838]) provides a partial technical basis for inclusion of the FEP in the TSPA-LA. The analysis report presents information about volcanic systems and the parameters that can be used to model their behavior. In particular, that report addresses the geometry of volcanic feeder systems, which is of primary importance in predicting how much of a repository would be affected by an eruption. The analysis report also addresses the physical and chemical properties of the magmas, which influence both eruptive styles and mechanisms for interaction with waste packages.

The results of *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003, Table 37 [DIRS 161838]) do not directly feed into the TSPA-LA model. Rather, the results provide input for the following cited reports. Because the outputs of the cited reports are used either implicitly or explicitly in the TSPA-LA model, and the outputs of the cited reports are dependent on the underlying inputs documented in the eruptive processes analysis report (BSC 2003 [DIRS 161838], the underlying inputs and related FEPs are considered to be implicitly included in the TSPA-LA model. The use of outputs is as follows:

The model report *Dike/Drift Interactions* (BSC 2003, Table 2 [DIRS 165923]) uses the following outputs from the eruptive processes analysis report (BSC 2003, Table 37 [DIRS 161838]):

- Velocity as a function of depth—used to determine the magma far field velocity
- Magmatic temperatures, viscosities, and densities—used to determine the bulk density and bulk viscosity of magma, the magma vesicle free density, and intrusion temperature
- Magma ascent rate below vesiculation depth and magma velocities
- Dike width—used to determine the dike far field width.

Number of Waste Packages Hit by Igneous Intrusion (BSC 2003, Table 4-1 [DIRS 161851]) also uses the output distributions from the eruptive processes analysis report (BSC 2003, Table 37 [DIRS 161838] as addressed in FEPs 1.2.04.04.0A (Igneous intrusion interacts with EBS components) and 1.2.04.06.0A (Eruptive conduit to surface intersects repository).

The primary factors of concern include the probability of the event occurring, the number of drifts and waste packages affected by the event, and the mechanism of radionuclide release to the accessible environment through a corresponding eruptive event or release via a groundwater pathway. The particular form of the intrusion (a dike, dike swarm or sill) is of lesser concern, so long as these differences are captured by the various parameter distributions and the event modeling allows for the intrusion of multiple drifts and damage of the waste packages within each of the intruded drifts.

The form of the intrusion is addressed in the model report *Dike/Drift Interactions* (BSC 2003 [DIRS 165923]), which considers the potential dike paths and dimensions in the dike propagation analysis. The dike propagation analyses use a numerical code based on a displacement-discontinuity boundary element formulation. The code includes all essential elements necessary for the simulation of hydraulic fracturing: fracture propagation, viscous fluid flow inside the fracture, and fluid leak-off in the surrounding formation. Fracture propagation is based on linearly elastic fracture mechanics. The approach is elastic and assumes plane strain conditions of deformation. The Dike Propagation model applies a fracture propagation approach using representative igneous dike properties to calculate key parameters such as dike width, dike pressure, and dike propagation velocity as the repository is approached and intersected. The sensitivity of the crack path to other model parameters (e.g., magma viscosity confining stress) and initial conditions (e.g., dike velocity at depth or driving pressure) also is considered. The model also uses a quantitative stress analysis to aid in evaluating how the stress field around the repository could influence the a basaltic igneous dike's direction of propagation and accommodates changing conditions along the pathway to which the dike may react, including the undisturbed area below the repository, the altered area around the repository and finally, conditions that apply as the dike continues upward after it has passed through the repository level. The input parameters for the model include the following:

- Geographic/geologic: Regional topography, stratigraphy, in situ stresses, repository depth
- Host rock properties: Young's modulus, Poisson's ratio, density, specific heat, thermal diffusivity, temperature

- Magma properties: Density, latent heat, far-field velocity, intrusion temperature, solid fraction vs. temperature, specific heat, thermal diffusivity, pressure
- Dike properties: Far-field width
- Drift Properties: Repository layout, heat release, diameter, depth, spacing.

The Dike Propagation model provides various outputs that are used as input parameters for the Magma and Gas Flow model and for assessing the formation of sills and secondary dikes. The Dike Propagation numerical model calculates and provides output to determine:

- The fracture propagation tip location and fluid front location with time and with respect to the repository level
- The magma pressure conditions and dike parameters with time at the point of intersection with the repository
- The extent of the magma loss into the repository and its effect on subsequent dike growth
- The change in confining stresses around the repository due to the presence of the dike.

The output of the Dike Propagation model is not used directly in the TSPA-LA model, but is used to refine the conceptual model of dike propagation. The model report *Dike/Drift Interactions* (BSC 2003, Section 8.1 [DIRS 165923]) provides conclusions related to the effects of various factors such as stress states around the repository, topography effects, and thermal stresses on dike propagation. The model output also provides support for determining the potential for initiation of new fractures or reopening of existing joints inside the drift as a result of dike-drift interaction; the likelihood of the dike continuing on its path at the initial point of dike-drift intersection or its being diverted, and the selected boundary conditions (related to dike propagation) for "leak-off" of magma into a drift. The model does not provide results for a pyroclastic magma. In this way, the model implicitly defines the manner in which igneous intrusion into the repository is included in the TSPA-LA model—that is, by defining the maximum length of an intersected drift that is involved in the direct flow path and providing input for the Magma and Gas Flow model.

The output of this model provides the support for a conceptual dike propagation model that precludes an alternative conceptual model describing development of a conduit extending (or "doglegging") from the point of drift intersection to the intersection of an eruptive conduit if the magma is effusive (i.e., does not expand rapidly). It also addresses the conditions pertaining to flow into drifts at the point of intersection if the magma is effusive. With regard to the "dog-leg", the model report states in Section 8.1.2 (BSC 2003 [DIRS 165923] as follows:

> "The "dog-leg" scenario of Woods et al. (2002 [DIRS 163662]) was evaluated for the non-explosive case of effusive flow, and that was not found to be credible. Based on an extensive simulation of crack-opening rates, the distance of the magma front from the drift periphery 300 s after magma has repressurized in the drift will be between 5 m and 60 m. However, in the same time, 300 s after the

drifts are completely filled, magma flowing up the main dike would reach ground surface (assuming a magma front velocity of 1m/s). Under extreme conditions of 10-MPa magma pressure inside the drift, the velocity of a magma front inside a joint is approximately 0.5 m/s (with a tendency to decrease as the pressure gradient decreases in response to the increasing length of the magma-filled portion of the joint), which is less than the expected velocity of the magma front inside the main dike. Analysis of the loss of heat from newly forming effusive-magma-filled cracks in cold rock show clearly that such cracks will not be able to grow to any appreciable width before they are halted by solidification. … The igneous consequence Peer Review Final Report concludes that the "dog-leg" scenario, in which a new fracture or re-opening of a pre-existing fracture opens sufficiently wide enough and continues to propagate carrying magma to the surface, is highly unlikely, but that analyses need to be performed to demonstrate this conclusion. The analyses contained in this AMR clearly demonstrate that the "dog leg" scenario is highly unlikely for the case of effusive flow. The possibility of a "dog-leg" scenario of Woods et al. (2002 [DIRS 163662]) for the case of pyroclastic flow was acknowledged as an alternative conceptual model, but due to the unavailability of a qualified mathematical code at the time this report was prepared, no analysis is available to support similar conclusions regarding the pyroclastic "dog leg." Nevertheless, it is highly unlikely that the pressures of a pyroclastic flow, while potentially greater than the rock strength, could sustain an open crack for a sufficient time to allow continuous flow of two-phase magma. Further analyses of pyroclastic flow using three-dimensional analyses will likely confirm this conclusion."

Consequently, the "dog-leg" alternative conceptual model is not considered credible and is not further considered in the TSPA-LA.

Related FEPs:

<u>*FEPs that examine related but distinct effects and consequences*</u>

Tectonic activity—large scale (1.2.01.01.0A)
Seismicity associated with igneous activity (1.2.03.03.0A)
Igneous activity changes rock properties (1.2.04.02.0A)
Magma or pyroclastic base surge transports waste (1.2.04.05.0A)
Eruptive conduit to surface intersects repository (1.2.04.06.0A)
Ashfall (1.2.04.07.0A)
Diapirism (1.2.09.01.0A)
Hydrologic response to igneous activity (1.2.10.02.0A)

<u>*FEPs that examine similar effects and consequences:*</u>

Igneous intrusion interacts with EBS components (1.2.04.04.0A)

Related Documents: *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* ANL-MGR-GS-000001 (BSC 2003 [DIRS 163769])

Characterize Eruptive Processes at Yucca Mountain, Nevada ANL-MGR-GS-000002 (BSC 2003 [DIRS 161838])

Dike/Drift Interactions
MDL-MGR-GS-000005 (BSC 2003 [DIRS 165923])

Supplemental Discussion: None

6.2.2.3 Igneous Intrusion Interacts with EBS Components (1.2.04.04.0A)

FEP Description: An igneous intrusion in the form of a dike occurs through the repository, intersecting the repository drifts. Magma, pyroclastics, and volcanic gases enter the drift and interact with the EBS components including the drip shields, the waste packages, pallet, and invert. This leads to accelerated drip shield and waste package failure (e.g., attack by magmatic volatiles, damage by flowing or fragmented magma, thermal effects) and dissolution or volatilization of waste.

Descriptor Phrases: Igneous intrusion (drip shield damage), Igneous intrusion (waste package damage), Igneous intrusion (cladding damage), Chemical effects of igneous intrusion in EBS (solubility), Thermal effects of igneous intrusion in EBS

[Note: This is a shared FEP. The scope and intent of this analysis report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Included* (BSC 2003 Table 5 [DIRS 161838]; BSC 2003 Table 4 [DIRS 165923]; BSC 2003, Table 3 [DIRS 161851]; BSC 2003, Table 6-1 [DIRS 165002])

Screening Argument: Not Applicable

TSPA Disposition: The primary focus of this FEP is interactions between the intrusion, the waste, and the waste packages. These interaction are *Included* in the TSPA-LA because magma could interact with the elements of the EBS, and the waste packages could be impaired due to perturbations of the drift environment, thereby resulting in damage to the waste packages and mobilization of waste.

Based on the results of C*haracterize Framework for Igneous Activity at Yucca Mountain*, *Nevada* (BSC 2003, Section 6.5.3.2 and Table 22 [DIRS 163769]) the computed mean annual frequency of intersection of the repository footprint by a dike is 1.7×10^{-8} for the LA footprint (see Assumption 5.1 of this analysis report, ANL-WIS-MD-000005 REV. 01). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003 [DIRS 161727, DIRS 162289]). The mean probability is used in the TSPA-LA to weight conditional dose calculations. Igneous intrusion into the repository (i.e., igneous activity) as provided in the FEP description, and as described for FEP 1.2.04.03.0A (Igneous intrusion into repository), has the potential to effect both the hydrologic and geochemical characteristics of the site, and due to extreme changes the in-drift environment, could damage EBS components and the waste packages. Combined, this could result in the release of radionuclides and affect the radiological exposure of the RMEI.

Because the probability of igneous intrusion is slightly greater than the FEP screening probability threshold, and because waste package damage cannot be constrained due to the thermal, mechanical, and geochemical environment associated with an intrusion into an emplacement drift, igneous intrusion into the repository is included within the TSPA-LA. The environmental conditions and their effect on waste packages are discussed in this FEP 1.2.04.04.0A (Igneous intrusion interacts with EBS components).

The TSPA-LA approach for addressing igneous intrusion is outlined in the document *Total System Performance Assessment-License Application Method and Approach* (BSC 2002, Section 8.1.2 [DIRS 160146]). The two igneous events (with individual probabilities and consequences) being modeled by the TSPA-LA are: 1) an igneous intrusion groundwater transport modeling case featuring the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to repository level where it intersects drifts; and 2) a volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. As a consequence of the first event, which is non-eruptive, waste from breached packages may provide a source of radionuclides when groundwater moves through the damaged packages at some time in the future (igneous intrusion groundwater transport modeling case). The potential consequence of the second event (volcanic eruption modeling case) is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the RMEI. Based on the current design, the location of the RMEI is assumed approximately 18 km south of the repository (10 CFR 63.312 and 10 CFR 63.302, 66 FR 55732 [DIRS 156671]).

This FEP is partially addressed, and the consequences constrained, by consideration of potential interaction of the drift and other EBS Components with magma flowing into an intersected drift. Properties and characteristics of basaltic magmas and basaltic eruptions are described in the analysis report *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* (BSC 2001, Section 6 [DIRS 161838]), and are based on the observed characteristics of past basaltic eruptions in the YMR and other analogous eruptions. These properties and characteristics are used as inputs and their significance discussed in the model report *Dike/Drift Interactions* (BSC 2003 [DIRS 165923]). The Magma and Gas Flow Model discussed in *Dike/Drift Interactions* (BSC 2003 [DIRS 165923]) addresses conditions that could occur when unpressurized magma encounters a representative emplacement drift. The model uses standard design equations from hydraulic engineering to describe the flow of effusive (i.e., not pyroclastic) magma into a drift after magma has risen to repository level. In addition, one derived equation is used to account for viscous drag in the dike as magma flows into a drift. The model does not address pyroclastic flow of magma that is accelerating rapidly due to vapor expansion. The parameters used and/or developed in the model report related to this FEP include the following:

- Geographic/geologic: Regional topography, stratigraphy, in situ stresses, repository depth
- Host rock properties: Young's modulus, Poisson's ratio, density, specific heat, thermal diffusivity, temperature, pH, pore-water composition
- Magma properties: Density, latent heat, far-field velocity, intrusion temperature, solid fraction vs. temperature, specific heat, thermal diffusivity, pressure
- Dike properties: Far-field width
- Drift Properties: Repository layout, heat release, diameter, depth, spacing, turnout dimensions Backfill properties: Friction angle, dilation, cohesion.

The Magma and Gas Flow output as discussed in Section 8.1 of BSC 2003 [DIRS 165923] defines:

- The environmental conditions (temperature, pressure, velocity of material, etc.) as a function of the distance from the point of dike intersection.
- Distribution of magmatic products as a function of distance from the point of dike intersection.

The model report *Dike/Drift Interactions* (BSC 2003, Section 8.1 [DIRS 165923]) provides conclusions related to various factors influencing post-intrusion environmental conditions within the drifts. The outputs of the model indicated that the entire length of an intersected drift has the potential to be filled, at least partially, with magmatic materials. The temperature history outputs from the Magma and Gas Flow model suggest that any waste package in contact with either magma or pyroclastic materials will be exposed to conditions at or near thermal limitations of the waste package materials.

The resulting damage mechanisms and extent of damage are further examined in the model report *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [DIRS 165002]) and lead to an assumption of no further protection being afforded by the waste packages in intersected drifts. The potential for damage to waste packages and waste forms from heat and migrating gas is examined in the cited model report (BSC 2003, [DIRS 165002]). That modeling effort leads to a conclusion that the properties of the host rock and the presence of backfill at the ends of the drifts preclude damage in non-intersected drifts from heat and gas migration from intersected drifts. The fractured and porous rock, as well as the crushed tuff used to backfill the perimeter drifts, represents a possible path for gas flow resulting from magma. However, gas movement through the backfill is slower than the rock matrix and does not move as far as the flow in the rock matrix (BSC 2003, Section 6.5.2.2.3 [DIRS 165002]). For a given gas flux rate, the pore velocity of gas moving through a less porous material is faster because the flow of gas occurs through a smaller area. This difference can be attributed to the difference in porosity between the two materials (host rock porosity = 0.154, backfill porosity = 0.545). In both cases, the velocity approaches zero around one year. As the pressure equilibrates to less than 10 atmospheres, the gas flow rate decreases. The gas front eventually stops at around 3.6 meters in the host rock and 1.4 meters in the backfill (BSC 2003, Section 6.5.2.2.3 [DIRS 165002]).

While advective gas flow is one component of movement between the drifts during the first year, diffusion is still occurring and becomes the single mode of gas movement at some point during gaseous equilibration. Results from the analyses of gaseous diffusion from the magma filled emplacement drift show that the gas concentrations entering the adjacent Zone 2 emplacement drifts, would be low and begin to significantly reduce after about two years (BSC 2003, Section 6.5.2.2.3 [DIRS 165002]). These results indicate that the waste packages in Zone 2 emplacement drifts would not be impacted by the volatile gases exsolving from the basalt magma and intruded into Zone 1 emplacement drifts.

The resulting environmental conditions and resultant damage states for the intruded drifts are passed to the TSPA-LA model, and in combination with the results of the analysis report *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2003 [DIRS 161851]), are used to determine the source term for calculating igneous-related dose.

The analysis provided in *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2003 [DIRS 161851]) uses repository design information and outputs from the revisions of the analysis reports *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [DIRS 163769]), and *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161838]) to calculate the number of waste packages exposed to Zone 1 (intersected drifts) magmatic environments. The analysis uses spreadsheet calculation operations to evaluate geometric relationships between dike intersection area and conduit geometry and the number of waste packages impacted by dikes and conduits. The types of information used include:

- Repository design information (repository area, drift diameter, drift spacing, waste package length, and waste package spacing)
- Igneous event probability
- Probability distributions and parameters associated with dikes within the repository (dike length, dike azimuth angle, dike width, and number of dikes in a swarm). In particular it uses:
  - Dike-width—used to determine maximum dike width
  - Number of dikes associated with formation of a new volcano—used to determine the maximum number of dikes in a swarm, and the distribution type for the number of dikes in a swarm
  - Dike spacing—used to determine dike spacing within a swarm.

The parameters developed in BSC 2003 [DIRS 161851] related to this FEP include:

- Probabilities for dike-swarm configurations
- Dike swarm interaction with repository drifts.

The number of waste package analysis results (BSC 2003 [DIRS 161851] include CDFs for the number of waste packages hit in an igneous intrusion scenario and in an eruptive release scenario. These CDFs are used directly and explicitly in the TSPA-LA model to determine the source term for the igneous event scenarios. Because the CDFs are dependent on the underlying inputs, the underlying inputs and related FEPs are considered implicitly included in the TSPA-LA model.

The interaction of the magma with the waste form is further examined in the model report *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [DIRS 165002]). That model report takes feeds from the analysis report *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161838]) in the form of:

- Magma chemistry—used to determine the mean chemical composition of basalt
- Gas composition—used to determine total moles of exsolving gases
- Water content of magma—used for bound the water content of basaltic magma
- Magmatic temperatures, viscosities, and densities—used to define basaltic characteristics and to define initial intrusive magma conditions.

The information developed in BSC 2003 [DIRS 165002] supports the use of the TSPA assumption that waste packages in Zone 1 emplacement drifts no longer provide protection for the waste forms. The fuel, glass, and other waste would be entrained into the magma. With regard to the igneous intrusion groundwater transport modeling case, no credit is taken for partial protection that residual elements of the waste package shells and the encapsulating basalt will provide. This is because quantification of these positive effects would be highly uncertain. In the intruded drifts, cooling joints would likely form in the basaltic magma during cooling, and some subsequent exposure to groundwater will occur. Dissolution of waste in basaltic melt is not considered explicitly, but is conservatively bounded by the presumption that waste is exposed directly to groundwater without any protection from the surrounding basalt. The subsequent movement of radionuclides in groundwater is then modeled directly in the TSPA-LA using the existing flow-and-transport models used for the nominal scenario. Accordingly, the transport would be dependent on the solubility limits of the exposed waste and the availability of groundwater as modeled for the nominal case. The TSPA-LA approach for addressing igneous intrusion is outlined in the document *Total System Performance Assessment-License Application Method and Approach* (BSC 2002, Section 8.1.2 [DIRS 160146]).

With regard to the volcanic eruption modeling case, the model report *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161840] provides the technical basis for assuming erupted materials are finely divided particles amenable for airborne transport (BSC 2003, Section 6.5.2.17 [DIRS 161840]). The technical basis for the fragmented fuel particle size is contained in the *Miscellaneous Waste Form FEPs* (CRWMS M&O 2001, Attachment I [DIRS 153938]).

The results of the igneous impact model report (BSC 2003 [DIRS 165002]) and the number of waste packages analysis report (BSC 2003 [DIRS 161851]) are used directly in the TSPA-LA. Consequently, this FEP is considered as implicitly included for damage state and changes in waste form by assuming that the waste packages in intersected drifts provide no further protection for waste, and that the waste is assimilated in magma. It is explicitly included using a probabilistic treatment regarding the number of waste packages damaged.

Related FEPs:

FEPs that examine related but distinct effects and consequences:

Ashfall (1.2.04.07.0A)
Seismicity associated with igneous activity (1.2.03.03.0A)
Mechanical impact on waste package (2.1.03.07.0A)
Mechanical impact on drip shield (2.1.03.07.0B)
Flow through seals (access ramps and ventilation shafts) (2.1.05.01.0A)
Degradation of seals (2.1.05.03.0A)
Mechanical degradation of pallet (2.1.06.05.0A
Mechanical degradation of invert (2.1.06.05.0B)
Effects of drip shield on flow (2.1.06.06.0A)
Thermal sensitization of waste packages (2.1.11.06.0A)
Thermal sensitization of drip shields (2.1.11.06.0B)
Thermal expansion/stress of in-package EBS components (2.1.11.05.0A)
Thermal expansion/stress of in-drift EBS components (2.1.11.07.0A)
Thermally-induced stress changes in the near field (2.2.01.02.0A)

FEPs that examine similar consequences and events

Igneous intrusion into the repository (1.2.04.03.0A)
Magma or pyroclastic base surge transports waste (1.2.04.05.0A)
Eruptive conduit to surface intersects repository (1.2.04.06.0A)

Related Documents: *Characterize Eruptive Processes at Yucca Mountain, Nevada* ANL-MGR-GS-000002 (BSC 2003 [DIRS 161838])

*Dike/Drift Interaction*s
MDL-MGR-GS-000005 (BSC 2003 [DIRS 165923])

Number of Waste Packages Hit by Igneous Intrusion
ANL-MGR-GS-000003 (BSC 2003 [DIRS 161851])

Igneous Intrusion Impacts on Waste Package and Waste Form
MDL-EBS-GS-000002 (BSC 2003 [DIRS 165002])

Supplemental Discussion: None

6.2.2.4 Magma or Pyroclastic Base Surge Transports Waste (1.2.04.05.0A)

FEP Description: As a result of the igneous intrusion, extrusive processes result in a pyroclastic density flow, base surge, dike apron, effusive lava flows *and/or* development of a volcanic vent at land surface.

	Some of the waste (entrained, dissolved, or volatized) is then transported away from the repository. Of most concern is transport directly along the land surface to the RMEI.
Descriptor Phrases:	Entrainment of waste in magma, Dissolution of waste in magma, Volatilization of waste in magma, Transport of waste to surface in liquid magma
Screening Decision:	*Excluded*—Low Consequence
Screening Argument:	This FEP is focused on near-surface eruption-related phenomena and on magmatic-related transport of entrained wastes. Hydro-volcanic phenomena also are addressed under this FEP and due to the distance to the RMEI, and as supported by the low probability of a maar crater extending to the repository depth and exhuming waste, hydrovolcanic phenomena have been excluded based on low consequence. Incorporation and transport directly to the receptor biosphere via an ashplume and/or subsequent reworking of the deposited ash following an eruptive event is addressed separately in FEP 1.02.04.07.0A (Ashfall), and its companion FEP 1.02.04.07.0C (Ash redistribution via soil and sediment transport).

Table 22 of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [DIRS 163769]) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3 x 10^{-8} (see Assumption 5.1 of this analysis report, ANL-WIS-MD-000005 REV. 01). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003 [DIRS 161727, DIRS 162289]). However, the geographical extent of magmatic and pycroclastic base surge events is insufficient to reach the location of the RMEI, so the FEP is *Excluded.*

The definitions of "accessible environment", "controlled area" and "reference biosphere" as described in Section 4.1.3.1 of this report (ANL-WIS-MD-000005 REV 01) indicate the distances of concern for the RMEI. These definitions and concepts indicate that the RMEI is located no closer than 18 km to the south in the direction of groundwater flow and over a contaminated groundwater plume, and that the limit of the controlled area is no greater than 5 km from the repository in any other direction (10 CFR 63.312 and 10 CFR 63.302, 66 FR 55732 [DIRS 156671]).

By contrast, all of the Quaternary volcanoes in the vicinity of Yucca Mountain are similar in that they are of small volume (~0.1 km^3 or less) and typically consist of a single main scoria cone surrounded by a small field of *aa* basaltic flows, which commonly extend approximately 1 km from the scoria cone (*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada,* BSC 2003, Section 6.2 [DIRS 163769]). Consequently, it is not credible to presume that extruded basalts with entrained wastes will extend to the RMEI located 18 km south of the repository.

Pyroclastic deposits consist of a wide range of materials, transport mechanisms and depositional environments. The total eruption volume of the post-Miocene basalts is about 6 km^3. The volume of individual episodes has decreased progressively through time, with the three Pliocene episodes having volumes of approximately 1 to 3 km^3 each and the three Quaternary episodes having a total volume of approximately 0.5 km^3. The pyroclastic deposits and associted volume of material indicate that pyroclastic eruptive mechanisms associated with strombolian eruption may result in transport of pyroclastic tephra (e.g., lapilli and ash) particles at distances sufficient to reach the RMEI. This aspect of an eruptive scenario has been included and is addressed separately in FEP 1.02.04.07.0A (Ashfall), and its companion FEP 1.02.04.07.0C (Ash redistribution via soil and sediment transport). Differential settling due to ash density is addressed in the eruptive scenario.

Of particular interest for this FEP, are hydrovolcanic deposits and pyroclastic surge deposits. Hydrovolcanic deposits consist of mostly ash deposited in density currents (surges), leaving distinctive thin planar beds and cross-beds. Pyroclastic surge deposits at Lathrop Wells cone have been observed and inferred to represent hydrovolcanic eruption during the early states of the evolution of the basalt center. A detailed description of deposits at a stratigraphic section (hydrovolcanic) located at N36° 41′ 42.7″, W116° 30′ 53.5″, at an elevation of 863.8 meters (2834 ft), located 0.7 km NW of the summit of Lathrop Wells cone, is provided in *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003, Section 6.4.2.3 [DIRS 161838]) along with the description of other surrounding hydrovolcanic deposits. As noted in BSC 2003 ([DIRS 161838]), these ash beds have been interpreted as hydrovolcanic in origin (pyroclastic surge deposits of Vaniman and Crowe (1981, pp. 20–21 [DIRS 101620]); and Wohletz (1986, p. 258 [DIRS 140956])). Within the area flanked by the cinder cone and the protruding ridge of Miocene tuff, there is a transition southward, over a distance of approximately 400 meters, from thousands of thin beds of hydrovolcanic facies to hundreds, and eventually to one or two resistant ash beds sandwiched between coarse lapilli beds. Observations in trenches immediately southwest of the cone also indicate a southward thinning hydrovolcanic sequence. BSC 2003 (Section 6.4.2.3 [DIRS 161838]) notes that the field relations suggest that the limited deposit resulted from a ground-hugging sector blast directed to the northwest. Because the unit slopes approximately 8 degrees back toward the cone and projects to beneath the cone base, the exact relations are covered, but there are currently no field data confirming a concentric tuff ring (Wohletz 1986, p. 262 [DIRS 140956]). At the Lathrop Wells scoria cone, about 6 meters below the south summit (elevation 954 m), there is a 40-cm thick, well-sorted, finely bedded, cross-bedded ash and coarse ash deposit. This deposit appears to be the result of a brief hydrovolcanic event late in the cone-building history (BSC 2003, Section 6.4.1.1 [DIRS 161838]). Crowe et al. (1986, pp. 32-34 [DIRS 101532] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) identified similar features, along with pyroclastic surge deposits for the southern and middle centers of the basalts of Nye Canyon. The Nye Canyon features were on the scale of 1 km or less.

Given the lateral scale of the observed hydrovolcanic deposits on the order of 1 km or less, it is not credible to presume that pyroclastic base surges with entrained wastes will reach the RMEI located 18 km south or to the control area boundaries at no greater than 5 km in other directions.

Another concern is the possibility that a large steam explosion could occur, such that a large phreatic or a phreatomagmatic crater (maar) might form. Such a process could directly excavate waste and disperse it over a large area of the surrounding surface. Hydrovolcanic activity requires that rising magma encounter water in an aquifer(s) or a shallow water body at the ground surface (Fisher and Schmincke 1984, pp. 231-264 [DIRS 162806]; Wohletz and Heiken 1992, pp. 85–154 [DIRS 105544]). The resulting steam explosion finely fragments the magma and produces large amounts of kinetic energy. If the encounter occurs below the ground surface, the host rocks are highly fractured and the eruption products are elevated in lithic clasts. For a large, disruptive steam explosion to occur, magma must come in rapid contact with a large volume of water at a shallow depth. Confining pressures must be sufficiently low to permit the formation of steam, and, as the steam violently expands, to allow disruption of the surrounding rock. Crowe et al. (1986, p. 47 [DIRS 101532]) suggest that a limited area of contact, such as a dike projecting through a thin (<10 m) aquifer, does not allow development of explosive instability, whereas contact with a standing body of water or thick (>30 m) horizon of water-saturated rock permits water to vaporize at explosive rates. They also suggest that magma/water mixing and explosion associated with maars, tuff rings, and tuff cones generally occur at depths less than 200 meters, which corresponds to 5 MPa or less, but also acknowledge that deeper aquifers contribute to hydroexplosions as well. They note, however, that deep interaction at confining pressures above the critical point of water probably involves a different set of explosive mechanisms.

Crowe et al. (1986, Figure 19 [DIRS 101532] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) present a plot of the relative-frequency of crater depth for known hydrovolcanic craters, maars, and tuff rings. The plot is positively skewed with a mean of 91 $\pm$ 67 m, and the maximum crater depth is plotted at approximately 365 meters. Crowe et al. (1986, pp. 58-59 [DIRS 101532]) conclude that "exhumation of a repository by explosive cratering associated with water/magma interaction is unlikely—the depth of burial of a repository at Yucca Mountain exceeds the crater depth of the largest known hydrovolcanic craters." However, this was based on an assumed repository depth of 380 meters. The mean crater depth for hydrovolcanic craters is 91 meters, which is insufficient to exhume to the repository depth, within an uncertainty of one standard deviation.

The minimum depth of the TSPA-LA repository (distance from the emplacement area to the overlying surface) is approximately 211 meters. The elevation along the eastern edge of the repository, with the exception of topographic relief in drainages and washes, is on the order of 1250 to 1280 meters (4,100 to 4,200 ft) . Drawing 800-IED-EBS0-00401-000-00C (BSC 2003 [DIRS 162289]), in comparison to Figure 1 of BSC 2002 [DIRS 159124], indicates that the easternmost drifts are in the area of lowest ground surface elevations and include drifts 2-1E through 2-19E. Drawing 800-IED-EBS0-000402-000-000-00B (BSC 2003 [DIRS 161727]) indicates that the endpoint elevations for these drifts varies from 1042 meters for Drift 2-1E to as high as 1063 meters for Drift 2-19E. This suggests a difference in elevation (or depth to the repository) of 208 meters to 238 meters. A more detailed analysis can be had by scaling the end-points of the drifts from the grid presented in Drawing 800-IED-EBS0-00401-000-00C (BSC 2003 [DIRS 162289] and subtracting the corresponding end-drift elevations from the nearest topographic grid point provided in DTN: MO0002SPATOP00.001 [DIRS 152643]. The northernmost and southernmost drifts were selected based on minimum and maximum drift elevations in the eastern part of the repository, and Figure 1 of BSC 2002 [DIRS 159124] and DTN: MO0002SPATOP00.001 [DIRS 152643] was inspected to determine where the deepest draw and lowest elevation of the topographic grid occurred within the repository footprint. The comparison of elevations is shown in Table 6-5.

Table 6-5. Calculation of Shallowest Depth of Waste Emplacement Drifts

Location	Approximate Northing	Approximate Easting	Elevation (m)	Depth of Repository (m)
East end of Drift 2-1E	775,000	565,500	1042 m	
Nearest Topographic Grid Point	775,000	565,600	1262 m (4141 ft)	
Difference in Elevation				220 m
East end of Drift 2-12 E	771,300	564,100	1055 m	
Nearest Topographic Grid Point	771,300	564,100	1267 m (4154 ft)	
Difference in Elevation				212 m
East end of Drift 2-19E	769,300	563,500	1063 m	
Nearest Topographic Grid Point	769,300	563,500	1283 m (4208 ft)	
Difference in Elevation				220 m

Note: Drift end coordinates on are in feet and are State Plane Coordinates. They are considered approximate because they were manually scaled from Figure 800-IED-EBSO-00401-000C (BSC 2003 [DIRS 162289]) to allow comparison with data from DTN: MO0002SPATOP00.001 [DIRS 152643], which is also in State Plane Coordinates. The end drift coordinates given in 800-IED-EBS0-000402-000-00B (BSC 2003 161727]) are given in meters rather than feet and are not readily comparable to the State Plane Coordinates.

The calculated minimum value could be in error by as much as 10 meters as it is based on only the three selected points. The minimum value of 211 meters is corroborated with a stated corroborating value of 215 meters of overburden above the waste emplacement area as indicated in 800-P0C-MGR0-00100-000-00E (BSC 2003, Section 7.1.8 [DIRS 165572]). For a greater than 215-meter crater depth, the relative frequency of occurrence is less than 15 percent (Crowe et al., Figure 19 [DIRS 101532] as referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]), and an assumption of less than 15 percent occurrence is appropriate for crater depths of greater than 148 meters (15 percent is the relative percent occurrence at the mean value of 91 meters, and 148 meters is the mean value plus one standard deviation of 57 meters). Furthermore, the hydrovolcanic event is conditional on a geologic setting conducive to a hydrovolcanic event. Consequently, the net probability of occurrence of a 215-meter hydrovolcanic crater associated with intrusion of the repository falls below the FEPs screening probability threshold. This assertion is based on an assumed probability of 15 percent for a hydrovolcanic eruption resulting in a crater depth of 215 meters or greater, an assumed independence of a hydrovolcanic explosion from a conditional dike intrusion into the repository, and calculated values of 1.3×10^{-8} for the mean probability of an eruptive center forming within the repository footprint.

Additionally, the distribution of existing hydrovolcanic deposits is limited to a radius on the order of 1 km or less, which is insufficient to reach the controlled area boundary, and the TSPA-LA includes a volcanic eruption modeling case that distributes ash to the location of the RMEI. Consequently, the transport by a hydrovolcanic cratering event as a separate modeling case can be *Excluded* based on low consequence.

TSPA Disposition: Not Applicable

Related FEPs

<u>*FEPs that examine related but distinct effects and consequences.*</u>

Igneous intrusion into repository (1.2.04.03.0A)
Eruptive conduit to surface intersects repository (1.2.04.06.0A)
Ashfall (1.2.04.07.0A)
Ash redistribution via soil and sediment transport (1.2.04.07.0C)
Hydrologic response to igneous activity (1.2.10.02.0A)

<u>*FEPs that examine similar effects and consequences*</u>

Igneous intrusion interacts with EBS components (1.2.04.04.0A)

Related Documents: *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* ANL-MGR-GS-000001 (BSC 2003 [DIRS 163769])

Characterize Eruptive Processes at Yucca Mountain, Nevada ANL-MGR-GS-000002 (BSC 2003 [DIRS 161838])

Supplemental Discussion: None

6.2.2.5 Eruptive Conduit to Surface Intersects Repository (1.2.04.06.0A)

FEP Description: As a result of an igneous intrusion, one or more volcanic vents forms at land surface. The conduit(s) supplying the vent(s) pass(es) through the repository, interacting with and entraining waste.

Descriptor Phrases: Conduit (vent) to surface intersects drift, Entrainment of waste in ash in conduit (vent), Transport of waste to surface in ash

Screening Decision: *Included* (BSC 2003 Table 5 [DIRS 161838]; BSC 2003 Table 3 [DIRS 161851]; BSC 2003, Table 6 [DIRS 161840])

Screening Argument: Not Applicable

TSPA Disposition: "Eruptive Conduit to Surface Intersects Repository" is *Included* in the TSPA-LA and is addressed through the modeling of an eruptive event. Consequences of an igneous intrusion through the repository and a resulting eruptive event are explicitly *Included* in the TSPA-LA, and appropriately weighted by the probability of occurrence of the event.

Igneous intrusion into the repository (i.e., igneous activity) as provided in the FEP description is described for FEP 1.2.04.03.0A (Igneous intrusion into repository). Table 22 of *Characterize*

Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003 [DIRS 163769]) provides a separate annualized frequency of one or more eruptive centers with the repository footprint of 1.3 x 10^{-8} (see Assumption 5.1 of this analysis report, ANL-WIS-MD-000005 REV. 01). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003 [DIRS 161727, DIRS 162289]). Additionally, the lateral extent of ashfall from such an event is sufficient to reach the location of the RMEI, so the FEP has been *Included.*

The TSPA-LA approach for addressing igneous intrusion is outlined in the document *Total System Performance Assessment-License Application Method and Approach* (BSC 2002, Section 8.1.2 [DIRS 160146]). The two igneous events (with individual probabilities and consequences) being modeled by the TSPA-LA are: 1) an igneous intrusion groundwater transport modeling case featuring the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to the repository level where it intersects drifts; and 2) a volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. As a consequence of the first event, which is non-eruptive, waste from breached packages may provide a source of radionuclides when groundwater moves through the damaged packages at some time in the future (igneous intrusion groundwater transport modeling case). The potential consequence of the second event (volcanic eruption modeling case) is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the RMEI. Based on the current design, the location of the RMEI is approximately 18 kilometers (km) south of the repository (10 CFR 63.312 and 10 CFR 63.302, 66 FR 55732 [DIRS 156671]).

Properties and characteristic of the basaltic eruption are described in *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* (BSC 2003, Section 6 [DIRS 161838]). The eruption characteristics used in the TSPA-LA model are based on the observed characteristics of past basaltic eruptions in the YMR and other analogous eruptions. For the volcanic eruption modeling case, a dike rises to the repository level, intersects one or more drifts in the repository, and proceeds toward the surface. Conduits develop from the surface downward within the repository footprint. Conduits within the repository footprint are presumed in the TSPA-LA to be located randomly along intersecting dikes. It is presumed for the volcanic-eruption-scenario analysis in the TSPA-LA that waste in waste packages, as well as other components of the EBS that will be breached by igneous activity, are available to be entrained in dike material. Where conduits intersect drifts, waste packages in intersected drifts are presumed to no longer provide protection for the waste. Waste material in these waste packages is entrained in a pyroclastic eruption. The model report *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* provides the technical basis for assuming erupted materials are finely divided particles amenable for airborne transport (BSC 2003, Section 6.5.2.17 [DIRS 161840]). The technical basis for the fragmented fuel particle size is contained in the *Miscellaneous Waste Form FEPs* (CRWMS M&0 2001, Attachment I [DIRS 153938]).

The conduit supplies a mass of ash and waste to the eruption occurring at the land surface of the mountain. It is presumed for the referenced analysis that all intrusive events contain an eruptive phase and produce a conduit venting to land surface. The bases for these assumptions about eruptive process and their effects are addressed by other igneous-related model or scientific analysis reports listed in Table 6-3 of this analysis report (ANL-WIS-MD-000005 REV 01).

As previously described for FEP 1.2.04.03.0A (Igneous intrusion into repository), the model report *Dike/Drift Interactions* (BSC 2003 [DIRS 165923]) provides conclusions related to various conceptual models for magma flow in drifts, including consideration of the “dog-leg scenario”. The “dog-leg” scenario is discussed in Section 8.1.2 of the model report (BSC 2003 [DIRS 165923], as its disposition is addressed in Section 6.2.2.2 of this analysis report (ANL-WIS-MD-000005 REV 01) for FEP 1.2.04.03.0A (igneous intrusion intersects repository).

The analysis report *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161838]) provides a technical basis for inclusion of the FEP in the TSPA-LA. That analysis report includes the results of field investigations dealing with physical volcanology and describes the conceptual models for eruptive processes including conduit formation. This information is used to develop parameter value distributions appropriate for evaluation of the related FEPs and analysis of the consequences of volcanic eruptions through a proposed repository at Yucca Mountain, Nevada. In particular, that analysis report addresses the following aspects of the FEP:

- The geometry of volcanic feeder systems, which is of primary importance in predicting how much of a repository LA footprint would be affected by an eruption
- The physical and chemical properties of the magmas, which influence both eruptive styles and mechanisms for interaction with waste packages
- Eruptive processes, including the ascent velocity of magma at depth, the onset of bubble nucleation and growth in the rising magmas, magma fragmentation, and velocity of the resulting gas-particle mixture.

The parameters related to this FEP that are developed in the eruptive processes analysis report include the following output distributions (BSC 2003, Table 37 [DIRS 161838]):

- Conduit diameter
- Eruptive power
- Duration of a single explosive phase constituting a violent strombolian eruptive phase
- Eruption duration for formation of an entire volcano
- Eruption volume
- Velocity as a function of depth.

The results documented in *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161838]) do not directly feed the TSPA-LA model. Rather, the results provide inputs for the reports identified in the following paragraphs. Because the outputs of the identified reports are used either implicitly or explicitly in the TSPA-LA model, and the outputs of the listed reports are dependent on the underlying inputs documented in this analysis report, the underlying inputs and related FEPs are considered to be implicitly included in the TSPA-LA model.

The analysis report *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2003 [DIRS 161851]) provides parameters to the TSPA-LA that addresses this FEP. The types of information used include:

- Repository design information (repository area, drift diameter, drift spacing, waste package length, and waste package spacing)
- Igneous event probability
- Probabilities and parameters associated with conduits occurring within the repository (conditional probability that more than one conduit will occur within the repository footprint and conduit diameter distributions).

The analysis (BSC 2003 [DIRS 161851]) uses the outputs from the revision of the analysis report *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [DIRS 163769]), including:

- Conditional joint probability distributions for length and azimuth of an intersecting dike system, within the repository LA footprint—used to determine the distribution of dike azimuth angles, as basis for selection of 30 degree representation
- Composite conditional probability distribution of the number of eruptive centers within the repository—used to determine the aggregate probability for number of conduits intersecting repository.

The analysis also uses the outputs from the revision of *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161838]):

- Conduit diameter—used to determine the conduit diameter distribution, modal conduit diameter, the maximum conduit diameter, and minimum conduit spacing.

For the volcanic eruption modeling case, the analysis (BSC 2003 [DIRS 161851]) provides a CDF for number of waste packages hit by an eruptive conduit. The CDF is based on a relationship between the resulting conduit areas and the fraction of the repository area occupied by waste packages. This relationship was used in conjunction with a joint distribution incorporating the variability in eruptive conduit diameters and in the number of eruptive conduits that could intersect the repository, to the calculated resulting CDF. The CDF is used directly by the TSPA-LA for the volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. Because the CDF is dependent on the underlying inputs, the underlying inputs and related FEPs are considered implicitly included in the TSPA-LA model.

The modeling of the eruptive event is outlined in the model report *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161840]). The TSPA-LA model, using ASHPLUME V 2.0, estimates radionuclide concentrations in contaminated ash falling at the location of the RMEI, approximately 18 km south of the repository. For the volcanic eruption modeling case, the TSPA-LA presumes that a hypothetical violent strombolian eruption occurs through a section of the repository, entraining radionuclide-bearing wastes in the ash plume that disperses downwind and deposits contaminated ash on the ground surface.

The output from the eruptive processes analysis report (BSC 2003, Table 37 [DIRS 161838]) is used in the model report *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003, Table 8 [DIRS 161840]) as input for developing the following parameters:

- Mean ash particle diameter
- Mean ash particle diameter standard deviation for particle size distribution
- Ash particle shape factor
- Ash particle density at minimum, and a maximum, particle size
- Log ash particle size for ash particle density at minimum, and at maximum, particle size
- Eruptive power, eruption duration, and initial rise velocity of plume.

Once entrained and erupted, atmospheric transport of ash and radionuclides is modeled directly in TSPA-LA using the software code ASHPLUME V 2.0 as identified and discussed in Section 8 of BSC 2003 ([DIRS 161840]). Section 6.5.1 and 6.5.2 of BSC 2003 ([DIRS 161840]) describes the mathematical model and parameter inputs respectively, used to calculate ash-and-waste dispersal in the wind. The TSPA-LA model stochastically samples the number of waste packages hit and the parameters used as input in each single ASHPLUME .dll realization. The ASHPLUME model is executed from within the TSPA-LA GoldSim model, and ASHPLUME results are produced therein. Consequently, the processes defined by the ASHPLUME mathematical model are considered as explicitly included in the TSPA-LA.

Related FEPs:

FEPs that examine related but distinct effects and consequences:

Igneous intrusion into repository (1.2.04.03.0A)
Magma or pyroclastic base surge transports waste (1.2.04.05.0A)

FEPs that examine similar effects and consequences:

Igneous intrusion interacts with EBS components (1.2.04.04.0A)
Ashfall (1.2.04.07.0A)

Related Documents:

Characterize Eruptive Processes at Yucca Mountain, Nevada ANL-MGR-GS-000002 (BSC 2003 [DIRS 161838])

Number of Waste Packages Hit by Igneous Intrusion ANL-MGR-GS-000003 (BSC 2003 [DIRS 161851])

Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada MDL-MGR-GS-000002 (BSC 2003 [DIRS 161840])

Supplemental Discussion: None

6.2.2.6 Ashfall (1.2.04.07.0A)

FEP Description: Finely-divided waste particles are carried up a volcanic vent and deposited at land surface from an ash cloud.

Descriptor Phrases: Volume and mass of erupted waste and ash, Entrainment of waste in ash plume in atmosphere, Atmospheric transport of waste in ash plume, Deposition of waste and ash

Screening Decision: *Included* (BSC 2003 Table 5 [DIRS 161838]; BSC 2003, Table 6 [DIRS 161840])

TSPA Disposition: The TSPA-LA approach for addressing igneous intrusion is outlined in the document *Total System Performance Assessment-License Application Method and Approach* (BSC 2002, Section 8.1.2 [DIRS 160146]) and includes consideration of exposure from an ashfall event.

Table 22 of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [DIRS 163769]) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3 x 10^{-8} (see Assumption 5.1 of this analysis report, ANL-WIS-000005 REV. 01). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003 [DIRS 161727, DIRS 162289]). Additionally, the lateral extent of ashfall is sufficient to reach the location of the RMEI, so the FEP has been included.

The two igneous events (with individual probabilities and consequences) being modeled by the TSPA-LA are: 1) an igneous intrusion groundwater transport modeling case featuring the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to the repository level where it intersects drifts; and 2) a volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. The potential consequence of the second event (volcanic eruption modeling case) is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the RMEI. Based on the current design, the location of the RMEI is approximately 18 kilometers (km) south of the repository (10 CFR 63.312 and 10 CFR 63.302, 66 FR 55732 [DIRS 156671]). The conceptual model for the eruptive process is discussed under FEP 1.2.04.06.0A (Eruptive conduit to surface intersects repository). The following discussion is focused on the eruption of entrained waste as ash into the atmosphere and subsequent transport and deposition.

The analysis report *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* (BSC 2003, Section 6 [DIRS 161838]) provides the technical basis for inclusion of the FEP in the TSPA-LA. Properties of basaltic eruptions described in the analysis report are based on the observed characteristics of past basaltic eruptions in the YMR and other analogous eruptions. This analysis report includes the results of field investigations dealing with physical volcanology and with ash and tephra redistribution, and includes the conceptual models for eruptive processes and for ash and tephra redistribution. This information is used to develop parameter value distributions appropriate for analysis of the consequences of volcanic eruptions through a proposed repository at Yucca Mountain, Nevada. In particular, this report addresses the following aspects of the related FEP:

- The duration of eruptions, their power output, and mass discharge rates
- The bulk grain size produced by relevant explosive eruptions and grain shapes.

The parameters developed in the eruptive processes analysis report (BSC 2003, Table 37 [DIRS 161838]) related to this FEP include the following:

- Eruptive power
- Eruption duration for formation of an entire volcano
- Duration of a single explosive phase constituting a violent strombolian eruptive phase
- Eruption volume
- Mean particle size erupted during violent strombolian phases
- Standard deviation of particle size distribution for a given mean
- Clast characteristics
- Density of erupted particles
- Tephra deposit density.

The results of the analysis report do not directly feed to the TSPA-LA model. Rather, the results provide input for the ASHPLUME model run within the TSPA-LA. Because the outputs of the listed report are used either implicitly or explicitly in the TSPA-LA model, and the outputs of the ASHPLUME model are dependent on the underlying inputs documented in the model report, the underlying inputs and related FEPs are considered to be implicitly included in the TSPA-LA model.

The output from the eruptive processes analysis report (BSC 2003, Table 37 [DIRS 161838]) is used in the model report *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003, Table 8 [DIRS 161840]) as input for developing the following parameters:

- Mean ash particle diameter
- Mean ash particle diameter standard deviation for particle size distribution
- Ash particle shape factor
- Ash particle density at minimum, and a maximum, particle size
- Log ash particle size for ash particle density at minimum, and at maximum, particle size
- Eruptive power and eruption duration.

Additionally, the following process parameters are developed within the ASHPLUME model report:

- Column diffusion constant, which affects the distribution of particles within the ash column

- Waste incorporation ratio, a mathematical construct used to transport a density-corrected "combined" ash and fuel particle

- Waste particle size (min, max, mode)

- Windspeed and wind direction, based on site-specific data collected over the appropriate range of ash column height

- Initial rise velocity of plume

- Eddy diffusivity constant, with the simplification made that particle diffusion time equals particle fall time).

Once entrained and erupted, atmospheric transport of ash and radionuclides is modeled directly in TSPA-LA using the software code ASHPLUME V 2.0 as identified and discussed in Section 8 of BSC 2003 ([DIRS 161840]). The TSPA-LA model, using ASHPLUME V 2.0, estimates radionuclide concentrations in contaminated ash falling at the location of the RMEI, approximately 18 km south of the repository. For the volcanic eruption modeling case, the TSPA-LA presumes that a hypothetical violent strombolian eruption occurs through a section of the repository, entraining radionuclide-bearing wastes in the ash plume that disperses downwind and deposits contaminated ash on the ground surface. Sections 6.5.1 and 6.5.2 of BSC 2003 ([DIRS 161840]) describes the mathematical model and parameter inputs, respectively, used to calculate ash-and-waste dispersal in the wind. The ASHPLUME model is executed from within the TSPA-LA GoldSim model, and ASHPLUME results are produced therein. The TSPA-LA model stochastically samples the number of waste packages hit and the parameters used as input in each single ASHPLUME realization. The ASHPLUME code specifically addresses the issues of waste incorporation into the volcanic ash, the extent of the ash plume into the atmosphere, the atmospheric transport of the ash and entrained waste, and the thickness of ash deposits in the vicinity of the RMEI. These aspects of the FEP are, therefore, considered explicitly included in the TSPA-LA model.

Related FEPs

FEPs that examine related but distinct effects and consequences:

Igneous intrusion into repository (1.2.04.03.0A)
Igneous intrusion interacts with EBS components (1.2.04.04.0A)
Magma or pyroclastic base surge transports waste (1.2.04.05.0A)
Ash redistribution via soil and sediment transport (1.2.04.07.0C)

FEPs that examine similar effects and consequences:

Eruptive conduit to surface intersects repository (1.2.04.06.0A)

Related Documents: *Characterize Eruptive Processes at Yucca Mountain, Nevada* ANL-MGR-GS-000002 (BSC 2003 [DIRS 161838])

	Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada MDL-MGR-GS-000002 (BSC 2003 [DIRS 161840])
Supplemental Discussion:	None

6.2.2.7 Ash Redistribution via Soil and Sediment Transport (1.2.04.07.0C)

FEP Description:	Following deposition of contaminated ash on the surface, ash deposits may be redistributed on the surface via aeolian and fluvial processes.
Descriptor Phrases:	Redistribution of contaminated ash (surficial)
Screening Decision:	*Included* (BSC 2003 Table 5 [DIRS 161838])
Screening Argument:	Not Applicable
TSPA Disposition:	Ashfall events and processes are directly addressed in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003 [DIRS 161840]). The TSPA-LA includes consideration of exposure from redistributed ash.

Table 22 of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [DIRS 163769]) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3 x 10^{-8} (see Assumption 5.1 of this analysis report, ANL-WIS-MD-000005 REV. 01). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003 [DIRS 161727, DIRS 162289]). Additionally, the lateral extent of ashfall from such an event, and subsequent ash redistribution, is sufficient to reach the location of the RMEI, so the FEP has been included.

For the volcanic eruption modeling case, the TSPA-LA presumes that a hypothetical violent strombolian eruption occurs through a section of the repository, entraining radionuclide-bearing wastes in the ash plume that disperses downwind and deposits contaminated ash on the ground surface. The TSPA-LA model, using ASHPLUME V 2.0, estimates radionuclide concentrations in contaminated ash falling at the location of the RMEI, approximately 18 km south of the repository (10 CFR 63.312 and 10 CFR 63.302, 66 FR 55732 [DIRS 156671]). The TSPA-LA approach for calculating exposure through the use of volcanic-specific biosphere dose conversion factors is further outlined in the document *Total System Performance Assessment-License Application Method and Approach* (BSC 2002, Section 8.1.2 [DIRS 160146]).

This hypothetical direct deposition of ash and waste in the vicinity of the RMEI presumably represents the greatest degree of exposure from an eruptive process. All other mechanisms (e.g., eolian or fluvial processes) allow for mixing and dilution of the ash and waste through distance and with time. Presumably, a volume of transported sediment with a highly diluted ash component would have less impact on the RMEI than would primary ashfall that fell directly on, or nearby, the RMEI. Accordingly, the "worst-case" conceptual model would be one in which winds blow the initial eruption column south from the repository toward the RMEI. This is the only conceptual model in which ash would directly fall on the RMEI without additional dilution. Regardless, the effects of ash redistribution via soil and sediment transport will be explicitly included in the TSPA-LA Model in conjunction with an ashfall event. A model abstraction will be run, developed, and executed as part of the TSPA-LA model.

To assess the degree to which redistribution and mixing processes (primarily fluvial processes) might affect the percent of ash/waste in reworked and transported sediment and its contribution to exposure, a study was performed using the ash deposits and tephra sheet of the Lathrop Wells cone and cesium-137 studies in the Fortymile Wash alluvial fan. The results of these studies are documented in *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* (BSC 2003, Section 6.5 [DIRS 161838]) and *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain,* Nevada (BSC 2003 [DIRS 161840]). Both reports include the results of field investigations and present the conceptual and technical basis for the ash redistribution model implemented within TSPA-LA. The technical basis for the TSPA ash redistribution model is supported by geomorphic data and analyses, including:

- The rate of erosion/deposition of sediments on the Fortymile Wash alluvial fan
- Ash dilution rate
- Site erosion/aggradation rate.

Conceptually, the region surrounding the RMEI is an alluvial fan and can be divided into two major geomorphic units: interchannel divides and the channels themselves. Within the channels, sediment transport processes will move contaminated ash through the region in response to storm events, effectively creating a permanent layer of contamination following an eruption. Eventually, the watershed will be depleted of contaminated ash, but the duration for this process is unknown and, therefore, the effect is assumed to remain constant. Mixing processes will dilute the ash with uncontaminated sediment, but existing data are insufficient to quantify that dilution. The conceptual basis, therefore, is to assume that the sediment in the channels has the initial concentration of radionuclides in the ashfall at the RMEI location. The concentration at the RMEI location represents a concentration undiluted by additional transport mechanisms.

Because of the topographic setting and hydraulic characteristics, alluvial fans are typified by coarse gravel in proximal reaches and a rapidly decreasing grain size downfan. Within this larger setting, local concentrations of placer minerals will occur, and may include denser and/or larger waste fragments. However, waste particles subject to differential settling, although more likely to result in localized concentrations, are less likely to be transported distances on the order of kilometers necessary to impact the RMEI. Consequently, not accounting for this differential settling is reasonable because the RMEI dose will come from exposures averaged over an area that is larger than individual placer deposits, and using a regional average concentration is therefore appropriate.

The cesium data (BSC 2003, Section 6.5.2.5 [161838]) suggest that there has been significant net erosion in the last 50 years (1-3 cm). Conceptually, it is assumed that any future ashfall deposits in the interchannel divide areas will be removed at least at that rate over the long term (although it is recognized that in the short term, the rate may be greater on the slopes of Yucaa Mountain, for unconsolidated material, and during major flood events). That rate (1–3 cm per 50 years) results in a zero layer thickness relatively quickly in the interchannel divide areas. However, in the interchannel divide areas, cesium data indicates that some cesium has leached into the lower soil horizons (down to 9 cm). The conceptual basis, therefore, is to assume a lower bound concentration fixed at 1/100th of the initial concentration. This assumption is consistent with the cesium data for the lower soil horizons in that it restricts the radionuclide concentration in the interdivide areas from reaching zero, even though the ash is gone. This also accounts for radionuclides that may be brought up onto the divides during the rare major flood events that inundate the entire fan.

Related FEPs

FEPs that examine related but distinct effects and consequences:

Magma or pyroclastic base surge transports waste (1.2.04.05.0A)
Eruptive conduit to surface intersects repository (1.2.04.06.0A)
Ashfall (1.2.04.07.0A)
Ash redistribution via groundwater (1.2.04.07.0B)
Hydrologic response to igneous activity (1.2.10.02.0A)

FEPs that examine similar effects and consequences:

Erosion/denudation (1.2.07.01.0A)
Deposition (1.2.07.02.0A)
Topography and morphology (2.3.01.00.0A)
Soil and sediment transport in the biosphere (2.3.02.03.0A)

Related Documents: *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* ANL-MGR-GS-000002 (BSC 2003 [DIRS 161838])

Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada MDL-MGR-GS-000002 (BSC 2003 [DIRS 161840])

6.2.2.8 Hydrologic Response to Igneous Activity (1.2.10.02.0A)

FEP Description: Igneous activity includes magmatic intrusions, which may alter groundwater flow pathways, and thermal effects, which may heat up groundwater and rock. Igneous activity may change the groundwater flow directions, water level, water chemistry, and temperature. Eruptive and extrusive phases may change the topography, surface drainage patterns, and surface soil conditions. This may affect infiltration rates and locations.

Descriptor Phrases: Water table elevation, Saturated flow and pathways in the SZ, Unsaturated flow and pathways in the UZ

[Note: This is a shared FEP. The scope and intent of this analysis report is to quantify the amplitude of the event to be considered. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs. Descriptor phrases not addressed or only partially addressed in this report are further addressed in the sharing FEP AMRs.]

Screening Decision: *Excluded*—Low Consequence

Screening Argument: Igneous intrusion into the repository (i.e., igneous activity) could potentially alter the hydrologic characteristics of the site and, thereby, affect flow-and-transport characteristics and release to the accessible environment and exposure. However, the orientation of the dikes and the limited scale of a few meters indicate that the hydrologic response would be of low consequence.

An appropriate analog for understanding the characteristics of a volcanic event at Yucca Mountain is the Paiute Ridge intrusive/extrusive center (Byers and Barnes 1967 [DIRS 101859]) on the northeastern margin of the Nevada Test Site. Paiute Ridge is a small-volume Miocene volcanic center comparable in volume and composition to Quaternary volcanoes near Yucca Mountain (CRWMS M&O 1998, p. 5-29 [DIRS 105347]). Paleomagnetic, geochronologic, and geochemical data indicate that the entire intrusive/extrusive complex formed during a brief magmatic pulse and, thus, represents a single volcanic event (Ratcliff et al. 1994 [DIRS 106634]; and CRWMS M&O 1998, p. 5-29 [DIRS 105347]). The vents and associated dike system formed within a north-northwest-trending extensional graben. This analog site provides excellent exposures of a variety of depths of the system, including remnants of surface lava flows, volcanic conduits, and dikes and sills intruded into tuff country rock at depths of up to 300 meters (CRWMS M&O 1998, pp. 5-27 through 5-41 [DIRS 105347]). There is evidence of shallow structural control of dike emplacement at Paiute Ridge, including dike emplacement along fault planes (Byers and Barnes 1967 [DIRS 101859]; and CRWMS M&O 1998, pp. 5-27 and 5-28, [DIRS 105347]). Dike lengths at Paiute Ridge range from <1 km to 5 km (CRWMS M&O 1998, p. 5-31 [DIRS 105347]), comparable to the range estimated for post-Miocene volcanism near Yucca Mountain.

Carter-Krogh and Valentine (1996, pp. 7 and 8 [DIRS 160928] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) described the margins of the Paiute Ridge dike complex as follows:

> "PR dike contains ubiquitous near-vertical joints that result in a pervasive platy texture with plates parallel to the dike-host contact. Conversely, with the exception of local cooling joints in fused wall rock (extending 10 cm to 20 cm into the wall rock, perpendicular to the dike margin), joints are never visible in the host rock along the length of the dike. The contact between basalt and the tuff host rock is consistently smooth and shows no brecciation. Along strike at this contact, the tuff host rock is fused or welded to varying degrees: in places the tuff is completely welded and forms black vitrophyre that grades rapidly away from the contact, over a distance of ca 20 cm to 100 cm, into nonwelded tuff that is

> apparently unaffected by the dike. In other places the tuff is only partly welded at the contact and black fiamme are elongated parallel to the contact. We infer that this "contact welding" is the combined result of heat from the dike and compressive stress exerted by the flowing magma on the wall rocks. Welded host rock commonly contains vesicles that are elongated vertically and parallel to the margin. In some places, welded tuff coats the basalt and displays rills or elongate smooth ridges (flutes). Most rills plunge nearly vertically, however, a sub-horizontal rill is present in the central part of the dike. At the dike tip, exposed at Slanted Buttes, scoria patches crop out near the dike-host contact."
>
> "The two eastern dikes, M and E … show geometries and textures similar to those of PR; however, M dike is much shorter and does not feed a sill, and E dike was emplaced closest to the paleosurface and feeds two sills. M dike … visibly occupies a normal fault, oriented N40° W, 61° E, … Its host rocks are only Tertiary tuffs, which show no brecciation or jointing near the dike contact … Texture within the dike is characterized by a vertical platy fabric that parallels the dike margins. E dike is the eastern-most dike studied within the graben. … Near the neck, the dike visibly occupies a NNW-trending, steeply E-dipping normal fault that displaces bedded tuffs 3.5 m and does not cut the dike …The texture of E dike is characterized by the pervasive vertical platy fabric common to M and PR dikes. Adjacent host tuffs are not jointed nor brecciated, except for local vertical jointing of the Rainier Mesa tuff, which is intruded by the dike at its shallowest level. The contact of the dike and host tuff is preserved in places and varies from partly to completely welded in the same manner as described above for the PR dike. Where complete welding has occurred, vesicles are vertical and parallel the dike margin. Contact welding of the host tuffs formed oblate fiamme that parallel the dike-host contact. Visible thermal effects on the wall rocks disappear within one meter of the dike margin."

This suggests that zones of change in rock properties (i.e., formation of vitrophyres and/or various degrees of welding of the host rock) are limited to between a few tens of centimeters to at most a meter perpendicular to the dike. Other features such as the platy texture along the dike margins and vesicles in the welded tuff are oriented parallel to the dike margins. This suggests that the primary direction of increased or decreased permeability (if any) is parallel with the dike margins. The description also indicates the interaction of faults and dikes and alludes to the segmented, discontinuous, *en echelon* structures observed for the dike complex.

Most researchers conclude that once dikes feeding volcanoes enter the shallow upper crust, their location and orientation are influenced by the orientation of the local stress field and the presence of faults that may locally control vent location and alignment. The evidence cited for these two conclusions includes several northeast-oriented vent alignments in the YMR and the association of eruptive centers with known or inferred faults (Smith et al. 1990 p. 83 [DIRS 101019]; CRWMS M&O 1996 Appendix E, [DIRS 100116] p. AM-4; Connor et al. 1996, p. 78 [DIRS 135969]; Reamer 1999, Section 4.1.3.3.3 [DIRS 119693]).

The results of the PVHA are summarized in the analysis report C*haracterize Framework for Igneous Activity at Yucca Mountain*, *Nevada* (BSC 2003 [DIRS 163769]), and the analysis report presents probability distributions for the length and orientation of volcanic dikes within the repository footprint. The individual PVHA expert dike length distributions can be aggregated to derive a PHVA aggregate dike length distribution. The aggregate dike-length distribution derived from the PVHA has 5th-percentile, mean, and 95th-percentile values of 0.6, 4.0, and 10.1 km, respectively and the most commonly assigned dike orientation centers on N30E (BSC 2003, Section 6.3.2 [DIRS 163769]). The analysis, based on the results of the PVHA, also assigns the highest probabilities of dike orientation to azimuths of between 20 and 40 degrees (BSC 2003, Table 18 [DIRS 163769]).

The anisotropic transmissivity in the SZ observed in the Yucca Mountain region has a maximum principal transmissivity direction of approximately N15E (BSC 2003, Section 6.5.2.10 [DIRS 164870]), which is consistent with the fault and fracture orientation, and a corroborative analysis by Ferrill et al. (1999, p. 1 [DIRS 118941]), which indicates N30E. Based on the PVHA results, future dikes also most likely will trend in a north-to-northeast direction, although this may be altered by the presence of existing faults, or localized changes in the stress field with the orientation being perpendicular to the least compressive stress. A north-to-northeast trend parallels or sub-parallels the faults and fractures active in the present-day in situ stress field. Dike features, such as the platy texture and welded surfaces that could affect the permeability, will presumably parallel the dike orientation and be aligned in a north-to-northeast orientation.

This parallel to subparallel orientation of dikes and maximum principal transmissivity, coupled with the expected limited affected volume of material around the dikes, indicates that dikes, even if differing in permeability, will not significantly affect groundwater flow patterns at the mountain scale. By way of corroboration, an early analysis of the effect of a dike on flow in the SZ was conducted and documented in Chapter 10 of the TSPA for the Viability Assessment (CRWMS M&O 1998, Section 10.4.4 [DIRS 100369]). The corroborative analysis suggested that there would be negligible impact for a dike oriented north-to northeast. The analysis included a variety of dike lengths and locations respective to the repository area. Additionally, the occurrence of such a change is conditional on a low probability event of an igneous intrusion.

CRWMS M&O (1998, p. 5-56 [DIRS 105347]) mentions the possibility of perched water forming near low-permeability intrusive bodies, and there is concern regarding the potential for a dike to provide a barrier to flow and/or cause impoundments. Because of the parallel to subparallel orientation of dikes with the existing orientation of the anisotropic maximum horizontal permeability in the SZ, a dike would not form a barrier or impoundment that would have any significant effect on flow in the SZ. In the UZ, the primary direction of groundwater flow is vertically through the fractures, although some horizontal flow component exists in the matrix. Because the joints on a dike margin would be near vertical, it would seem that the formation of a significant perched water zone is problematic without the formation of a sill. The potential for formation of a sill is addressed in the FEP 1.2.04.03.0A (Igneous intrusion into repository). The formation of a perched water zone is addressed in the FEP 2.2.07.07.0A (Perched water develops) and has been included in the TSPA-LA. Even if a perched water zone were to form and then drain, there would be only a minimal impact, as explained in the FEP 2.2.06.03.0A (Seismic activity alters perched water zone).

With regard to geochemical changes and based on the study of natural-analogue sites, CRWMS M&O (1998, p. 5-1 and 5-2 [DIRS 105347] referenced in DTN: MO0310INPDEFEP.000

[DIRS 165880]) mentions that, for shallow, small-volume basaltic intrusions, the chemical and mineralogical studies of host tuffs indicate that alteration is limited to within a few tens of meters of the intrusion. More particularly, from a study of the Paiute Ridge analogue site, there is no indication for extensive hydrothermal circulation and alteration, brecciation and deformation related to magmatic intrusion, and vapor-phase recrystallization during the magmatic intrusions into the vitric and zeolitized tuffs (CRWMS M&O 1998, p. 5-42 [DIRS 105347] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). The analogue studies show that alteration is quite limited, typically only found within 5 to 10 m of intrusions (CRWMS M&O) 1998, p. 5-41 [DIRS 105347] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). At the Paiute Ridge site, low-temperature secondary minerals persist near the contact with intrusions (CRWMS M&O 1998, p. 5-46 [DIRS 105347]). This suggests that little destruction of sorptive minerals is expected. Given the limited area of alteration and the consequent change of rock properties around the intrusion, the effect of alteration is minimal, and alteration does not provide a mechanism to significantly change the dose. Therefore, this FEP is *Excluded* from the TSPA-LA based on low consequence.

CRWMS M&O (1998, p. 5-86 [DIRS 105347]) also considered the effects of hydrothermal systems (the heating up of groundwater and rock) resulting from igneous intrusions. Findings from the Paiute Ridge analogue site indicate that "the occurrence of clinoptilolite and opal also suggests that thermal transfer into the adjacent country rock was minimal" (CRWMS M&O 1998, p. 5-57 [DIRS 105347] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). Findings from the Grants Ridge site suggest the absence of a hydrothermal system, except for localized recrystallization of volcanic glass within the contact zone (CRWMS M&O 1998, p. 5-74 [DIRS 105347]). Further, the study concluded that "…an intrusion at Yucca Mountain would not result in large amounts of hydrothermally driven mass transfer" (CRWMS M&O 1998, p. 5-74 [DIRS 105347]).

With regard to post-intrusion in-drift conditions, the TSPA-LA addresses conditions through an assumption (see BSC 2003, Section 5.1.3 [DIRS 165002] for justification) that the permeability of any contact metamorphic aureole surrounding the intruded drifts is as great as that of the bulk host rock. The basalt is assumed to fracture during cooling so that it too provides no barrier to flow. After post-intrusive magma cooling and reversion to normal in-drift environmental conditions, the seepage water is expected to flow through the contact metamorphic aureole and react first with the basalt in the intruded emplacement drifts, resulting in basalt-equilibrated seepage water. The geochemical interaction of seepage water with the basalt and the resulting hydrochemistry are simulated using EQ6 model, all as described in BSC 2003 (Section 6.5.3 [DIRS 165002]).

By way of corroborative information, for a dike initially intruding into the SZ, Rojstaczer (1991 [DIRS 163416]) indicates a rise in the water table of a few tens of meters. Also of a corroborative nature and based on their initial stage work with highly simplified systems used to represent Yucca Mountain, Valentine and others (CRWMS M&O 1998, p. 5-86 [DIRS 105347]) suggest that the horizontal distance over which an intrusion affects convective air flow is always less than 2.5 km, and that the dike or sill particles representing magmatic volatiles never travel more than approximately 500 meters horizontally. Consequently, the development of hydrothermal systems from igneous activity is *Excluded* from the TSPA-LA based on low consequence due to their limited size respective to the repository footprint.

The potential for igneous activity (primarily via eruption or effusive flow) to change surface topography, and subsequently affect drainage and infiltration is possible, albeit at the same or slightly lower probability than for an eruptive event. The net effect could, hypothetically, result in temporary damming of a drainage intersected by a dike at the surface, or from the sluffing of ash materials from hill slopes. While possible, the steep topographic gradients at Yucca Mountain above the repository, the increased sedimentation rate associated with ash redistribution in comparison to unaffected areas as discussed for FEP 1.2.04.07.0C (Ash redistribution via soil and sediment transport), and the limited extent of effusive flow from small-scale volcanoes such as Lathrop Wells, would tend to limit the consequences of any such topographic changes. The net result through time would likely resemble something akin to Lathrop Wells cone, wherein drainage patterns readjust and re-equilibrate to match the change in conditions, resulting in relocation of the drainage rather than any significant ponding or increased infiltration effects.

Furthermore, in 10 CFR 63.305(b and c) (66 FR 55732 [DIRS 156671]), the NRC states that:

b) 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 the 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."

c) 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 over the next 10,000 years.

The definition of reference biosphere at 10 CFR 63.2 (66 FR 55732 [DIRS 156671]) specifically identifies topography as being a component of the reference biosphere.

> *Reference biosphere* means the description of the environment inhabited by the reasonably maximally exposed individual. The reference biosphere comprises the set of specific biotic and abiotic characteristics of the environment, including, but not necessarily limited to, climate*, topography*, soils, flora, fauna, and human activities.

By NRC's juxtaposition of varying geologic and hydrologic factors with the required characteristics of the reference biosphere, it is inferred that the listed regulatory constraint of changes in the reference biosphere may also be applicable to conditions at Yucca Mountain. In particular, it is inferred that changes in the biosphere (other than climate), which result from geologic disruptive events, should not be projected. Specifically identified in the definition of the referenced biosphere are changes to soil, topography, and flora. By inference, an allowable interpretation is that DOE should not project changes in the topography and soils properties and must assume that the topography and soils remains constant.

Whether the damming of drainages by ash or effusive magma flow is a geologic or topographic change is subject to discussion. For purposes of this analysis report, it is classified as a topographic change in that topography is defined as "the physical features of a district or region, such as are represented on maps, taken collectively; especially, the relief and contour of the land (Bates and Jackson 1984 [DIRS 128109]). The mechanisms for damming of the streams stem from a change in relief or contour, although in this case the triggering mechanism for the change is a geologic event.

Similarly, the change in infiltration rates to a change in soils stemming from a geologic event also appears to be precluded by the regulations. Regardless, from USGS 2001 (Section 6.1.2 [DIRS 1620355]) and from Flint and Flint (1995 [DIRS 100394] referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]), the USGS states that the soils exceeding 6 meters in thickness eliminate the infiltration of water to the soil/bedrock contact except in channels. This implies that the unconsolidated surficial deposits will trap infiltrating water, but rather than shielding this water from evapotranspiration, it will allow evapotranspiration to remove the water that otherwise would escape the zone of evapotranspiration through infiltration directly into rock fractures. Furthermore, significant reduction of volume of basaltic ash per volume of sediment has been observed to occur over short distances at the Lathrop Well Cone (BSC 2003, Section 6.5.1.4 [DIRS 161838]), suggesting that such affects would be extremely localized.

A more restrictive and alternative interpretation would strictly limit the constraints to the reference biosphere (i.e., that area inhabited by the RMEI and/or that outside of the controlled area) located 18 km south of the repository and not to the repository area. Alternatively, the changes in topography and soil could, hypothetically, be classified as hydrologic changes rather than geologic or topographic, because the changes affect surface drainages and infiltration. Or, the juxtaposition of the regulations could be inferred to mean that the static condition of the biosphere characteristics apply to the nominal case, but not the disruptive case.

Regardless of the regulatory interpretation, the technical basis of the argument is sufficient to presume low consequence of the resulting changes in topography and soils and Yucca Mountain that result from an eruptive event.

In summary, the parallel orientation of dikes and the direction of maximum transmissivity, coupled with the expected, limited affected-volume of the SZ and the generally low probability of an igneous intrusion, indicates that dikes, even if differing in permeability from the host rock, will not significantly affect groundwater-flow patterns or water levels. Because there would be no significant change to the flow system, hydrologic response to igneous activity does not provide a mechanism for significantly changing dose. Given the limited area of alteration and the consequent change of rock properties around the intrusion, the effect of alteration would be minimal, and alteration would not provide a mechanism to significantly change the dose. Furthermore, the development of hydrothermal systems from igneous activity is *Excluded* from the TSPA-LA based on low consequence due to their limited size and minimal rise in the water table respective to the repository footprint. Consequently, "Hydrologic response to igneous activity" is *Excluded* from the TSPA-LA based on low consequence.

TSPA Disposition: Not Applicable

Related FEPs:

FEPs that examine related but distinct effects and consequences

Tectonic activity—large scale (1.2.01.01.0A)
Igneous intrusion into repository (1.2.04.03.0A)
Magma or pyroclastic base surge transports waste (1.2.04.05.0A)
Ash redistribution via soil and sediment transport (1.2.04.07.0C)
Erosion/denudation (1.2.07.01.0A)
Deposition (1.2.07.02.0A)
Diapirism (1.2.09.01.0A)
Hydrologic response to seismic activity (1.2.10.01.0A)
Water table decline (1.3.07.01.0A)
Water table rise (1.3.07.02.0A)
Rind (chemically altered zone) forms in the near field (2.1.09.12.0A)
Rock properties of host rock and other units (2.2.03.02.0A)
Perched water develops (2.2.07.07.0A)
Geochemical interactions and evolution in the SZ (2.2.08.03.0A)
Geochemical interactions and evolution in the UZ (2.2.08.03.0B)
Topography and Morphology (2.3.01.00.0A)

FEPs that examine similar effects and consequences

Hydrothermal activity (1.2.06.00.0A)
Thermally-induced stress changes in the near field (2.2.01.02.0A)
Thermomechanical stresses alter characteristics of fractures near repository (2.2.10.04.0A)
Thermomechanical stresses alter characteristics of faults near repository (2.2.10.04.0B)
Thermomechanical stresses alter characteristics of rocks above and below the repository (2.2.10.05.0A)

Related Documents: None

Supplemental Discussion: None

7. CONCLUSIONS

Table 7.1 provides a summary of the DE FEP-screening decisions and the basis for the decisions. This analysis report may be affected by technical product input information that requires confirmation. Any changes to the document that are required because of completing the confirmation activities will be reflected in subsequent revisions. The quality status of the technical product input may be confirmed by review of the database.

Table 7-1. Summary of DE FEP Screening Decisions.

TSPA-LA FEP Number	TSPA-LA FEP Name	Screening Decision and Basis	Section Where Addressed
Seismic-related FEPs			
1.2.01.01.0A	Tectonic activity—large scale	Excluded— Low Consequence	6.2.1.1
1.2.02.03.0A	Fault displacement damages EBS components	Included	6.2.1.2
1.2.03.02.0A	Seismic ground motion damages EBS components	Included	6.2.1.3
1.2.03.02.0B	Seismic-induced rockfall damages EBS components	Included	6.2.1.4
1.2.03.02.0C	Seismic-induced drift collapse damages EBS components	Excluded— Low Consequence	6.2.1.5
1.2.03.02.0D	Seismic-induced drift collapse alters in-drift thermohydrology	Included	6.2.1.6
1.2.03.03.0A	Seismicity associated with igneous activity	Included	6.2.1.7
1.2.10.01.0A	Hydrologic response to seismic activity	Excluded— Low Consequence	6.2.1.8
2.2.06.01.0A	Seismic activity changes porosity and permeability of rock	Excluded— Low Consequence	6.2.1.9
2.2.06.02.0A	Seismic activity changes porosity and permeability of faults	Excluded— Low Consequence	6.2.1.10
2.2.06.02.0B	Seismic activity changes porosity and permeability of fractures	Excluded— Low Consequence	6.2.1.11
2.2.06.03.0A	Seismic activity alters perched water zones	Excluded— Low Consequence	6.2.1.12
Igneous-related FEPs			
1.2.04.02.0A	Igneous activity changes rock properties	Excluded— Low Consequence	6.2.2.1
1.2.04.03.0A	Igneous intrusion into repository	Included	6.2.2.2
1.2.04.04.0A	Igneous intrusion interacts with EBS components	Included	6.2.2.3
1.2.04.05.0A	Magma or pyroclastic base surge transports waste	Excluded— Low Consequence	6.2.2.4
1.2.04.06.0A	Eruptive conduit to surface intersects repository	Included	6.2.2.5
1.2.04.07.0A	Ashfall	Included	6.2.2.6
1.2.04.07.0C	Ash redistribution via soil and sediment transport	Included	6.2.2.7
1.2.10.02.0A	Hydrologic response to igneous activity	Excluded— Low Consequence	6.2.2.8

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8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

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8.3 SOURCE DATA

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ATTACHMENT A

GLOSSARY

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annual exceedance probability–The probability that a specified value (such as for ground motions or fault displacement) will be exceeded during one year.

aperture–The gap between two walls or faces of a fracture.

ash flow–A density current, generally a hot mixture of volcanic gases and tephra that travels across the ground surface. The solid materials contained in a typical ash flow are generally unsorted and ordinarily include volcanic dust, pumice, scoria, and blocks in addition to ash.

ash fall–Airborne ash that falls from an eruption cloud, and the resulting deposit.

asperity–A measure of the roughness of the area of contact between two surfaces of a fracture.

background earthquake–An earthquake that does not produce ground breakage, hence is not associated with a known fault. Such earthquakes are considered to be random in time and space. In the Great Basin, background earthquakes have magnitudes of less than 6.0.

basalt–A dark-colored, fine-grained volcanic or intrusive rock (dike or sill intrusion) consisting chiefly of calcic plagioclase, pyroxene, and olivine.

base level–The theoretical lowest level toward which erosion progresses, considered practically as the level below which a stream cannot erode its bed.

blind fault–A fault that dies out in bedrock and is not exposed at earth's surface.

block faulting–Segmentation of the crust into block-like masses by systematic normal faulting.

caldera complex–An assemblage of extrusive and intrusive rocks and associated structures generated by explosive and effusive volcanism that comprise a number of genetically related overlapping or adjacent or proximal calderas.

caliche–A calcareous soil component typically forming friable to hard, off-white, crudely layered to finely laminated intervals near the surface of stony desert soils; several cm or more thick. Old, thick caliche intervals (calcretes) have the texture and hardness of concrete aggregate.

colluvial slope–A hill slope mantled with loose, heterogeneous soil and rock fragments that are the result of weathering and accumulation by creep and unchanneled snow melt or runoff.

conduit–The vertical or subvertical, essentially cylindrical, tube that brings magmatic material to land surface. Conduit is the appropriate term regarding the subsurface, and PA conceptual models emphasize the interactions that occur at the intersection of a conduit with the repository.

Crater Flat tectonic domain–A tectonic domain is a block of the Earth's crust bounded by major faults or zones of complex shear and deformation. A domain features a history and styles of deformation that distinguish it from adjacent areas of the crust. The Crater Flat domain includes Yucca Mountain and is characterized by normal faulting into the Crater Flat basin which lies immediately to the west of Yucca Mountain.

debris flow–A moving mass of rock fragments and mud, comprised mostly of fragments larger than sand size; water-mobilized colluvium; also the deposit of such a flow.

detachment faulting–A style of normal faulting wherein large, extensional displacement occurs on a fault plane that dips less than 30°. In places, the lower plates (footwalls) of detachment faults have been uplifted from mid-crustal depths, implying that detachment is accompanied by significant isostatic uplift or uplift by magmatic inflation.

dike–A tabular intrusion of magma that is at a high angle to layering in the intruded strata (i.e., vertical or subvertical at Yucca Mountain).

dike system–One or more dikes that are closely related in space and time. Dike systems may include multiple dikes that share a common magmatic source with a single volcano. This definition does not preclude the possibility that a dike system may feed more than one volcano.

dip-slip faulting–Faulting in which the hanging wall moves down the dip of the fault plane. Normal faulting has slip directly along the dip normal to the strike of the fault; oblique faulting has a component of slip parallel to the fault strike (i.e., some lateral displacement).

disruptive FEP–An *Included* FEP that has a probability of occurrence during the period of performance less than 1.0 (but greater than the cutoff of $10^{-4}/10^{4}$ year).

disruptive event scenario class–The scenario class, or set of related scenarios classes, that describes the behavior of the system if perturbed by disruptive events. The disruptive scenario classes contain all disruptive FEPs that have been retained for analysis.

eruptive event (with respect to repository performance)–The formation of a volcano that includes at least one subsurface conduit that intersects a drift containing waste packages.

event–A natural or anthropogenic phenomenon that has the potential to affect disposal-system performance and that occurs during an interval that is short compared to the period of performance.

Excluded FEP–A FEP that is identified by the FEP screening process as not requiring modeling in the quantitative TSPA.

expected FEP–An *Included* FEP that, for the purposes of the TSPA, is presumed to occur with a probability equal to 1.0 during the period of performance.

extrusive event (with respect to repository performance)–Synonymous with eruptive event.

faulting–Process of fracture and attendant slip along a fracture plane or recurrent slip along a such a plane.

fault strand–A fault segment expressed as a continuous intersection with the earth's surface, as indicated by a scarp, scarp line, or series of exposed displacement features, all having the same style of offset. A fault strand is generally taken to connote a relatively short fault segment or "splay" that is one of a series of many faults that together form the principal fault zone. The zone is usually not straight and well developed, and faults may bifurcate or anastomose or step over from one fault to another. Slip can be transferred across many strands.

feature–An object, structure, or condition that has a potential to affect disposal-system performance.

flowing interval–A fracture or fractured zone that transmits flow in the SZ.

folding–Bending in strata. Formation of folds expressed by geometric features that include fold limbs, fold axes, and axial planes. Large or systematic compressive and drag folds are results of tectonic activity.

fracture–A brittle crack in rock. Groups of fractures in more or less regular orientation and spacing are termed joints. Fractures form by bending (shear joints) or tension or principal stress reduction (extension joints). Cooling joints are formed by tension exerted by contraction as an intrusive or extrusive volcanic rock cools.

future–A single, deterministic representation of the future state of the system. An essentially infinite set of futures can be imagined for any system.

geodetic strain rate–Regional strain rate determined at the earth's surface by repeated measurement of displacements of precisely located landmarks (monuments) embedded in the deforming medium.

geologic setting–The geologic, hydrologic, and geochemical systems of the region in which a geologic repository is or may be located.

geothermal gradient–The rate of increase of temperature with depth in the earth

heat flow–The amount of heat energy leaving the earth's crust, measured in Heat Flow Units (HFU) or calories/m^2/sec.

hydrovolcanic eruption–Very energetic explosive eruptions triggered by the rapid mixing of ground or surface water with rising magma eruptions. Rather than formation of scoria cones by ballistic deposition, tephra and lithic clasts are deposited as fallout and pyroclastic density currents leaving surge deposits and typically forming wide, shallow tuff rings.

igneous activity–Any process associated with the generation, movement, emplacement, or cooling of molten rock within the earth or on the earth's surface.

Included FEP–A FEP that is identified by the FEP screening process as requiring analysis in the quantitative TSPA.

intrusive event (with respect to repository performance)–An igneous structure (such as a dike, dike system, or other magmatic body in the subsurface) that intersects the repository footprint at the repository elevation.

key block–Critical blocks formed in the rock mass surrounding an excavation (by the intersection of three or more planes of structural discontinuity). These blocks are capable of displacement so that they are likely to move into the drift opening unless restraint is provided.

lithophysae–A subrounded cavity from about one to several cm in diameter formed in silicic volcanic rocks (e.g., welded tuff) by gas bubbles evolved during cooling; lithophysae are typically lined or largely filled with finely crystalline or cryptocrystalline rinds of secondary, vapor-phase minerals.

maar–A low-relief, broad volcanic crater formed by shallow explosive eruptions. The explosions are usually caused by the heating and boiling of groundwater resulting from magma invading the groundwater table.

magma–Partially or completely molten rock within the earth's crust or mantle.

magmatic inflation–Uplift of the crust caused by intrusion of subjacent magma, which can occur due to large-volume batholithic melts, dike swarms, or lower crustal magmatic underplating.

mantle–The zone of the earth below the crust and above the core, typified by high seismic velocity and dense iron- and magnesium-rich silicate mineral components.

mantle plume–A large mass of molten mantle material rising up from the lower mantle into the base of the crust by the process of convection and buoyancy. Mantle plumes are typically hundreds of km in area.

Miocene–Epoch of the Tertiary Period between 24 Ma and 5 Ma.

modeling case–A well-defined, connected sequence of FEPs that can be thought of as an outline of a future condition of the repository system. Modeling cases can be undisturbed, in which case the performance would be the expected, or nominal, behavior for the system. Modeling cases can also be disturbed, if altered by disruptive events such as human intrusion or natural phenomena such as volcanism, seismicity, or nuclear criticality.

nominal scenario class–The scenario class, or set of related scenarios classes, that describes the expected or nominal behavior of the system as perturbed only by the presence of the repository. The nominal scenario class contains all expected FEPs that have been retained for analysis.

nonwelded unit–A volcanic ash, or tuff, that is crumbly or easily excavated because the component glass shards did not weld together during compaction of relatively cool ash or ash having relatively sparse glass content.

paleoseismic slip–The amount of fault slip indicated by buried offset strata; individual paleoearthquakes are indicated by discrete amounts of offset.

percolation flow–Flow of groundwater through small, interconnected rock or soil pores.

playa–A dried lake bed. Playas have, typically, a flat, salty surface that forms the low part of a confined desert basin.

Pleistocene–The epoch of the Quaternary Period from about 1.6 Ma to 10 Ka.

Plio-Pleistocene–Combined duration of the Pliocene and Pleistocene epochs of the Cenozoic era, from 10 Ka to 5 Ma.

potentiometric surface A notional surface representing the total head of groundwater as defined by the level at which such water stands in a well. The water table is a particular type of potentiometric surface pertaining to an unconfined aquifer in which the surface is in equilibrium with atmospheric pressure.

process–A natural or anthropogenic phenomenon that has the potential to affect disposal-system performance and that operates during all or a significant part of the period of performance.

pumice–Highly vesicular or frothy siliceous glass formed during volcanic eruption; typically a pale gray color.

pumiceous–Having observable pumice content.

pyroclastic–Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent.

Quaternary–The period of the Cenozoic Era from 1.6 Ma to present includes the Pleistocene and Holocene Epochs.

reference biosphere–The description of the environment inhabited by the reasonably maximum exposed individual (RMEI). The reference biosphere comprises the set of specific biotic and abiotic characteristics of the environment, including but not necessarily limited to, climate, topography, soils, flora, fauna, and human activities.

regional slope–The surface defined by the elevations of resistant peaks in a given area; it approximates the surface formed by uplift prior to erosional incision.

regional subsidence–Broad depression of the earth's surface resulting from tectonic activity such as extension, crustal cooling, or deep crustal or mantle flow.

regional uplift–Broad elevation of the earth's surface resulting from tectonic activity such as compression or igneous intrusion.

rockburst–A sudden and often violent failure of masses of rocks in quarries, tunnels, or mines. It is an uncontrolled disruption of rock associated with a violent release of energy additional to that derived from falling rock fragments.

rollover–A steepening of dip in the downthrown block of a normal fault as the fault plane is approached.

scenario class–A set of related modeling cases that share sufficient similarities that they can usefully be aggregated for the purposes of screening or analysis. The number and breadth of scenario classes depends on the resolution at which modeling cases have been defined. Coarsely defined modeling cases result in fewer, broad scenario classes, whereas narrowly defined modeling cases result in many narrow scenario classes. Scenario classes (and modeling cases) should be aggregated at the coarsest level at which a technically sound argument can be made, while still maintaining adequate detail for the purposes of analysis.

seismic activity–The recurrence and distribution of earthquakes associated with a specified seismic source.

seismicity–The capacity of a fault, group of faults, or region of the crust to generate earthquakes, as determined by instrumental or paleoseismic history; the relative rate at which earthquakes recur (syn. seismic activity).

springline–The imaginary line at which an arch, vault, or drift begins to curve; for circular cross-sections, this corresponds to the vertical mid-point along the drift wall.

stoping–In the FEPs context, this term is used to mean the progressive, generally upward, breaking and removal of rock along a drift, fracture, fault, or other feature due to natural causes.

strain rate–The rate at which a unit of length is shortened or lengthened under a stress load, usually given in terms of inverse seconds. Strain rate is often expressed in units of mm/yr where an actual length difference rather than a ratio is calculated.

strand–See fault strand.

stream gradient–Angle between inclination of a stream channel bed and the horizontal measured in direction of flow (i.e., the “slope” of a stream).

subducting slab–A section of oceanic (basaltic) crust in process of being drawn down into the upper mantle by tectonic forces as crustal plates interact.

tectonic activity–The dynamic manifestation of stress loads generated within the earth’s crust (e.g., igneous intrusion, earthquakes, uplift).

tectonic deformation–The suite of geological structures generated by body stresses exerted within the earth’s crust; such structures range in scale from microscopic (e.g., mylonite fabric) to regional (e.g., overthust belts). Also, the process by which such structures together is formed.

tectonic extension–Stretching or extension of the crust as a result of deep-seated tectonic stress, such as back-arc spreading.

tectonic process–The dynamic evolution of structure generated through the buildup and relaxation of regional stress.

tectonism–All movement of the crust produced by tectonic processes, including mountain building (orogeny), regional uplift and subsidence; the general expression of tectonic process through time and space.

tephra–A collective term used for all pyroclastic material, regardless of size, shape or origin, ejected during an explosive volcanic eruption. Originally applied exclusively to fallout ejecta, but now also applies to pyroclastic flow deposits.

errain relief–For some defined area of the earth's surface, it is the measure of difference between the lowest local elevation and the highest local elevation.

topography–The physical features of a district or region, such as are represented on maps, taken collectively; especially the relief and contour of the land.

Type I fault–Faults or fault zones that are subject to displacement and are of sufficient length and location that they may affect repository design or performance.

vent–The intersection of a conduit with land surface. Volcanoes may have more than one vent.

vertical axis rotation–Folding referenced to a vertical axis. Hence, folded beds or layers change strike around the inferred vertical axis.

violent strombolian eruption–volcanic eruptions with violent blasts that project voluminous showers of scoria and bombs to heights of hundreds or thousands of feet, accompanied by a dense black ash cloud. Violent strombolian eruptions are characterized by vertical eruption of a high-speed jet of a gas-clast mixture.

volcanic activity–The suite of events and processes associated with extrusion of molten rock, such as eruption, lava emission, or cone formation comprising the subaerial components of igneous activity.

volcanic event–The formation of a volcano (with one or more vents) resulting from the ascent of basaltic magma through the crust as a dike or system of dikes.

volcano–A geologic feature than includes an edifice of magmatic material erupted on the land surface, one or more conduits that feed the eruption, and a dike or dike system that feeds the conduit or conduits.

water table–The surface of unconfined groundwater at which the pressure is equal to that of the atmosphere.

welded unit–A volcanic ash, or tuff, that is strongly indurated because hot glass shards were partially melted together (welded) during compaction of the ash bed while the ash was still hot.