DOC.20040329.0004

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2. Scientific Analyses Title

Features, Events, and Processes in SZ Flow and Transport

3. DI (Including Revision Number)

ANL-NBS-MD-000002 REV02

4. Total Attachments: N/A

5. Attachment Numbers - Number of pages in each: N/A

	Printed Name	Signature	Date
6. Originator	Kathy Economy		3/25/04
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11. Remarks

Revision History

12. Revision/ICN No.	13. Description of Revision/Change
00	Initial Issue
01	Revision to add 2 new secondary SZ FEPs, address comments by Winston and Strawn, update the text to describe the results of other FEP and change the format of section 6.2 to include the numbers for secondary FEPs, standardize callouts to include the document identifier, add subheadings and sections to address: related primary FEPs, summary of screening argument, TSPA disposition and supplemental discussion (full screening argument for lengthy evaluations) and related NRC IRSRs.
02	Provide updated SZ FEP screening in alignment with the FEP list modifications given in the TSPA LA FEP list. Provide updated SZ FEP screening to reflect current project knowledge of SZ issues documented in updated SZ AMRs. Resolve TBVs: (1) Resolution of TBV-4924 is documented in Section 6.2.10. (2) Resolution of TBV-4933 (initiated by REV 01 of this document) is resolved in Section 6.2.46. There are no TERS or CIRS affiliated with this AMR.

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ACRONYMS AND ABBREVIATIONS

1-D	One-Dimensional
Am	americium
AMR	Analysis Model Report
ATC	Alluvial Tracer Complex
atm	atmosphere
BDCF	Biosphere Dose Conversion Factor
BSC	Bechtel SAIC Company
C	centigrade
CA	California
CDF	cumulative distribution function
CFR	Code of Federal Regulations
cm	centimeter
COLVO	Colloid Retardation in the Volcanics (a sampled parameter used in the SZFT models)
CORAL	Colloid Retardation Factor in the Alluvium
CORVO	Colloid Retardation Factor in Volcanic Units
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
Cs	cesium
CSNF	commercial spent nuclear fuel
DCVO	Diffusion Coefficient in Volcanics
DE	disruptive event
DIRS	Document Input Reference System
DOE	U. S. Department of Energy
DTN	Data Tracking Number
D_w	water density
EBS	Engineered Barrier System
Eh	electrode potential
EPA	Environmental Protection Agency
ESF	Exploratory Studies Facility
FEP	Feature, Event, and Process
FISVO	Flowing Interval Spacing in the Volcanic Units (a sampled parameter used in the SZFT models)
FPVO	Flowing Interval Porosity (sampled parameter used in the SZFT models)
FPLAW	western boundary of the alluvial uncertainty zone
FPLAN	northern boundary of the alluvial uncertainty zone

ACRONYMS AND ABBREVIATIONS (Continued)

GWSPD	scaling parameter for groundwater specific discharge (a sampled parameter used in the SZFT models)
HAVO	Horizontal Anisotropy in the Volcanic Units (a sampled parameter used in the SZFT models)
HFM	Hydrogeologic Framework Model
ka	thousand years
K_d	sorption coefficient
km	kilometer
LA	License Application
LANL	Los Alamos National Laboratory
LDISP	Longitudinal Dispersivity (sampled parameter used in the SZFT models)
m	meter
m.y.a.	million years ago
ml	milliliter
N/A	Not Applicable
Np	neptunium
NRC	Nuclear Regulatory Commission or National Research Council
NTS	Nevada Test Site
OCRWM	Office of Civilian Radioactive Waste Management
ORD	Office of Repository Development
Pa	protactinium
PA	Performance Assessment
P_d	particle density
PSHA	Probabilistic Seismic Hazard Analysis
Pu	plutonium
QA	Quality Assurance
QARD	Quality Assurance Requirements and Description
Ra	radium
RMEI	Reasonably Maximally Exposed Individual
RN	radionuclide
SAR	Safety Analysis Report
SNL	Sandia National Laboratories
SR	Site Recommendation

ACRONYMS AND ABBREVIATIONS (Continued)

STN	software tracking number
sv	settling velocity
SZ	saturated zone
SZFT	Saturated Zone Flow and Transport
Tc	technetium
Th	thorium
THC	Thermal-Hydrologic-Chemical
TSPA	Total System Performance Assessment
U	uranium
USGS	United States Geological Survey
UZ	unsaturated zone
WF	waste form
YM	Yucca Mountain
YMP	Yucca Mountain Project

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1. PURPOSE

The U.S. Department of Energy (DOE) must provide a reasonable assurance that the performance objectives for the Office of Repository Development (ORD) radioactive-waste repository can be achieved for a 10,000-year post-closure period. The guidance that mandates this direction is under the provisions of the Code of Federal Regulations 10 CFR Part 63 [156605] (Nuclear Regulatory Commission (NRC) regulations governing Yucca Mountain). This assurance must be demonstrated in the form of a performance assessment (PA). From 10 CFR Part 63.2, the definition of performance assessment means an analysis that:

1. Identifies the features, events, processes (except human intrusion), and sequences of events and processes (except human intrusion) that might affect the Yucca Mountain disposal system and their probabilities of occurring during 10,000 years after disposal;

2. Examines the effects of those features, events, processes, and sequences of events and processes upon the performance of the Yucca Mountain disposal system; and

3. Estimates the dose incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence.

To demonstrate that regulatory-specified performance objectives of 10 CFR Part 63.2 [156605] can be achieved for a 10,000-year post-closure period, the ORD is implementing a Features, Events, Processes (FEP) analysis and scenario development methodology based on the work of Cranwell et al. (1990 [101234]). The methodology, incorporated into a Total System Performance Assessment (TSPA), provides a systematic approach for considering, as completely as practical, the possible future state of a repository system. The TSPA seeks to span the set of all possible future states using a finite set of scenario classes. A scenario is a well-defined, connected sequence of FEPs that is an outline of a possible future condition of the proposed repository system. A scenario class is a set of related scenarios sharing sufficient similarities that they can usefully be aggregated for the purposes of screening or analysis. The objective of FEP analysis and scenario development is to define a limited set of scenario classes and scenarios that can reasonably be analyzed quantitatively while still maintaining comprehensive coverage of the range of possible future states of the disposal system.

Thus, FEPs are a fundamental aspect of a PA, where (1) a *feature* is an object, structure, or condition that has a potential to affect disposal system performance, (2) an *event* is a natural or human-caused 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, and (3) a *process* is a natural or human-caused phenomenon that has a potential to affect disposal system performance and that operates during all or a significant part of the period of performance. Identifying FEPs that are potentially relevant to the functioning of the disposal system conceptually produces the initial domain or parameter space of the model of the disposal system, and a screening process omits those portions of the domain that are not pertinent. When developing the conceptual model of the disposal system, the formal and defensible selection of the pertinent domain of FEPs is one aspect that sets PAs apart from typical scientific or engineering analyses. Because of the nature of FEP screening and model development, several iterations of the PA process are potentially necessary, both to eliminate those FEPs of negligible influence and to improve the modeling of those retained FEPs.

This scientific analysis report focuses on FEP analysis of saturated-zone (SZ) FEPs to be considered in the TSPA model for the license application (LA).

1.1 SCOPE

This scientific analysis report is governed by the Office of Civilian Radioactive Waste Management (OCRWM) *Technical Work Plan for: Saturated Zone Flow and Transport Modeling and Testing Technical Work Plan* TWP-NBS-MD-000002 Rev 01 ICN 01 (BSC 2003 [166034], Section 2.7), Work Package ASZM04.

This report has a two-fold scope:

1. It gives the TSPA-LA disposition (i.e., how the FEP is implemented) for 21 SZ FEPs to be included in the TSPA-LA analysis model and relates them to the scientific analyses reports or model reports in which these dispositions are developed and documented.

2. It documents the screening argument (i.e., technical basis and rationale) for the 25 SZ FEPs that are excluded from the TSPA-LA analysis based on the criteria specified in 10 CFR Part 63 [156605]. These criteria are identified in Section 4.3 of this report.

The scope of this report also provides evidence for the acceptance criteria as specified in the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [163274], Section 2.2.1.2.1.3) and summarized in Section 4.2 of this report.

1.2 FEP ANALYSIS—BACKGROUND

1.2.1 FEP Identification and Screening

The development of a comprehensive list of FEPs potentially relevant to post-closure performance of the Yucca Mountain repository is an ongoing, iterative process based on site-specific information, design, and regulations. The first step of the FEP analysis process is the identification of FEPs potentially relevant to the performance of the potential Yucca Mountain repository. An initial list of FEPs relevant to Yucca Mountain was developed from a comprehensive list of FEPs from radioactive waste disposal programs in other countries (BSC 2001 [154365], Section 2.1) and was supplemented with additional Yucca Mountain Project (YMP)-specific FEPs from project literature, technical workshops, and reviews (Freeze et al. 2001 [154365], Sections 2.2 through 2.4). The initial FEP list contained 328 FEPs, of which 176 were included in TSPA-Site Recommendation (SR) models (*Total System Performance Assessment for the Site Recommendation,* CRWMS M&O 2000 [153246], Tables B-9 through B-17).

For TSPA-LA, FEP analysis included a reorganization and re-evaluation of the FEP list in accordance with *The Enhanced Plan for Features Events and Processes (FEPs) at Yucca*

Mountain (BSC 2002 [158966], Section 3.2) and the Key Technical Issue Letter Report *Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* REG-WIS-PA-000003 REV 00 ICN 04 (Freeze 2003 [165394]). The reorganization and re-evaluation resulted in a preliminary list of SZ FEPs as extracted from the preliminary TSPA-LA FEP list (Data Tracking Number (DTN): MO0307SEPFEPS4.000 [164527]). Further evaluation by knowledgeable SZ subject-matter experts resulted in subsequent changes from the preliminary TSPA-LA FEP list. The result was a list of 46 SZ FEPs, as identified in Table 1.2-1. Table 1.2-1 summarizes the changes from TSPA-SR to the FEP organization and descriptions being used for TSPA-LA that appear in this report. Changes made subsequent to the preliminary TSPA-LA FEP list (DTN: MO0307SEPFEPS4.000 [164527]) are identified with italicized text.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
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 are 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.	**1.2.02.01.0A Fractures** Groundwater flow in the Yucca Mountain region and transport of any released radionuclides may take place along fractures. The rate of flow and the extent of transport in fractures are influenced by characteristics such as orientation, aperture, asperity, fracture length, connectivity, and the nature of any linings or infills.	This FEP now addresses existing fractures. Changes to fractures are moved to 2.2.10.04.0A (thermal) and 2.2.06.02.0B (seismic).
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 cavitation of existing faults may enhance the groundwater flow, thus decreasing the transport times for potentially released radionuclides.	**1.2.02.02.0A Faults** Numerous faults of various sizes have been noted in the Yucca Mountain Region and in the repository area in specific. Faults may represent an alteration of the rock permeability and continuity of the rock mass, alteration or short-circuiting of the flow paths and flow distributions close to the repository, and represent unexpected pathways through the repository.	Name changed to be consistent with fractures, FEP 1.2.02.01.0A. The FEP description has changed to focus on effects of existing faults and how incorporated into the models. Changes to faults were moved to 2.2.10.04.0B (thermal) and 2.2.06.02.0A (seismic). (*Minor typo in description corrected*.)

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
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).	Not applicable – Not assigned to SZ for LA	This FEP was deleted because it was redundant to other seismic FEPs.
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.	**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 an issue.
1.2.04.07.00 Ashfall Finely divided waste particles are carried up a volcanic vent and deposited on the surface from an ash cloud or pyroclastic flow.	**1.2.04.07.0B Ash redistribution in groundwater** Following deposition of contaminated ash on the surface, contaminants may leach out of the ash deposit and be transported through the subsurface to the compliance point.	This FEP was split into three to address direct exposure from ashfall (A), redistribution of ash via groundwater (B), and redistribution of ash via surface transport mechanisms (C). Only 1.2.04.07.0B is addressed in this report.
1.2.06.00.00 Hydrothermal Activity This category contains FEPs associated with naturally-occurring high-temperature groundwater, including processes such as density-driven groundwater flow and hydrothermal alteration of minerals in the rocks through which the high-temperature groundwater flows.	**1.2.06.00.0A Hydrothermal activity** Naturally-occurring high-temperature groundwater may induce hydrothermal alteration of minerals in the rocks through which the high-temperature groundwater flows.	Description edited for clarity.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
1.2.09.02.00 Large-scale Dissolution Dissolution can occur when any soluble mineral is removed by flowing water, and large-scale dissolution is a potentially important process in rocks that are composed predominantly of water-soluble evaporite minerals, such as salt.	**1.2.09.02.0A Large-scale dissolution** Dissolution can occur when any soluble mineral is removed by flowing water, and large-scale dissolution is a potentially important process in rocks that are composed predominantly of water-soluble evaporite minerals, such as salt.	No change.
1.2.10.01.00 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.	**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.	*Name changed to "Hydrologic" from "Hydrological."*
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.	**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.
1.3.07.01.00 Drought/Water Table Decline Climate change could produce an extended drought, leading to a decline in the water table in the saturated zone, which would affect the release and exposure pathways from the repository.	**1.3.07.01.0A Water table decline** Climate change could produce decreased infiltration (e.g., an extended drought), leading to a decline in the water table in the saturated zone, which would affect the release and exposure pathways from the repository.	Name and description edited for clarity. *"Potential" deleted from description, no longer a "potential" repository.*

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
1.3.07.02.00 Water Table Rise Climate change could produce increased infiltration, leading to a rise in the regional water table, possibly affecting the release and exposure pathways from the repository. A regionally higher water table and change in flow patterns might move discharge points closer to the repository, or flood the repository.	**1.3.07.02.0A Water table rise affects SZ** Climate change could produce increased infiltration, leading to a rise in the regional water table, possibly affecting the release and exposure from the repository by altering flow and transport pathways in the SZ. A regionally higher water table and change in SZ flow patterns might move discharge points closer to the repository.	FEP split into SZ and Unsaturated Zone (UZ). Name and description edited to be SZ specific. *Also, the word 'potential' deleted from description, no longer a "'potential' repository."*
1.4.07.01.00 Water Management Activities Water management is accomplished through a combination of dams, reservoirs, canals, pipelines, and collection and storage facilities. Water management activities could have a major influence on the behavior and transport of contaminants in the biosphere.	**1.4.07.01.0A Water management activities** Water management is accomplished through a combination of dams, reservoirs, canals, pipelines, and collection and storage facilities. Water management activities could have a major influence on the behavior and transport of contaminants in the biosphere.	No change.
1.4.07.02.00 Wells One or more wells drilled for human use (e.g. drinking water, bathing) or agricultural use (e.g. irrigation, animal watering) may intersect the contaminant plume.	**1.4.07.02.0A Wells** One or more wells drilled for human use (e.g. drinking water, bathing) or agricultural use (e.g. irrigation, animal watering) may intersect the contaminant plume.	*Recycling issue now addressed in 1.4.07.03.0A*
Not applicable (new FEP for TSPA-LA)	**1.4.07.03.0A –Recycling of accumulated radionuclides from soils to groundwater** Radionuclides that have accumulated in soils (e.g., from deposition of contaminated irrigation water) may leach out of the soil and be recycled back into the groundwater as a result of recharge (either from natural or agriculturally induced infiltration). The recycled radionuclides may lead to enhanced radionuclide exposure at the receptor.	*New FEP created to cover the recycling issue.*

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.1.09.21.00 Suspension of Particles Larger than Colloids Ground water flow through the waste could remove radionuclide-bearing particles by a rinse mechanism. Particles of radionuclide bearing material larger than colloids could then be transported in water flowing through the waste and Engineered Barrier System (EBS) by suspension.	**2.1.09.21.0B Transport of particles larger than colloids in the SZ** Particles of radionuclide-bearing material larger than colloids could be entrained in suspension and then be transported in water flowing through the SZ.	FEP split into EBS, UZ, and SZ. Name and description edited to be SZ specific.
2.2.03.01.00 Stratigraphy Stratigraphic information is necessary information for the performance assessment. This information should include identification of the relevant rock units, soils and alluvium, and their thickness, lateral extents, and relationships to each other. Major discontinuities should be identified.	**2.2.03.01.0A Stratigraphy** Stratigraphic information is necessary information for the performance assessment. This information should include identification of the relevant rock units, soils and alluvium, and their thickness, lateral extents, and relationships to each other. Major discontinuities should be identified.	No change.
2.2.03.02.00 Rock Properties of Host Rock and Other Units Physical properties such as porosity and permeability of the relevant rock units, soils, and alluvium are necessary for the performance assessment. Possible heterogeneities in these properties should be considered.	**2.2.03.02.0A Rock properties of host rock and other units** Physical properties such as porosity and permeability of the relevant rock units, soils, and alluvium are necessary for the performance assessment. Possible heterogeneities in these properties should be considered. Questions concerning events and processes that may cause these physical properties to change over time are considered in other FEPs.	Description edited for clarity.
2.2.06.01.00 Changes in Stress 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. **(This FEP was not assigned to SZ for TSPA-SR.)**	**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 transport times for potentially released radionuclides.	FEP Description modified to limit discussion in this FEP to seismic-related events. Thermal effects on rock stresses are covered in FEP 2.2.10.05.0B. *Minor typo in description corrected.*

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.06.02.00 Changes in Stress 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.	**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 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 on faults are covered in FEP 2.2.10.04.0B.
Not Applicable (new FEP for TSPA-LA)	**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 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 on fractures are covered in FEP 2.2.10.04.0A.
2.2.06.03.00 Changes in Stress Alter 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.	Not applicable – Not assigned to SZ for LA	This FEP is now assigned to Disruptive Event (DE) and UZ.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.07.12.00 Saturated Groundwater Flow Groundwater flow in the saturated zone below the water table may affect long-term performance of the repository. The location, magnitude, and direction of flow under present and future conditions and the hydraulic properties of the rock are all relevant.	**2.2.07.12.0A Saturated groundwater flow in the geosphere** Groundwater flow in the saturated zone below the water table may affect long-term performance of the repository. The location, magnitude, and direction of flow under present and future conditions and the hydraulic properties of the rock are all relevant.	Name changed, *description changed to reflect that it is no longer a "potential" repository.*
2.2.07.13.00 Water-Conducting Features Geologic features in the saturated zone may affect groundwater flow by providing preferred pathways for flow.	**2.2.07.13.0A Water-conducting features in the SZ** Geologic features in the saturated zone may affect groundwater flow by providing preferred pathways for flow.	Name changed.
2.2.07.14.00 Density Effects on Groundwater Flow (Concentration) Spatial variation in groundwater density may affect groundwater flow.	**2.2.07.14.0A Chemically-induced density effects on groundwater flow** Chemically-induced spatial variation in groundwater density may affect groundwater flow.	Name and description edited to included "chemically-induced." Thermally induced density effects are covered by 2.2.10.13.0A.
2.2.07.15.00 Advection and Dispersion Advection and dispersion processes may affect contaminant transport in the saturated zone.	**2.2.07.15.0A Advection and dispersion in the SZ** Advection and dispersion processes may affect contaminant transport in the SZ.	Name changed.
2.2.07.16.00 Dilution of Radionuclides in Groundwater Dilution due to mixing of contaminated and uncontaminated water may affect radionuclide concentrations in groundwater during transport in the saturated zone and during pumping at a withdrawal well	**2.2.07.16.0A Dilution of radionuclides in groundwater** Dilution due to mixing of contaminated and uncontaminated water may affect radionuclide concentrations in groundwater during transport in the saturated zone and during pumping at a withdrawal well.	No change.
2.2.07.17.00 Diffusion Molecular diffusion processes may affect radionuclide transport in the saturated zone.	**2.2.07.17.0A Diffusion in the SZ** Molecular diffusion processes may affect radionuclide transport in the SZ.	Name changed.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.08.01.00 Groundwater Chemistry/Composition in UZ and SZ Chemistry and the characteristics of groundwater in the saturated and unsaturated zones may affect groundwater flow and radionuclide transport. Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may vary spatially throughout the system as a result of different rock mineralogy, and may also change through time, as a result of the evolution of the disposal system or from mixing with other waters.	**2.2.08.01.0A Chemical characteristics of groundwater in the SZ** Chemistry and other characteristics of groundwater in the saturated zone may affect groundwater flow and radionuclide transport of dissolved and colloidal species. Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may vary spatially throughout the system as a result of different rock mineralogy.	Split FEP into SZ and UZ. Name and description edited to be SZ specific. For LA, this FEP addresses ambient SZ chemistry and spatial variability in SZ chemistry.
2.2.08.02.00 Radionuclide Transport in a Carrier Plume Radionuclide transport occurs in a carrier plume in the geosphere. Transport may be as dissolved or colloidal species, and transport may occur in both the unsaturated and saturated zone.	Not applicable – Not assigned to SZ for LA	This FEP was deleted because it was found to be redundant with SZ FEPs 2.2.08.01.0A and 2.2.08.03.0A, and with UZ FEPs 2.2.08.01.0B and 2.2.08.03.0B.
2.2.08.03.00 Geochemical Interactions in the Geosphere Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties, and sorption on contaminants. These interactions may result from the evolution of disposal system or from external processes such as weathering. Effects on hydrologic flow properties of the rock, radionuclide solubility, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time-scale of concern.	**2.2.08.03.0A Geochemical interactions and evolution in the SZ** Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may change through time, as a result of the evolution of the disposal system or from mixing with other waters. Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties and sorption of contaminants. Effects on hydrologic flow properties of the rock, radionuclide solubilities, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time scale of concern.	Split FEP into UZ and SZ. Name and description edited to be SZ specific. For LA, this FEP addresses changes to SZ chemistry over time.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.08.06.00 Complexation in the Geosphere Complexing agents such as humic and fulvic acids present in natural groundwater could affect radionuclide transport.	**2.2.08.06.0A Complexation in the SZ** Complexing agents such as humic and fulvic acids present in natural groundwaters could affect radionuclide transport in the SZ.	Split FEP into SZ and UZ. Name and description edited to be SZ specific.
2.2.08.07.00 Radionuclide Solubility Limits in the Geosphere Solubility limits for radionuclides in geosphere groundwater may be different than in the water in the waste and EBS.	**2.2.08.07.0A Radionuclide solubility limits in the SZ** Solubility limits for radionuclides may be different in saturated zone groundwater than in the water in the unsaturated zone or in the waste and EBS.	Split FEP into SZ and UZ. Name and description edited to be SZ specific.
2.2.08.08.00 Matrix Diffusion Matrix diffusion is the process by which radionuclides and other species transported by advective flow in fractures or other pathways move into the matrix of the porous rock by diffusion. Matrix diffusion can be a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.	**2.2.08.08.0A Matrix diffusion in the SZ** Matrix diffusion is the process by which radionuclides and other species transported in the SZ by advective flow in fractures or other pathways move into the matrix of the porous rock by diffusion. Matrix diffusion can be a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.	Split FEP into SZ and UZ. Name and description edited to be SZ specific.
2.2.08.09.00 Sorption in the UZ and SZ Sorption of dissolved and colloidal radionuclides can occur on the surfaces of both fractures and matrix in rock or soil along the transport path. Sorption may be reversible or irreversible, and it may occur as a linear or nonlinear process. Sorption kinetics and the availability of sites for sorption should be considered.	**2.2.08.09.0A Sorption in the SZ** Sorption of dissolved and colloidal radionuclides in the SZ can occur on the surfaces of both fractures and matrix in rock or soil along the transport path. Sorption may be reversible or irreversible, and it may occur as a linear or nonlinear process. Sorption kinetics and the availability of sites for sorption should be considered. Sorption is a function of the radioelement type, mineral type, and groundwater composition.	Split FEP into SZ and UZ. Name and description edited to be SZ specific.
2.2.08.10.00 Colloid Transport in the Geosphere Radionuclides may be transported in groundwater in the geosphere as colloidal species. Types of colloids include true colloids, pseudo colloids, and microbial colloids.	**2.2.08.10.0A Colloidal transport in the SZ** Radionuclides may be transported in groundwater in the SZ as colloidal species. Types of colloids include true colloids, pseudo colloids, and microbial colloids.	Split FEP into SZ and UZ. Name and description edited to be SZ specific.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.08.11.00 Distribution and Release Of Nuclides Radionuclides may be released to the biosphere following groundwater transport in unsaturated and saturated zones.	**2.2.08.11.0A Groundwater discharge to surface within the reference biosphere** Radionuclides transported in groundwater as solutes or solid materials (colloids) from the far field may discharge at specific "entry" points that are within the reference biosphere. Natural surface discharge points, including those resulting from water table or capillary rise, may be surface water bodies (rivers, lakes), springs, wetlands, holding ponds, or unsaturated soils.	For LA, only addresses natural discharge. Well discharge is in 1.4.07.01.0A and 1.4.07.02.0A. Corresponding changes to name and description.
2.2.09.01.00 Microbial activity in Geosphere Microbial activity in the geosphere may affect radionuclide mobility in rock and soil through colloidal processes, by influencing the availability of complexing agents, or by influencing groundwater chemistry.	**2.2.09.01.0A Microbial activity in the SZ** Microbial activity in the SZ may affect radionuclide mobility in rock and soil through colloidal processes, by influencing the availability of complexing agents, or by influencing groundwater chemistry.	Split FEP into SZ and UZ. Name and description edited to be SZ specific.
2.2.10.01.00 Repository Induced Thermal Effects in the Geosphere Thermal effects on groundwater density may cause changes in flow in the unsaturated and saturated zones.	Not applicable – Not assigned to SZ for LA	This FEP was changed to be UZ specific. 2.2.10.13.0A now covers this information for the SZ.
2.2.10.02.00 Thermal Convection Cell Develops in SZ Thermal effects due to waste emplacement result in convective flow in the saturated zone beneath the repository.	**2.2.10.02.0A Thermal convection cell develops in SZ** Thermal effects due to waste emplacement result in convective flow in the saturated zone beneath the repository.	*Description edited; no longer a "potential" repository.*
2.2.10.03.00 Natural Geothermal Effects The existing geothermal gradient, and spatial or temporal variability in that gradient, may affect groundwater flow in the unsaturated and saturated zones.	**2.2.10.03.0A Natural geothermal effects on flow in the SZ** The existing geothermal gradient, and spatial or temporal variability in that gradient, may affect groundwater flow in the SZ.	Split FEP into SZ and UZ. Name and description edited to be SZ specific.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.10.04.00 Thermo-mechanical Alteration of Fractures Near Repository Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the material properties (both hydrologic and mechanical) of fractures in the rock. Cooling following the peak thermal period will also change the stress field, further affecting fracture properties near the repository. **(This FEP was not assigned to SZ for TSPA-SR.)**	**2.2.10.04.0A Thermo-mechanical stresses alter characteristics of fractures near repository** Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the fracture properties (both hydrologic and mechanical) of fractures in the rock. Cooling following the peak thermal period will also change the stress field, further affecting fracture properties near the repository.	This FEP now includes text related to thermal effects on fractures in the UZ and SZ from TSPA-SR FEPs 2.2.06.01.00, 2.2.06.02.00, 2.2.06.03.00, and 1.2.02.01.00.
Not Applicable (new FEP for the TSPA-LA)	**2.2.10.04.0B Thermo-mechanical stresses alter characteristics of faults near repository** Heat from the waste causes thermal expansion of the surrounding rock, generating changes to the stress field that may change the fault properties (both hydrologic and mechanical) in and along faults. Cooling following the peak thermal period will also change the stress field, further affecting fault properties near the repository.	New FEP created for consistent level of detail to address thermal effects on faults, similar to that for rocks and fractures. This FEP includes text related to thermal effect on faults in the SZ and UZ from TSPA-SR FEPs 2.2.06.01.00, 2.2.06.02.00, 2.2.06.03.00, and 1.2.02.02.00.
2.2.10.05.00 Thermo-mechanical Alteration of Rocks Above and Below the Repository Thermal-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone. **(This FEP was not assigned to SZ for TSPA-SR.)**	**2.2.10.05.0A Thermo-mechanical stresses alter characteristics of rocks above and below the repository** Thermal-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone.	This FEP now includes text related to thermal effects on rock properties in the UZ and SZ from TSPA-SR FEPs 2.2.06.01.00, 2.2.06.02.00, and 2.2.06.03.00.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.10.06.00 Thermo-chemical Alteration Thermal and chemical processes related to the emplacement of waste in the repository may alter the hydrologic properties of the saturated zone. Precipitation of zeolites, silica, or calcite is a relevant process.	Not applicable – Not assigned to SZ for LA	This FEP was changed to be UZ specific. 2.2.10.08.0A now covers this information for the SZ.
2.2.10.07.00 Thermo-chemical Alteration of the Calico Hills unit Fracture pathways in the Calico Hills are altered by the thermal and chemical properties of the water flowing out of the repository.	Not applicable – Not assigned to SZ for LA	This is applicable to the UZ only.
2.2.10.08.00 Thermo-chemical Alteration of the Saturated Zone (precipitation plugs primary porosity) Thermal and chemical processes related to the emplacement of waste in the repository may alter the hydrologic properties of the saturated zone. Precipitation of zeolites, silica, or calcite are relevant processes	**2.2.10.08.0A Thermo-chemical alteration in the SZ (solubility, speciation, phase changes, precipitation/dissolution)** Thermal effects may affect radionuclide transport directly by causing changes in radionuclide speciation and solubility in the SZ, or, indirectly, by causing changes to host rock mineralogy that affect the flow path. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.	Name and description edited. SZ information merged from TSPA-SR FEP 2.2.10.06.00.
2.2.10.13.00 Density-driven Groundwater Flow (thermal) Thermal effects in the geosphere could affect the long-term performance of the disposal system. Thermal effects are most important in waste, engineered barrier system, and the disturbed zone surrounding the excavation.	**2.2.10.13.0A Repository-induced thermal effects on flow in the SZ** Thermal effects in the geosphere could affect the long-term performance of the disposal system, including effects on groundwater flow (e.g., density-driven flow), mechanical properties, and chemical effects in the SZ.	Name and description edited to be SZ specific. SZ information merged from TSPA-SR FEP 2.2.10.01.00.

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.2.11.01.00 Naturally Occurring Gases in the Geosphere Naturally occurring gases in the geosphere may intrude into the repository or may influence groundwater flow paths and releases to the biosphere. Potential sources for gas might be clathrates, microbial degradation of organic material or deep gases in general.	**2.2.11.01.0A Gas effects in the SZ** Pressure variations due to gas generation may affect flow patterns and contaminant transport in the SZ. Degassing could affect flow and transport of gaseous contaminants. Potential gas sources include degradation of repository components and naturally occurring gases from clathrates, microbial degradation of organic material or deep gases in general.	Name and description edited to be SZ specific.
2.2.12.00.00 Undetected Features This category contains FEPs related to undetected features in the geosphere that can affect long-term performance of the disposal system. Undetected but important features may be present, and may have significant impacts. These features include unknown active fracture zones, inhomogeneities, faults and features connecting different zones of rock, different geometries for fracture zones, and induced fractures due to the construction or presence of the repository.	**2.2.12.00.0B Undetected features in the SZ** This FEP is related to undetected features in the SZ portion of the geosphere that can affect long-term performance of the disposal system. Undetected but important features may be present, and may have significant impacts. These features include unknown active fracture zones, inhomogeneities, faults and features connecting different zones of rock, and different geometries for fracture zones.	FEP Split into SZ and UZ. Name and description edited to be SZ specific.
2.3.02.02.00 Radionuclide Accumulation in Soils Radionuclide accumulation in soils may occur as a result of upwelling of contaminated groundwater (leaching, evaporation at discharge location) or deposition of contaminated water or particulates (irrigation water, runoff, atmospheric deposition).	Not applicable – Not assigned to SZ for LA	This FEP is now assigned to Biosphere. Recycling of radionuclides is addressed in 1.4.07.03.0A

Table 1.2-1. SZ FEPs Considered in the TSPA-SR and TSPA-LA and Changes Between the Two Lists (Continued)

TSPA-SR FEP Name and Description	TSPA-LA FEP Name and Description	Change from SR to LA [a]
2.3.11.04.00 Groundwater Discharge to Surface Radionuclides transported in groundwater as solutes or solid materials (colloids) from the far field to the biosphere will discharge at specific "entry" points in the biosphere. Surface discharge points may be surface water bodies (rivers, lakes), wetlands, or unsaturated terrestrial soils.	**2.3.11.04.0A Groundwater discharge to surface outside the reference biosphere** Radionuclides transported in groundwater as solutes or solid materials (colloids) from the far field may discharge at specific "entry" points that are outside the reference biosphere. Natural surface discharge points, including those resulting from water table or capillary rise, may be surface water bodies (rivers, lakes), springs, wetlands, holding ponds, or unsaturated soils.	Name and description edited to include water table and capillary rise.
3.1.01.01.00 Radioactive Decay and Ingrowth Radioactive decay of the fuel in the repository changes the radionuclide content in the fuel with time and generates heat. Radionuclide quantities in the system at any time are the result of the radioactive decay and the growth of daughter products as a consequence of that decay (i.e., ingrowth). The type of radiation generated by the decay depends on the radionuclide, and the penetrating distance of the radiation depends on the type of radiation, its energy, and the surrounding medium.	**3.1.01.01.0A Radioactive decay and ingrowth** Radioactivity is the spontaneous disintegration of an unstable atomic nucleus that results in the emission of subatomic particles. Radioactive isotopes are known as radionuclides. Radioactive decay of the fuel in the repository changes the radionuclide content in the fuel with time and generates heat. Radionuclide quantities in the system at any time are the result of the radioactive decay and the growth of daughter products as a consequence of that decay (i.e., ingrowth). Over a 10,000-year performance period, these processes will produce daughter products that need to be considered in order to adequately evaluate the release and transport of radionuclides to the accessible environment.	Description edited for clarity.
3.2.07.01.00 Isotopic Dilution Mixing or dilution of the radioactive species from the waste with species of the same element from other sources (i.e., stable and/or naturally occurring isotopes of the same element) will lead to a reduction of the radiological consequences.	**3.2.07.01.0A Isotopic dilution** Mixing or dilution of the radioactive species from the waste with species of the same element from other sources (i.e., stable and/or naturally occurring isotopes of the same element) could lead to a reduction of the radiological consequences.	No change.

[a] Italicized text indicates changes made subsequent to DTN: MO0307SEPFEPS4.000 [164527].

The second step of the FEP analysis process is the screening of potentially relevant FEPs based on the criteria identified in Section 4.3 of this report. A schematic of the FEP identification and screening process is given in Figure 1.2-1. Although shown as sequential activities, iteration occurs as new information becomes available that might result in new FEPs and/or changes to the technical bases for screening.

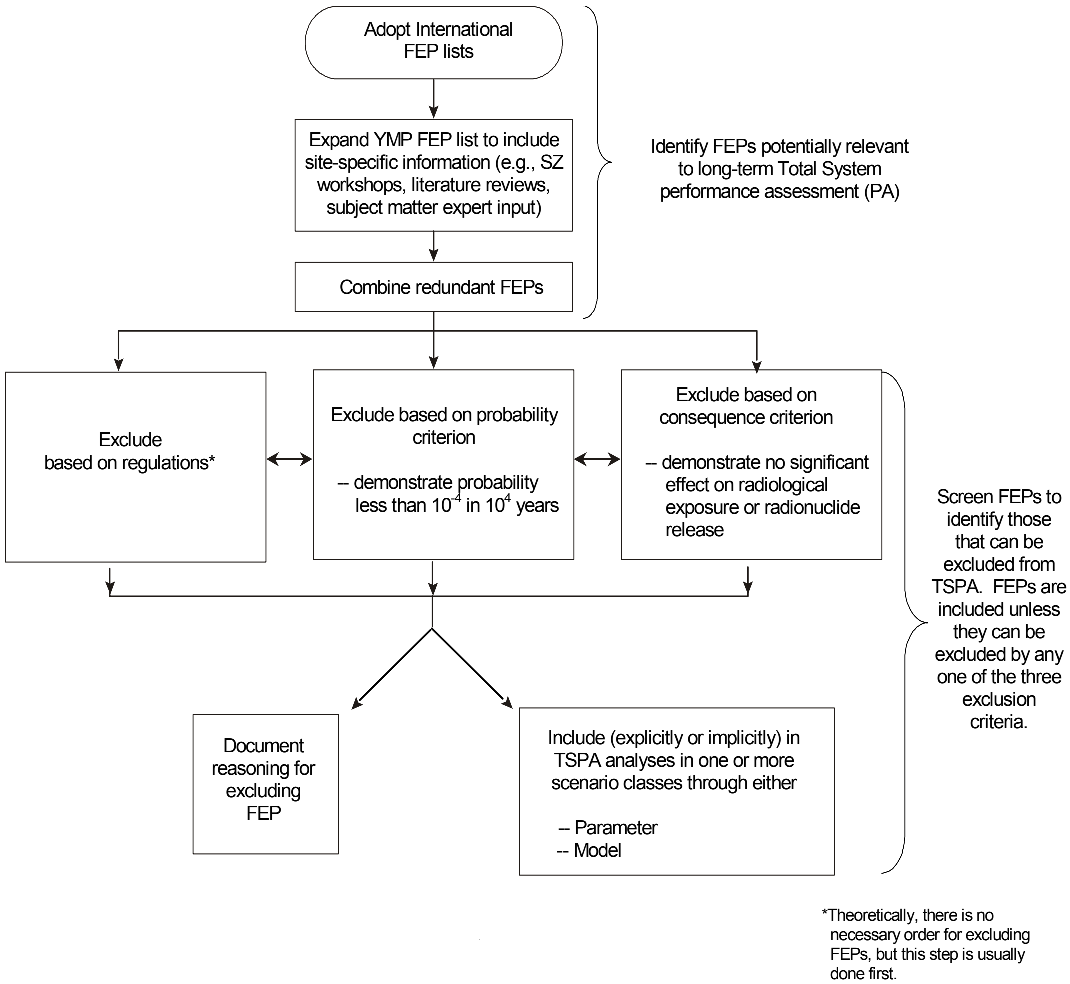

Figure 1.2-1. Development and Screening Process for FEPs Related to the Saturated Zone

Table 1.2-2 and Table 1.2-3 list all SZ included and excluded FEPs, accompanied by FEP descriptions. Additionally, Table 1.2-2 maps the included SZ FEPs to supporting SZ reports where the FEP implementation in TSPA-LA is fully documented (where the TSPA-LA disposition is developed). Table 1.2-2 also identifies supplemental supporting SZ reports where a partial treatment of the implementation of the FEP is described. For each excluded FEP, Table 1.2-3 identifies this report as the SZ report where the FEP screening argument is fully documented. It also identifies supplemental supporting SZ reports that provide additional information about the technical basis for exclusion and are used to support exclusion of that particular FEP. Note that excluded FEPs are not explicitly mentioned in the supporting SZ reports. In some cases, a FEP covers multiple technical areas and is shared with other FEP analysis reports. Shared FEPs are identified in Tables 1.2-2 and 1.2-3.

Table 1.2-2. Included Saturated Zone FEPs

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
1.2.02.01.0A	Fractures	Groundwater flow in the Yucca Mountain region and transport of any released radionuclides may take place along fractures. The rate of flow and the extent of transport in fractures are influenced by characteristics such as orientation, aperture, asperity, fracture length, connectivity, and the nature of any linings or in-fills.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *MDL-NBS-HS-000010 (BSC 2003 [167208]); MDL-NBS-HS-000011 (BSC 2003 [166262]); ANL-NBS-HS-000039 (BSC 2003 [167209])*	UZ
1.2.02.02.0A	Faults	Numerous faults of various sizes have been noted in the Yucca Mountain region and in the repository area in specific. Faults may represent an alteration of the rock permeability and continuity of the rock mass, alteration or short-circuiting of the flow paths and flow distributions close to the repository, and represent unexpected pathways through the repository.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *MDL-NBS-HS-000010 (BSC 2003 [167208]); MDL-NBS-HS-000011 (BSC 2003 [166262]; ANL-NBS-HS-000039 (BSC 2003 [167209])*	UZ
1.3.07.02.0A	Water table rise affects SZ	Climate change could produce increased infiltration, leading to a rise in the regional water table, possibly affecting the release and exposure pathways from the repository by altering flow and transport pathways in the SZ. A regionally higher water table and change in SZ flow patterns might move discharge points closer to the repository.	*MDL-NBS-HS-000021 (BSC 2003 [167651])* *NOTE:* This FEP was not explicitly listed as an included FEP in any of the supporting SZ reports. However, details of the implementation of the FEP in TSPA-LA are described in MDL-NBS-HS-000021 (BSC 2003 [167651]).	None
1.4.07.01.0A	Water management activities	Water management is accomplished through a combination of dams, reservoirs, canals, pipelines, and collection and storage facilities. Water management activities could have a major influence on the behavior and transport of contaminants in the biosphere.	MDL-NBS-HS-000021 (BSC 2003 [167651])	Biosphere
1.4.07.02.0A	Wells	One or more wells drilled for human use (e.g., drinking water, bathing) or agricultural use (e.g., irrigation, animal watering) may intersect the contaminant plume. .	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *MDL-NBS-HS-000011 (BSC 2003 [166262])*	Biosphere

Table 1.2-2. Included Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
2.2.03.01.0A	Stratigraphy	Stratigraphic information is necessary information for the performance assessment. This information should include identification of the relevant rock units, soils, and alluvium, and their thickness, lateral extents, and relationships to each other. Major discontinuities should be identified.	MDL-NBS-HS-000011 (BSC 2003 [166262], Section 6) *MDL-NBS-HS-000021 (BSC 2003 [167651]*	UZ
2.2.03.02.0A	Rock properties of host rock and other units	Physical properties such as porosity and permeability of the relevant rock units, soils, and alluvium are necessary for the performance assessment. Possible heterogeneities in these properties should be considered. Questions concerning events and processes that may cause these physical properties to change over time are considered in other FEPs.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *ANL-NBS-HS-000039 (BSC 2003 [167209]); MDL-NBS-HS-000010 (BSC 2003 [167208]); MDL-NBS-HS-000011 (BSC 2003 [166262])*	UZ
2.2.07.12.0A	Saturated groundwater flow in the geosphere	Groundwater flow in the saturated zone below the water table may affect long-term performance of the repository. The location, magnitude, and direction of flow under present and future conditions and the hydraulic properties of the rock are all relevant.	MDL-NBS-HS-000011 (BSC 2003 [166262]), Section 6.2) *ANL-NBS-HS-000021 (BSC 2003 [167211])*	None
2.2.07.13.0A	Water-conduct -ing features in the SZ	Geologic features in the saturated zone may affect groundwater flow by providing preferred pathways for flow.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *MDL-NBS-HS-000010 (BSC 2003 [167208]); MDL-NBS-HS-000011 (BSC 2003 [166262]); ANL-NBS-HS-000039 (BSC 2003 [167209])*	None
2.2.07.15.0A	Advection and dispersion in the SZ	Advection and dispersion processes may affect contaminant transport in the SZ.	MDL-NBS-HS-000010 (BSC 2003 [167208], Section 6) *MDL-NBS-HS-000011 (BSC 2003 [166262]); MDL-NBS-HS-000021 (BSC 2003 [167651]); ANL-NBS-HS-000039 (BSC 2003 [167209])*	None
2.2.07.16.0A	Dilution of radionuclides in groundwater	Dilution due to mixing of contaminated and uncontaminated water may affect radionuclide concentrations in groundwater during transport in the saturated zone and during pumping at a withdrawal well.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *MDL-NBS-HS-000010 (BSC 2003 [167208])*	None

Table 1.2-2. Included Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
2.2.07.17.0A	Diffusion in the SZ	Molecular diffusion processes may affect radionuclide transport in the SZ.	MDL-NBS-HS-000010 (BSC 2003 [167208], Section 6.2) *MDL-NBS-HS-000021 (BSC 2003 [167651]); ANL-NBS-HS-000039 (BSC 2003 [167209])*	None
2.2.08.01.0A	Chemical characteristics of groundwater in the SZ	Chemistry and other characteristics of groundwater in the saturated zone may affect groundwater flow and radionuclide transport of dissolved and colloidal species. Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may vary spatially throughout the system as a result of different rock mineralogy.	MDL-NBS-HS-000010 (BSC 2003 [167208], Section 6) *MDL-NBS-HS-000011 (BSC 2003 [166262]); ANL-NBS-HS-000021 (BSC 2003 [167211]); MDL-NBS-HS-000021 (BSC 2003 [167651])*	None
2.2.08.06.0A	Complexation in the SZ	Complexing agents such as humic and fulvic acids present in natural groundwaters could affect radionuclide transport in the SZ.	MDL-NBS-HS-000010 (BSC 2003 [167208], Section 6.2) *MDL-NBS-HS-000021 (BSC 2003 [167651])*	None
2.2.08.08.0A	Matrix diffusion in the SZ	Matrix diffusion is the process by which radionuclides and other species transported in the SZ by advective flow in fractures or other pathways move into the matrix of the porous rock by diffusion. Matrix diffusion can be a very efficient retarding mechanism, especially for strongly sorbed radionuclides, due to the increase in rock surface accessible to sorption.	MDL-NBS-HS-000010 (BSC 2003 [167208], Section 6.2) *MDL-NBS-HS-000021 (BSC 2003 [167651]); ANL-NBS-HS-000039 (BSC 2003 [167209])*	None

Table 1.2-2. Included Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
2.2.08.09.0A	Sorption in the SZ	Sorption of dissolved and colloidal radionuclides in the SZ can occur on the surfaces of both fractures and matrix in rock or soil along the transport path. Sorption may be reversible or irreversible, and it may occur as a linear or nonlinear process. Sorption kinetics and the availability of sites for sorption should be considered. Sorption is a function of the radio-element type, mineral type, and groundwater composition.	MDL-NBS-HS-000010 (BSC 2003 [167208], Section 6.2) *MDL-NBS-HS-000021 (BSC 2003 [167651])*	None
2.2.08.10.0A	Colloidal transport in the SZ	Radionuclides may be transported in groundwater in the SZ as colloidal species. Types of colloids include true colloids, pseudo colloids, and microbial colloids.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *MDL-NBS-HS-000010 (BSC 2003 [167208]); ANL-NBS-HS-000031 (BSC 2003 [162729]); ANL-NBS-HS-000039 (BSC 2003 [167209)*	None
2.2.08.11.0A	Groundwater discharge to surface within the reference biosphere	Radionuclides transported in groundwater as solutes or solid materials (colloids) from the far-field may discharge at specific "entry" points that are within the reference biosphere. Natural surface discharge points, including those resulting from water table or capillary rise, may be surface water bodies (rivers, lakes), springs, wetlands, holding ponds, or unsaturated soils.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2)	Biosphere
2.2.10.03.0A	Natural geothermal effects on flow in the SZ	The existing geothermal gradient, and spatial or temporal variability in that gradient, may affect groundwater flow in the SZ.	MDL-NBS-HS-000011 (BSC 2003 [166262], Section 6)	None

Table 1.2-2. Included Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
2.2.12.00.0B	Undetected features in the SZ	This FEP is related to undetected features in the SZ portion of the geosphere that can affect long-term performance of the disposal system. Undetected but important features may be present and may have significant impacts. These features include unknown active fracture zones, inhomogeneities, faults and features connecting different zones of rock, and different geometries for fracture zones.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2) *ANL-NBS-HS-000039 (BSC 2003 [167209])*	None
3.1.01.01.0A	Radioactive decay and ingrowth	Radioactivity is the spontaneous disintegration of an unstable atomic nucleus that results in the emission of subatomic particles. Radioactive isotopes are known as radionuclides. Radioactive decay of the fuel in the repository changes the radionuclide content in the fuel with time, and generates heat. Radionuclide quantities in the system at any time are the result of the radioactive decay and the growth of daughter products as a consequence of that decay (i.e. ingrowth). Over a 10,000-year performance period, these processes will produce daughter products that need to be considered in order to adequately evaluate the release and transport of radionuclides to the accessible environment.	MDL-NBS-HS-000021 (BSC 2003 [167651], Section 6.2)	Biosphere, UZ, WF

NOTE: Titles of the scientific analyses reports and model reports listed in this table under their document identifiers are as follows:

MDL-NBS-HS-000021, *SZ Flow and Transport Model Abstraction* (BSC 2003 [167651]); MDL-NBS-HS-000010, *Site-Scale Saturated Zone Transport* (BSC 2003 [167208]); MDL-NBS-HS-000011, *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262]); ANL-NBS-HS-000021, *Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain* (BSC 2003 [167211]); ANL-NBS-HS-000031, *Saturated Zone Colloid Transport* (BSC 2003 [162729]); ANL-NBS-HS-000039, *Saturated Zone In-Situ Testing* (BSC 2003 [167209]).

Table 1.2-3. Excluded Saturated Zone FEPs

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
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 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.	This report.	DE, UZ
1.2.04.07.0B	Ash redistribution in groundwater	Following deposition of contaminated ash on the surface, contaminants may leach out of the ash deposit and be transported through the subsurface to the compliance point.	This report.	None
1.2.06.00.0A	Hydrothermal activity	Naturally-occurring high-temperature groundwater may induce hydrothermal alteration of minerals in the rocks through which the high-temperature groundwater flows.	This report. *ANL-NBS-HS-000021 (BSC 2003 [167211])*	UZ
1.2.09.02.0A	Large-scale dissolution	Dissolution can occur when any soluble mineral is removed by flowing water, and large-scale dissolution is a potentially important process in rocks that are composed predominantly of water-soluble evaporite minerals, such as salt.	This report.	UZ
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.	This report. *ANL-NBS-HS-000021 (BSC 2003 [167211]);* *MDL-NBS-HS-000011 (BSC 2003 [166262])*	DE, UZ

Table 1.2-3. Excluded Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
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.	This report.	DE, UZ
1.3.07.01.0A	Water table decline	Climate change could produce decreased infiltration (e.g., an extended drought), leading to a decline in the water table in the saturated zone, which would affect the release and exposure pathways from the repository.	This report. *MDL-NBS-HS-000010 (BSC 2003 [167208]);* *MDL-NBS-HS-000011 (BSC 2003 [166262]);* *MDL-NBS-HS-000021 (BSC 2003 [167651]);* *ANL-NBS-HS-000021 (BSC 2003 [167211])*	UZ
1.4.07.03.0A	Recycling of accumulated radionuclides from soils to groundwater	Radionuclides that have accumulated in soils (e.g., from deposition of contaminated irrigation water or particulates) may leach out of the soil and be recycled back into the groundwater as a result of recharge (either from natural or agriculturally induced infiltration). The recycled radionuclides may lead to enhanced radionuclide exposure at the receptor	This report.	None
2.1.09.21.0B	Transport of particles larger than colloids in the SZ	Particles of radionuclide-bearing material larger than colloids could be entrained in suspension and then be transported in water flowing through the SZ.	This report. *MDL-NBS-HS-000011 (BSC 2003 [166262])* *MDL-NBS-HS-000021 (BSC 2003 [167651]);* *ANL-NBS-HS-000031 (BSC 2003 [162729])*	None
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.	This report. *MDL-NBS-HS-000021 (BSC 2003 [167651])*	DE, UZ

Table 1.2-3. Excluded Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
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.	This report.	DE, UZ
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.	This report.	DE, UZ
2.2.07.14.0A	Chemically-induced density effects on groundwater flow	Chemically-induced spatial variation in groundwater density may affect groundwater flow.	This report.	None

Table 1.2-3. Excluded Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
2.2.08.03.0A	Geochemical interactions and evolution in the SZ	Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may change through time, as a result of the evolution of the disposal system or from mixing with other waters. Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties, and sorption of contaminants. Effects on hydrologic flow properties of the rock, radionuclide solubilities, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time scale of concern.	This report. *MDL-NBS-HS-000010 (BSC 2003 [167208]); ANL-NBS-HS-000021 (BSC 2003 [167211]*	None
2.2.08.07.0A	Radionuclide solubility limits in the SZ	Solubility limits for radionuclides may be different in saturated-zone groundwater than in the water in the unsaturated zone or in the waste and EBS.	This report. *MDL-NBS-HS-000021 (BSC 2003 [167651])*	None
2.2.09.01.0A	Microbial activity in the SZ	Microbial activity in the SZ may affect radionuclide mobility in rock and soil through colloidal processes, by influencing the availability of complexing agents, or by influencing groundwater chemistry.	This report. *MDL-NBS-HS-000010 (BSC 2003 [167208])*	None
2.2.10.02.0A	Thermal convection cell develops in SZ	Thermal effects due to waste emplacement result in convective flow in the saturated zone beneath the repository.	This report. *MDL-NBS-HS-000011 (BSC 2003 [166262])*	None
2.2.10.04.0A	Thermo-mechanical stresses alter characteristics of fractures near repository	Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the fracture properties (both hydrologic and mechanical) of fractures in the rock. Cooling following the peak thermal period will also change the stress field, further affecting fracture properties near the repository.	This report.	UZ

Table 1.2-3. Excluded Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
2.2.10.04.0B	Thermo-mechanical stresses alter characteristics of faults near repository	Heat from the waste causes thermal expansion of the surrounding rock, generating changes to the stress field that may change the fault properties (both hydrologic and mechanical) in and along faults. Cooling following the peak thermal period will also change the stress field, further affecting fault properties near the repository.	This report.	UZ
2.2.10.05.0A	Thermo-mechanical stresses alter characteristics of rocks above and below the repository	Thermal-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone.	This report.	UZ
2.2.10.08.0A	Thermo-chemical alteration in the SZ (solubility, speciation, phase changes, precipitation/ dissolution)	Thermal effects may affect radionuclide transport directly by causing changes in radionuclide speciation and solubility in the SZ, or, indirectly, by causing changes to host rock mineralogy that affect the flow path. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.	This report. *MDL-NBS-HS-000021 (BSC 2003 [167651]; MDL-NBS-HS-000010 (BSC 2003 [167208])*	None
2.2.10.13.0A	Repository-induced thermal effects on flow in the SZ	Thermal effects in the geosphere could affect the long-term performance of the disposal system, including effects on groundwater flow (e.g., density-driven flow), mechanical properties, and chemical effects in the SZ.	This report. *MDL-NBS-HS-000011 (BSC 2003 [166262])*	None

Table 1.2-3. Excluded Saturated Zone FEPs (Continued)

LA FEP Number	FEP Name	YMP Description	Supporting SZ Reports Listed by Document Identifiers (SZ Reports Listed in Italics Only Partially Address the FEP)	FEP Shared With
2.2.11.01.0A	Gas effects in the SZ	Pressure variations due to gas generation may affect flow patterns and contaminant transport in the SZ. Degassing could affect flow and transport of gaseous contaminants. Potential gas sources include degradation of repository components and naturally occurring gases from clathrates, microbial degradation of organic material, or deep gases in general.	This report.	None
2.3.11.04.0A	Groundwater discharge to surface outside the reference biosphere	Radionuclides transported in groundwater as solutes or solid materials (colloids) from the far-field may discharge at specific "entry" points that are outside the reference biosphere. Natural surface discharge points, including those resulting from water table or capillary rise, may be surface water bodies (rivers, lakes), springs, wetlands, holding ponds, or unsaturated soils.	This report.	Biosphere
3.2.07.01.0A	Isotopic dilution	Mixing or dilution of the radioactive species from the waste with species of the same element from other sources (i.e., stable and/or naturally occurring isotopes of the same element) could lead to a reduction of the radiological consequences.	This report. *ANL-NBS-HS-000021 (BSC 2003 [167211])*	None

NOTE: Titles of the scientific analyses reports and model reports listed in this table under their document identifiers are as follows:

MDL-NBS-HS-000021, *SZ Flow and Transport Model Abstraction* (BSC 2003 [167651]); MDL-NBS-HS-000010, *Site-Scale Saturated Zone Transport* (BSC 2003 [167208]); MDL-NBS-HS-000011, *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262]); ANL-NBS-HS-000021, *Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain* (BSC 2003 [167211]); ANL-NBS-HS-000031, *Saturated Zone Colloid Transport* (BSC 2003 [162729]); ANL-NBS-HS-000039, *Saturated Zone In-Situ Testing* (BSC 2003 [167209]).

1.2.2 Integration of SZ FEP Screening into the TSPA-LA FEP Database

The FEP list used for the TSPA-LA screening presented in this analysis report was extracted from DTN: MO0307SEPFEPS4.000 [164527] and revised by SZ subject matter experts as documented in Table 1.2-1. In order to assist the Project during the license-review process, the ORD FEP team is constructing an electronic FEP database (i.e., the Yucca Mountain FEP database), where each FEP is entered as a separate record. Fields within each record provide unique FEP identification numbers, FEP descriptions, origin, FEP mapping to their assigned analysis and model reports, and mapping to related FEPs. Fields also provide (1) summaries of screening arguments for excluded FEPs, (2) TSPA dispositions for included FEPs, and (3) references to supporting documentation for each included and excluded FEP.

This analysis report documents the technical bases for screening arguments and TSPA dispositions for the SZ FEPs that will be incorporated into the YMP TSPA-LA FEP database. For shared FEPs, this analysis 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.

2. QUALITY ASSURANCE

The scientific analysis documented in this report was evaluated in accordance with AP-2.27Q, *Planning for Science Activities* [159604] and AP-SIII.9Q, *Scientific Analyses* [167992], and was determined to be quality-affecting and subject to the OCRWM *Quality Assurance Requirements and Description* (QARD) (DOE 2002 [159475]). Accordingly, efforts to develop this report have been conducted in accordance with the ORD quality assurance (QA) program using approved procedures identified in the *Technical Work Plan For: Saturated Zone Flow and Transport Modeling and Testing*, TWP-NBS-MD-000002 (BSC 2003 [166034]). Additional guidance has been provided in the *Scientific Processes Guidelines Manual* (BSC 2002 [160313]).

The FEPs documented herein do not themselves qualify as "Q" items listed on the Q-list (a list of structures, systems, or components that are determined to be important to safety and natural or engineered barriers that are determined to be important to waste isolation (*Q-List,* BSC 2003 [165179], Appendix A), but have the potential to affect the performance of the natural barriers included on the Q-list. The report contributes to the analysis and modeling used to support performance assessment and provides insight into the performance of natural barriers identified in the Q-List as "safety significance," reflecting their importance to waste isolation. The conclusions of this analysis report do not directly impact engineered features important to safety, as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List* [164786].

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3. USE OF COMPUTER SOFTWARE

This scientific analysis report uses no computational software; therefore, this analysis is not subject to software controls. The analyses and arguments presented herein are based on guidance and regulatory requirements, results of analyses and model reports, or technical literature.

This report was developed using only commercially available software, which is exempt from Yucca Mountain (YM) qualification procedures. Sigma Plot, Scientific Graphic Software, Version 3.06, Jandel Corporation, and Microsoft Excel 97 Software Release-1 are commercial software packages used in this analysis to display the data visually using only standard built-in mathematical functions. SigmaPlot is also used to plot data from the analysis. Except for simple built-in functions in support of simple calculations, plotting and visualization, no routines or macros were developed using this commercial software. The values used and displayed are approximate in nature and are used only to identify a range of expected values. The discussions in this report provide the technical basis to include or exclude a FEP. Any values or data used to represent included FEPs are developed in the cited reports according to their respective and appropriate QA procedures.

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4. INPUTS

Section 4.1 identifies all direct inputs (data, parameters, and technical information) used in this analysis. The status of each input is reflected on the Document Input Reference System (DIRS) report. Inputs have been obtained from controlled source documents and other appropriate sources in accordance with the controlling procedures AP-SIII.9Q, *Scientific Analysis* [167992], and AP-3.15Q *Managing Technical Product Inputs* [163414]. Section 4.2 addresses the FEPs screening criteria and relevant definitions detailed in NRC's 10 CFR 63 [156605] as identified in *Project Requirements Document* (Canori and Leitner 2003 [161770]).

4.1 DATA AND PARAMETERS

The inputs for included FEP TSPA dispositions are identified in Table 4.1-1 and are listed numerically by the DIRS number of the originating report. The inputs for excluded FEP screening arguments are identified in Table 4.1-2 and are also listed numerically by DIRS number. The nature of the FEPs screening arguments is such that cited data, parameters, and values are often used to derive reasoned arguments. Consequently, these cited inputs to the FEPs screening arguments will be affected by any anticipated cited input uncertainties of the above.

These inputs (inclusive of conclusions drawn from analyses and model reports) are considered appropriate for inclusion or exclusion of SZ FEPs (i.e., FEP screening) in the development of the SZ Flow and Transport Model Abstraction for TSPA-LA. These direct inputs to the analysis developed in this report are the best relevant and qualified inputs because they are taken from the Yucca Mountain site and region. Justifications in using those data obtained from outside sources, and not considered as established fact, are also listed in Table 4.1-2.

Table 4.1-1. Inputs for Included SZ FEPs

Applicable Section	FEP	Data Name	Originating Report
Table 1.2-1	All	List of TSPA-LA FEPs	DTN: MO0307SEPFEPS4.000 [164527]
Section 6.2.14	2.2.03.01.0A	TSPA Disposition for Stratigraphy	*Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.2)
Section 6.2.19	2.2.07.12.0A	TSPA Disposition for Saturated groundwater flow in the geosphere	
Section 6.2.35	2.2.10.03.0A	TSPA Disposition for Natural geothermal effects on flow in the saturated zone	
Section 6.2.22	2.2.07.15.0A	TSPA Disposition for Advection and dispersion in the SZ	*Site-Scale Saturated Zone Transport* (BSC 2003 [167208], Section 6.2)
Section 6.2.24	2.2.07.17.0A	TSPA Disposition for Diffusion in the SZ	
Section 6.2.25	2.2.08.01.0A	TSPA Disposition for Chemical characteristics of groundwater in the SZ	
Section 6.2.27	2.2.08.06.0A	TSPA Disposition for Complexation in the SZ	
Section 6.2.29	2.2.08.08.0A	TSPA Disposition for Matrix diffusion in the SZ	
Section 6.2.30	2.2.08.09.0A	TSPA Disposition for Sorption in the SZ	
Section 6.2.1	1.2.02.01.0A	TSPA Disposition for Fractures	*SZ Flow and Transport Model Abstraction* (BSC 2003 [167651], Section 6.2)
Section 6.2.2	1.2.02.02.0A	TSPA Disposition for Faults	
Section 6.2.10	1.3.07.02.0A *	(Implicit) TSPA Disposition * for Water table rise affects SZ	
Section 6.2.11	1.4.07.01.0A	TSPA Disposition for Water management activities	
Section 6.2.12	1.4.07.02.0A	TSPA Disposition for Wells	
Section 6.2.15	2.2.03.02.0A	TSPA Disposition for Rock properties of host rock and other units	
Section 6.2.20	2.2.07.13.0A	TSPA Disposition for Water-conducting features in the SZ	
Section 6.2.23	2.2.07.16.0A	TSPA Disposition for Dilution of radionuclides in groundwater	
Section 6.2.31	2.2.08.10.0A	TSPA Disposition for Colloidal transport in the SZ	
Section 6.2.32	2.2.08.11.0A	TSPA Disposition for Groundwater discharge to surface within the reference biosphere	
Section 6.2.42	2.2.12.00.0B	TSPA Disposition for Undetected features in the saturated zone	
Section 6.2.44	3.1.01.01.0A	TSPA Disposition for Radioactive decay and ingrowth	

* = This FEP was not explicitly listed as an included FEP in any of the supporting SZ reports. However, details of the implementation of the FEP in TSPA-LA are described in BSC 2003 [167651], Section 6.5).

Table 4.1-2. Input for Excluded SZ FEPs

Where Used	FEP Number	Data Name	Used From	Originating Report
Section 6.2.9	1.3.07.01.0A	1) Past climate fluctuations are cyclical and are propagated through the UZ to SZ. 2) Calcite crystal formation is a function of the degree of saturation. 3) Evidence of past water table elevations is seen in crystal morphology and growth in Browns Room. 4) Crystal morphology in Browns Room indicates that the water table dropped by at least 6 m between 53,000 and 92,000 years ago. 5) The current climate represents an extremely arid condition.	Entire and Figure 6	"Paleoclimatic Inferences from a 120,000-Yr Calcite Record of Water-Table Fluctuation in Browns Room of Devils Hole, Nevada." *Quaternary Research* (Szabo, B.J.; Kolesar, P.T.; Riggs, A.C.; Winograd, I.J.; and Ludwig, K.R. 1994. [100088])
Intended Use Justification: 1) Authors considered as experts in the field of paleo-climatology. 2) Journal publication that, as a prerequisite for publication, has gone through rigorous peer review. 3) Information in this article widely used in other Yucca Mountain documents.				
Section 6.2.4	1.2.04.07.0B	Equation for radioactive decay.	Chapter 14, Equation 14.11	*Physical and Chemical Hydrogeology* (Domenico, P.A. and Schwartz, F.W. 1990 [100569])
Sections 6.2.4, 6.2.6	1.2.04.07.0B, 1.2.09.02.0A	1) Carbonate and halite solubilities; 2) volcanic rocks tend to weather to clay minerals with a relatively small amount of silica going into solution; 3) equation for retardation factor.	Pages 106, 404	*Groundwater* (Freeze, R.A. and Cherry, J.A. 1979 [101173])
Sections 6.2.7, 6.2.16, 6.2.17, 6.2.18	1.2.10.01.0A, 2.2.06.01.0A, 2.2.06.02.0A, 2.2.06.02.0B	Probability and degree of displacement for the Solitario Canyon Fault.	Figure 8-3	*Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (CRWMS M&O 1998 [103731])
Section 6.2.16	2.2.06.01.0A	Probability and degree of displacement for the Bow Ridge Fault.	Figure 8-2	
Section 6.2.16	2.2.06.01.0A	Nine regional and fault hazard displacement zones within the YM region.	Figure 4-9	
Sections 6.2.7, 6.2.16, 6.2.17, 6.2.18	1.2.10.01.0A, 2.2.06.01.0A, 2.2.06.02.0A, 2.2.06.02.0B	A projected 2 to 4 m mean fault displacement for majority of faults in Yucca Mountain Project (YMP) vicinity at a 1E-8 annual exceedance probability.	Section 8.2	
Sections 6.2.7, 6.2.16, 6.2.18	1.2.10.01.0A, 2.2.06.01.0A, 2.2.06.02.0B	Mean displacement in host rock is less than 0.1 cm for a 1E-08 annual exceedance probability between Solitario Canyon and the Ghost Dance Faults and within the repository's elevation.	Section 8	
Intended Use Justification: 1) Authors considered as experts in the field of seismology. 2) This is an expert elicitation document. 3) Information in this article widely used in other Yucca Mountain documents.				

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Sections 6.2.7, 6.2.16, 6.2.17	1.2.10.01.0A, 2.2.06.01.0A, 2.2.06.02.0A	1) Predicted rise in water table given future seismic events. 2) Numerical results using a seismic dislocation model indicate the maximum rise in the water table would be approximately 10 m. 3) Results from the regional stress model approach indicated a maximum water table rise of 50 m. 4) Predicted seismic events within the YM region over the next 10,000 years will not alter the large and globally extensive stresses imposed in the rock and in effect over the past 10-15 million years.	Chapter 5	*Ground Water at Yucca Mountain, How High Can It Rise? Final Report of the Panel on Coupled Hydrologic/Tectonic /Hydrothermal Systems at Yucca Mountain* (National Research Council. 1992. [105162]) * Located within DTN: MO0310INPDEFEP.000 [165880]
Intended Use Justification: 1) Council consists of experts in their respective geoscience fields. 2) Information in this article widely used in other Yucca Mountain documents.				
Sections 6.2.3, 6.2.5, 6.2.8	1.2.04.02.0A, 1.2.02.02.0A, 1.2.06.00.0A	Grants Ridge and Paiute Ridge igneous activity produced only localized changes in rock mineralogy.	Section 5, pages 57 and 74	*Synthesis of Volcanism Studies for the Yucca Mountain Site Characterization Project* (CRWMS M&O 1998 [105347]) * *Located within DTN: MO0310INPDEFEP.000 [165880]
Section 6.2.8	1.2.10.02.0A	An intruding dike chemically and mineralogically alters the parent rock within a few meters to a few tens of meters within the intruding dike parent rock interface.	Section 5, pages 1-2	
Section 6.2.8	1.2.10.02.0A	Paiute Ridge intrusive/extrusive center that formed during a brief magmatic pulse representing a single volcanic event.	Entire	"Paleomagnetic Record of a Geomagnetic Field Reversal from Late Miocene Mafic Intrusions, Southern Nevada." *Science* (Ratcliff, C.D.; Geissman, J.W.; Perry, F.V.; Crowe, B.M.; and Zeitler, P.K. 1994 [106634])
Intended Use Justification: 1) Journal publication that, as a prerequisite for publication, has gone through rigorous peer review. 2) Information in this publication widely used in other Yucca Mountain documents.				
Section 6.2.13	2.1.09.21.0B	Viscosity of water value.	Page 715	*Data Book on the Viscosity of Liquids* (Viswanath, D.S. and Natarajan, G. 1989 [129867])
Section 6.2.13	2.1.09.21.0B	Density of water value.	Page 534	*Fluid Mechanics* (Streeter, V.L. and Wylie, E.B. 1979 [145287])

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Sections 6.2.33, 6.2.41	2.2.09.01.0A 2.2.11.01.0A	Organic carbon levels in YM wells.	Table S01053003	*Field, Chemical and Isotopic Data from Wells in Yucca Mountain Area, Nye County, Nevada, Collected Between 12/11/98 and 11/15/99.* DTN: GS010308312322.003 [154734] (Table S01053003)
Sections 6.2.4, 6.2.21	1.2.04.07.0B, 2.2.07.14.0A	Expected volume of groundwater is to be used in determining RN concentration in contaminant plume equals 3,000 acre-feet per year.	63.332	10 CFR 63. Energy: *Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada* [156605]
Section 6.2.26	2.2.08.03.0A	Regulations dictate present socio-economic practices are reflective of future practices.	63.305	
Sections 6.2.43, 6.2.46	2.3.11.04.0A	Reference biosphere in which the RMEI will reside; RMEI lives above the highest concentration of RN in plume.	63.2, 63.312	
Intended Use Justification: Volume of water to be used to determine RN concentrations, definitions, and projected societal futures considered in the analysis are specified in the above NRC regulation.				
Sections 6.2.3, 6.2.5, 6.2.8	1.2.04.02.0A, 1.2.02.02.0A, 1.2.06.00.0A	Paiute Ridge investigations suggest igneous activities altered rock properties within only a few tens of centimeters out from the rock/dike interface and at most a meter perpendicular to the intruding dike.	Pages 7 and 8	*Structural Control on Basaltic Dike and Sill Emplacement, Paiute Ridge Mafic Intrusion Complex, Southern Nevada* (Carter Krogh, K.E. and Valentine, G.A. 1996 [160928]) * Located within DTN: MO0310INPDEFEP.000 [165880]
Section 6.2.8	1.2.10.02.0A	Paiute Ridge investigation suggests that dike location and orientation was influenced by the orientation of the local stress field and the presence of existing faults.	Pages 7 and 8	
Intended Use Justification: 1) Authors considered as experts in the field of volcanology. 2) Information in this article widely used in other Yucca Mountain documents.				
Section 6.2.4	1.2.04.07.0B	Number of waste packages brought to the surface by a single volcanic eruption intersecting one drift.	Attachment A	*Number of Waste Packages Hit by Igneous Intrusion* (BSC 2003 [161851])
Section 6.2.4	1.2.04.07.0B	Grams and activity of radionuclides per CSNF waste package - nominal case..	Table 21, Attachment III	*Initial Radionuclide Inventories.* (BSC 2003 [161961])
Section 6.2.13	2.1.09.21.0B	Colloid filtering and settling observed in lab and field tests.	Sections 6.4.2 and 6.5	*Saturated Zone Colloid Transport* (BSC 2003 [162729])

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Section 6.2.4	1.2.04.07.0B	Approximate UZ thickness in region near hypothetical pumping well.	Borehole data	GS010908312332.002. Borehole Data from Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model. Submittal date: 10/02/2001. [163555]
Sections 6.2.3, 6.2.5	1.2.04.02.0A 1.2.06.00.0A	Igneous activity within the Yucca Mountain region is now in a relatively quiescent phase.	Section 6.2	*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769])
Section 6.2.4	1.2.04.07.0B	Probability of a dike intersecting the repository footprint–1.7 E-08/year; probability of volcanic eruption within the repository footprint, conditional on dike intersection–1.3 E-08/year; probability of such an eruptive event within 10,000 years, when dose rate is potentially significant–1.3 E-04/year.	Sections 7.1, 7.2	
Section 6.2.5	1.2.06.00.0A	Past hydrothermal areas (Calico Hills, Claim Canyon, and along the south flank of Shoshone Mountain) are not along the SZ flow path and lie north and northeast of Yucca Mountain; future igneous activity within the Crater Flat basin will typically cause minimal, highly localized basaltic dike-like intrusions.	Figure 3, Sections 6.3.2, 6.4.2	
Section 6.2.4	1.2.04.07.0B	BCDFs for selected radionuclides.	Table 6.2-5	*Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [164403])
Table 1.2-1	All	List of TSPA-LA FEPs.	Entire	DTN: MO0307SEPFEPS4.000 [164527]
Section 6.2.4	1.2.04.07.0B	Estimated recharge flux rates in upper Jackass Flats is 2.21 mm/year.	Table 6.1.3-1	*Recharge and Lateral Groundwater Flow Boundary Conditions for the Saturated Zone Site-Scale Flow and Transport Model* (BSC 2001[164648])

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Section 6.2.13	2.1.09.21.0B	RN bearing particles larger than colloids are not introduced from the UZ to the SZ.	Section 6.3.4	*Features, Events, and Processes in UZ Flow and Transport* (BSC 2003 [164873])
Section 6.2.34	2.2.10.02.0A	Thermal effects have an insignificant impact on flow in the UZ.	Section 6.8.9	
Sections 6.2.36, 6.2.38, 6.2.39	2.2.10.04.0A, 2.2.10.05.0A, 2.2.10.08.0A	Repository induced thermo-mechanical stresses on fractures, rock properties, and repository induced thermal-chemical effects on dissolution and precipitation are excluded in the UZ (near field).	Sections 6.8.12, 6.8.14	
Section 6.2.37	2.2.10.04.0B	Effects of thermal loading on faults are excluded in the near field.	Section 6.8.11	
Section 6.2.4	1.2.04.07.0B	Average volumetric moisture content for Amargosa Desert native soil.	Entire and Figure 16	*Selected Micrometerological and Soil-Moisture Data at Amargosa Desert Research Site in Nye County Near Beatty, Nevada,* (Johnson, Michael J., Charles J. Mayers, and Brian J. Andraski 2002 [165069])
Intended Use Justification: 1) USGS soil moisture data taken from site specific location. 2) Publication, that as a prerequisite for release, has gone through USGS review.				
Section 6.2.6	1.2.09.02.0A	Along the predicted SZ transport path the depth of carbonate aquifer is over 1,000 m below the current water table.	Figures 6-2 and 6-18	*Errata, Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model* (USGS 2003 [165176])

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Section 6.2.6	1.2.09.02.0A	The transport pathways in the SZ are primarily through volcanic tuffs and alluvial material.	Section 6.6.2.3	*Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262])
Section 6.2.7	1.2.10.01.0A	Calibration process includes (1) spatially varying multiple flow and transport parameters such as permeability, porosity, anisotropy, faults and fault zones, and the orientation and nature of faults to measured and interpolated water levels, and (2) sensitivity of the calibrated parameters to grid size and grid resolution.	Sections 6.5.3.2, 6.6.1, and 7.0	
Section 6.2.9	1.3.07.01.0A	Collective thickness of SZ units where most of flow and transport takes place is 300 m.	Section 6.5.3.3	
Sections 6.2.9, 6.2.13	1.3.07.01.0A, 2.1.09.21.0B	Saturated zone base case flow calculations show transport path under current and wetter climate conditions is mainly in the following units: Prow Pass, Bullfrog, and Tram subunits of Crate Flat Formation, Upper Volcanic Confining Unit, Upper Volcanic Aquifer, Undifferentiated Valley Fill and Alluvium.	Sections 6.6.2.2, 6.6.2.3	
Section 6.2.13	2.1.09.21.0B	Permeability of the confining unit between the Carbonate aquifer and the Bullfrog unit is 10E-15 m^2.	Figure 37	
Section 6.2.13	2.1.09.21.0B	The temperature range for Yucca Mountain SZ waters is approximately 20 to 55ºC, with the majority of temperatures within the upper 20 to lower 30ºC.	Section 7.4	
Section 6.2.13	2.1.09.21.0B	Carbonate Aquifer hydraulic head measurements is 752.4 m at well UE-25p#1 and 730.2 m in shallower units at approximately the same location (wells UE-25c#1, UE-25c#2, UE-25c#3).	Table 13	
Section 6.2.13	2.1.09.21.0B	Mean permeability value for the alluvium is 2E-13 m^2.	Table 23	

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Section 6.2.13	2.1.09.21.0B	On a regional scale, fracture permeability in the Bullfrog, Tram and Prow Pass units ranges over 3 orders of magnitude.	Section 6.6.1.4	*Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262]) (continued)
Section 6.2.16	2.2.06.01.0A	1) The Bow Ridge Fault is one of many faults incorporated in the Imbricate Zone. 2) Hydrological properties and dimensions of the Imbricate Zone.	Section 6.5.3.4 and Table 12	
Section 6.2.16	2.2.06.01.0A	The Imbricate Zone has relatively lower anisotropy ratios than other volcanic regions in the SZ flow domain.	Section 6.4.3.2 and Figure 7	
Section 6.2.17	2.2.06.02.0A	Solitario Canyon fault is a groundwater divide between the Yucca Mountain and Crater Flat regions.	Section 6.3.2	
Section 6.2.26	2.2.08.03.0A	1) SZ flow primarily takes place in the Prow Pass and Bullfrog units; 2) characteristics of flow in Prow Pass and Bullfrog units.	Section 6.2.4.4	
Sections 6.2.34, 6.2.40	2.2.10.02.0A, 2.2.10.13.0A	There are locations along the SZ transport path where ambient temperatures increase with depth, with some temperatures as high as 40 to 45ºC.	Table 28	
Sections 6.2.34, 6.2.36, 6.2.37, 6.2.38, 6.2.39, 6.2.40	2.2.10.02.0A, 2.2.10.04.0A, 2.2.10.04.0B, 2.2.10.05.0A, 2.2.10.08.0A, 2.2.10.13.0A	Description of model used to evaluate mountain-scale effects of thermal loading on host rock due to waste emplacement.	Section 6.5	*Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498])
Sections 6.2.34, 6.2.39, 6.2.40	2.2.10.02.0A, 2.2.10.08.0A, 2.2.10.13.0A	Thermal loading on host rock due to waste emplacement causes host rock to reach a peak temperature of 103°C around 1000 years after waste emplacement.	Section 6.5.10	

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Sections 6.2.34, 6.2.39, 6.2.40	2.2.10.02.0A, 2.2.10.08.0A, 2.2.10.13.0A	1) The thermal pulse due to waste emplacement causes water table temperatures to peak around 2,000 years. 2) Temperatures at the water table below the repository footprint vary locally between at 32 to 34ºC. 3) Beneath the repository, temperatures at the water table decrease to within 1 to 2ºC of ambient levels at about 5,000 years after waste emplacement.	Section 6.3.1 and Figures 6.3.1-6, 6.3.1-7	*Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498]) (continued)
Section 6.2.36	2.2.10.04.0A	At 10,000 years, thermal-mechanical stresses do not impart significant changes on vertical fracture permeabilities beyond 50 m below the repository.	Figure 6.5.12-2	
Sections 6.2.36, 6.2.37	2.2.10.04.0A, 2.2.10.04.0B	1) Thermally induced stresses due to waste emplacement impart compressive stresses in fractures below the repository. 2) Thermally induced stresses due to waste emplacement impart a combination of compressive and tensile stresses above the repository.	Sections 6.5.10, 6.5.11	
Sections 6.2.36, 6.2.38	2.2.10.04.0A, 2.2.10.05.0A	Model results: 1) Thermally induced mechanical stresses primarily affect vertical fractures residing between 150 m above and 70 m below the repository and approximately 100 m lateral to the repository plane; 2) Horizontal fractures located between 140 m above and 50 m below the repository are affected by thermal-mechanical stresses, but to a significantly lesser extent; 3) There are little to no changes in the permeabilities of both vertical and horizontal fractures located approximately 150 m below the repository.	Figures 6.5.12-1, 6.5.12-2, 6.5.12-3	
Sections 6.2.36, 6.2.37, 6.2.38	2.2.10.04.0A, 2.2.10.04.0B, 2.2.10.05.0A	Results indicate the highest thermally induced stresses occur at approximately 100 years within the repository horizon, are horizontal in direction, and are compressive in nature below the repository; moving away from the repository, stresses dampen.	Section 6.5.11	

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Sections 6.2.36, 6.2.37	2.2.10.04.0A, 2.2.10.04.0B	Above the repository thermally induced stresses are a combination of compressive and tensile in nature. Compressive stresses transition to tensile stresses at approximately 180 m above the repository. Changes from compressive to tensile stresses are not seen below the repository.	Sections 6.5.10 and 6.5.11	*Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498]) (Continued)
Sections 6.2.36, 6.2.38	2.2.10.04.0A, 2.2.10.05.0A	A reduction in vertically aligned fracture apertures reduces fracture permeability.	Section 6.5.12	
Section 6.2.39	2.2.10.08.0A	Modeling results indicate CO_2 concentrations just above the water table do not vary significantly during the modeled time period.	Figures 6.4-12 and 6.4-16	
Section 6.2.39	2.2.10.08.0A	Alteration of silicate bearing minerals decreases with distance from the repository. Minimal-to-no mineral alteration is seen just above the water table. Concurrently, no noticeable precipitation or dissolution of calcite bearing minerals in fracture fillings is seen.	Section 6.4.3.3 and Figures 6.4-20 through 6.4-24	
Sections 6.2.39, 6.2.40	2.2.10.08.0A, 2.2.10.13.0A	Model results show pH concentrations above the water table vary between 8.14 and 8.45. Variations in pH just above the water table are not accompanied with noticeable precipitation or dissolution of minerals such as calcite in fracture fillings.	Section 6.4.3.3.1, Figures 6.4-12 and 6.4-13; Section 6.4.3.3.2 and Figures 6.4-16 and 6.4-17; Section 6.4.3.3.3 Figure 6.4-18	
Section 6.2.13	2.1.09.21.0B	Colloid particle density (P_d) values.	Sections 5.10 and 6.3.1	*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003 [166845])

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Section 6.2.26	2.2.08.03.0A	Model assumes that the SZ groundwaters along the transport path are oxidizing from the UZ/SZ interface to the 18-km compliance boundary.	Section 6.3	*Site-Scale Saturated Zone Transport* (BSC 2003 [167208])
Section 6.2.33	2.2.09.01.0A	The range of groundwater compositions in the SZ are represented by water taken from wells UE-25p#1 and J-13 used to derive Kd distributions.	Attachment I	
Section 6.2.39	2.2.10.08.0A	In the model, no credit is being taken for sorption onto zeolites that reside along the SZ flow path.	Table 6.4-1	
Section 6.2.5	1.2.06.00.0A	Evidence of past hydrothermal mineral alteration seen in Calico Hills, Claim Canyon, and along the south flank of Shoshone	Figure 3	*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain* (BSC 2003 [167211])
Section 6.2.7	1.2.10.01.0A	Geochemical modeled flow patterns and deduced mixing zones of paleoclimate waters	Section 7.1.4	
Sections 6.2.7, 6.2.26, 6.2.33	1.2.10.01.0A, 2.2.08.03.0A, 2.2.09.01.0A	Geochemical analysis indicates the current SZ groundwater under the repository and along the SZ transport path is paleoclimate recharge water.	Section 7.1.2	
Section 6.2.9	1.3.07.01.0A	Geochemical and isotopic analyses indicate SZ groundwater along the projected flow path is between 10,000 to 16,000 years old, and its composition reflects recharge that occurred up until the late Pleistocene.	Section 7.1	
Sections 6.2.26, 6.2.33	2.2.08.03.0A, 2.2.09.01.0A	Paleoclimate recharge waters are reflective of cooler climatic conditions and cooler recharge waters 10,000 to 16,000 years old.	Section 6.3	
Section 6.2.45	3.2.07.01.0A	Examples of naturally occurring isotopes within the SZ flow domain (84S, 86S, 87S, 88S, 234U, 238U, 12C, 13C).	Section 6.7.1.2	

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Sections 6.2.3, 6.2.7, 6.2.16, 6.2.17, 6.2.18	1.2.04.02.0A, 1.2.10.01.0A 2.2.06.01.0A,	Evaluation of uncertainties in flowing interval properties.	Section 6.3, Table 6-8, Figure 6-6	*SZ Flow and Transport Model Abstraction* (BSC 2003 [167651])
Section 6.2.4	1.2.04.07.0B	Values for, Kd, bulk density, sorption, porosity, and retardation factor.	Table 6-8	
Section 6.2.4	1.2.04.07.0B	800-year SZ transport time starting below the repository footprint to compliance boundary.	Figure 6-28	
Section 6.2.9	1.2.04.07.0B	Uncertainty in the volcanic-alluvium contact zone is modeled in the SZ.	Section 6.5.2.2	
Section 6.2.13	2.1.09.21.0B	In the alluvium mean effective porosity is 0.18.	Table 6-8	
Section 6.2.13	2.1.09.21.0B	Effective porosity in SZ volcanic units is 0.01.	Section 6.5.2	
Sections 6.2.28, 6.2.39	2.2.08.07.0A, 2.2.10.08.0A	A solubility limit for each radionuclide is not implemented in the SZ.	Entire	
Section 6.2.33	2.2.09.01.0A	RN bearing SZ colloids natural inorganic ligands and inorganic constituents generated by the degradation of emplaced waste.	Sections 6.5.2.11 and 6.5.2.12	
Section 6.2.7	1.2.10.01.0A	Tectonic activity in the Yucca Mountain region is in a waning phase with the focal point moving westward.	Section 6.2.1.1	*Errata for Features, Events, and Processes: Disruptive Events* (BSC 2004 [167720])
Section 6.2.16	2.2.06.01.0A	Zone of alteration in rock can extend a few meters to tens of meters due to fault displacement.	Section 6.2.1.10	

Table 4.1-2. Input for Excluded SZ FEPs (Continued)

Where Used	FEP Number	Data Name	Used From	Originating Report
Section 6.2.17	2.2.06.02.0A	A seismically induced change in rock properties adjacent to a fault (which implicitly affects the rock's hydrologic properties) will tend to occur in a relatively narrow zone and be on the order of a few meters to, at most, tens of meters wide.	Section 6.2.1.10	*Errata for Features, Events, and Processes: Disruptive Events* (BSC 2004 [167720]) (Continued)
Sections 6.2.17, 6.2.18	2.2.06.02.0A, 2.2.06.02.0B	Energy produced from a seismic event will be dissipated along existing faults.	Section 6.2.1.10	
Sections 6.2.16, 6.2.17, 6.2.18	2.2.06.01.0A, 2.2.06.02.0A 2.2.06.02.0B	Solitario Canyon Fault's cumulative displacement is approximately 260 m where it intersects the ECRB Cross-drift; with this relatively large displacement, its zone of alteration consists of approximately a 20-m brecciated and gouge zone and seismically induced fractured area that extends tens of meters from the fault.	Section 6.2.1.10	
Section 6.2.46	1.4.07.03.0A	Regulatory basis that determines where RMEI's well is to be located and where RMEI resides.	Entire	*Adoption of Licensing Position - Paper - LP-028 DRAFT REV0F -Recycling of Radionuclides at the Location of the Reasonably Maximally Exposed Individual in the Screening Argument for the SZ FEP 1.4.07.03.0A (Recycling of Accumulated Radionuclides from Soils to Groundwater)* (Economy 2004 [167914])
Intended Use Justification: 1) Position based on NRC requirements. 2) Interpretation of regulatory based position developed by Regulatory Coordination Group.				
Section 6.2.9	1.3.07.01.0A	Prediction of a cooler and wetter glacial transition climatic condition will follow the brief monsoonal period and will persist for about 8,500 years	Section 7	*Eratta for Future Climate Analysis* (USGS 2003 [167961])
Section 6.2.13	2.1.09.21.0B	The difference between the alluvium head measurement at NC-EWDP 19D and NC-EWDP 19P is 5.3 m, the elevation difference between these 2 wells is 293 m.	Table 6-1	*Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Mode, , with 001 Errata 001 002.* (USGS 2004 [168473])

Citations marked with an * were classified as TBV in the *Errata for Features, Events, and Processes: Disruptive Events* (BSC 2004 [167720], Section 4.1.1), 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.

Table 4.1-3. Other Regulations Used in This FEP AMR

Where Used	Data Name	Originating Report
Section 4.3.1	Low probability criterion.	10 CFR 63. Energy: *Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada*. [156605] (63.312, 63.102, 63.114, 6.3.342, 63.305, 63.302, 63.2, entire)
Section 4.3.2	Low consequence criteria.	
Section 4.3.3.1	Reference biosphere and geologic setting.	
Section 4.3.3.2	Characteristics of the RMEI to be used in exposure calculations, distance from the repository to the receptor	
Section 5.3	Justification for assumption that potential and naturally occurring geologic and climatic events (but perhaps not necessarily the magnitude) have occurred at least once in the past within the geologic record used as the basis for the TSPA.	
Section 1	Definition of performance assessment, provisions followed, FEPS analysis issued to follow provisions	
Section 1	Criteria specified in regulations.	

4.2 CRITERIA

4.2.1 Acceptance Criterion for FEP Identification

The NRC provides guidance in the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [163274], Section 2.2.1.2.1.3) on the screening process to exclude FEPs as follows:

> **"Acceptance Criterion 1: The Identification of an Initial 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."

How Addressed

FEPs related to the SZ flow and transport processes evaluated in this report are listed in Section 1, Tables 1.2-2 and 1.2-3, of this report. Identified on the two tables are those SZ Analysis Model Reports (AMRs) that provide supporting technical discussions relevant to a specific FEP. Documentation of the evolution of the YMP FEP list is provided in Section 1.2.1.

4.2.2 Acceptance Criterion for FEP Screening

The NRC (2003 [163274], Section 2.2.1.2.1.3) stipulates Acceptance Criterion 2 to be:

> **"Acceptance Criterion 2: Screening of the Initial List of Features, Events, and Processes Is Appropriate**
>
> The U.S. Department of Energy 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;
>
> The U.S. Department of Energy 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, 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; and
>
> The U.S. Department of Energy 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."

How Addressed

The above criterion permits an exclusion argument for FEPs that are not consistent with the regulations because of waste characteristics, repository design, or site characteristics, provided there is adequate rationale and justification. Additionally, a FEP may be excluded from TSPA-LA if it is demonstrated that the likelihood of a specific occurrence is below the quantitative probability of one chance in 10,000 of occurring over a period of 10,000 years. The final criterion permits exclusion of FEPs that do not significantly change radiological exposure to the reasonably maximally exposed individual and release to the accessible environment, provided there is adequate technical basis in accompanying discussions or calculations, including the use of either bounding or representative estimates. The sequence implemented in excluding a SZ FEP is provided in Section 6.1. Generally, a regulatory-type screening criterion is examined first, followed by a screening rationale based on either a low-probability or a low-consequence criteria. In Section 6.2 are brief discussions, labeled as *Screening Arguments*, providing the rationale behind excluding a FEP. A summary of Screening Arguments and the exclusion criterion is provided in Section 7, Table 7.1-1.

4.3 REGULATORY BASIS FOR NRC GUIDANCE

This scientific analysis report complies with the NRC's criteria for FEP screening, given in 10 CFR Part 63 [156605]. The criteria that can be used to exclude a FEP from TSPA-LA are given in the following subsections.

4.3.1 Low-Probability Criterion

The low-probability criterion is explicitly stated in 10 CFR Part 63, Section 114(d) [156605]:

> "Consider only events that have at least one chance in 10,000 of occurring over 10,000 years."

and supported by 10 CFR Section 63.342 [156605]:

> "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 low-probability criterion (i.e., very unlikely FEPs) is stated as less than one chance in 10,000 of occurring in 10,000 years ($10^{-4}/10^{4}$ year). As explained in Assumption 5.2, an equivalence of 10^{-8} annual-exceedance probability is assumed by the DOE.

Furthermore, it is stated in Section 63.342 [156605] that:

> "DOE's assessments for the human intrusion and ground-water protection standards should not include consideration of unlikely features, events, and processes, or sequences of events and processes, i.e., those that are estimated to have less than one chance in 10 and at least one chance in 10,000 of occurring within 10,000 years of disposal."

As explained in Assumption 5.2, this criterion for unlikely FEPs corresponds to an annualized probability of less than 10^{-5}, but greater than or equal to 10^{-8}, which is the lower boundary for very unlikely events.

4.3.2 Low-Consequence Criteria

Criteria for low-consequence screening arguments are provided in 10 CFR Part 63 [156605], Section 114(e) and (f), which indicates that performance assessments shall:

> "(e) 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."

> "(f) 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."

This is supported by 10 CFR 63.342 [156605]:

> "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."

The terms “significantly changed” and “changed significantly” are undefined terms in the NRC’s regulations. The absence of significant change is inferred for FEPs screening purposes to be equivalent to having negligible or no effect. Because the relevant performance measures differ for different FEPs (e.g., effects on performance can be measured in terms of changes in concentrations, flow rates, travel times, or other measures as well as overall exposure to the reasonably maximally exposed individual (RMEI), and release to the accessible environment), there is no single quantitative test of “significance.”

Some FEPs have a beneficial effect on the TSPA, as opposed to an adverse effect. As identified in 10 CFR 63.102(j) [156605], the concept of a performance assessment includes that:

> “The features, events, and processes considered in the performance assessment should represent a wide range of both beneficial and potentially adverse effects on performance (e.g., beneficial effects of radionuclide sorption; potentially adverse effects of fracture flow or a criticality event). Those features, events, and processes expected to materially affect compliance with [10 CFR] 63.113(b) or be potentially adverse to performance are included, while events (event classes or scenario classes) that are very unlikely (less than one chance in 10,000 over 10,000 years) can be excluded from the analysis. …”

The Yucca Mountain Review Plan, NUREG-1804 (NRC 2003 [163274], Section 2.2.1), states that:

> “In many regulatory applications, a conservative approach can be used to decrease the need to collect additional information or to justify a simplified modeling approach. Conservative estimates for the dose to the reasonably maximally exposed individual may be used to demonstrate that the proposed repository meets U.S. Nuclear Regulatory Commission regulations and provides adequate protection of public health and safety. …The total system performance assessment is a complex analysis with many parameters, and the U.S. Department of Energy may use conservative assumptions to simplify its approaches and data collection needs. However, a technical basis … must be provided.”

On the basis of these statements, those FEPs that are demonstrated to have only beneficial effects on the radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, can be excluded on the basis of low consequence because they have no adverse effects on performance.

4.3.3 By-Regulation Criteria

Regulations that specify characteristics, concepts, and definitions may serve as the basis for exclusion of FEPs by regulation. These include the characteristics, concepts and definitions pertaining to the reference biosphere and geologic setting (see Section 4.3.3.1), climatic cycle (see Section 4.3.3.1), and the RMEI (see Section 4.3.3.2). Explicit in 10 CFR Section 63.305(c) [156605] is the ability to predict the evolution of a future geologic and hydrologic setting and climatic condition given current knowledge of these natural processes.

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 accompanying geographical constraints or constrain the future state of the geologic setting and evaluate whether there is a potentially significant consequence of such events.

4.3.3.1 Reference Biosphere, Geologic Setting, and Climate

NRC regulations 10 CFR Part 63, [156605] and Environmental Protection Agency (EPA) regulations 40 CFR Section 197.15 (64 FR 46976 [105065]) specify assumptions (which, in effect, serve as criteria) pertinent to screening many of the SZ FEPs regarding the reference biosphere and geologic setting. Per 10 CFR Section 63.2 [156605], 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."

An assumption pertaining to the characteristics of the reference biosphere is presented in 10 CFR Section 63.305(a) [156605]:

> "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."

This assumption is important in that it echoes the regulations at 10 CFR Section 63.305(b) [156605] that:

> "DOE should not project changes in society, the biosphere (other than climate), human biology, and increase or decreases of human knowledge or technology."

Consequently, by definition, changes to soils, topography, flora, fauna, and human activities must be consistent with present knowledge of the conditions in the region.

Furthermore, 10 CFR Section 63.305(d) [156605] states that:

> "Biosphere pathways must be consistent with arid or semi-arid conditions."

With regard to evaluation of changes in the geologic setting and climate, 10 CFR Section 63.305(c) [156605] states that:

> "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."

This criterion requires that evolution of the geologic and hydrologic system and climate cycle be considered based on present knowledge of the factors that could affect the Yucca Mountain disposal system.

Guidance to assumptions pertaining to the characteristics of the reference biosphere and geologic setting, and adopted in this report, is presented in the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [163274]), Section 2.2.1.3.12.4 (2)):

> "Specific features, events, and processes have been included in the analyses, and appropriate technical bases have been provided for inclusion or exclusion, in compliance."

4.3.3.2 Reasonably Maximally Exposed Individual (RMEI)

The characteristics of the RMEI to be used in exposure calculations are given at 10 CFR Section 63.312 (a, b, c, d, and e) [156605]. Pertinent to the SZ FEPs is the criteria in 10 CFR Section 63.312(a) [156605] that the RMEI:

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

For the SZ FEPs, the distance from the repository to the receptor is a criterion of primary interest. From 10 CFR Section 63.302 [156605]:

> "Accessible environment means any location outside the controlled area."

Moreover, the controlled area is defined as:

> "(1) The surface area, identified by passive institutional controls, that encompasses no more than 300 square kilometers (km^2). 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 5 km from the repository footprint in any other direction; and,
>
> (2) The subsurface underlying the surface area."

The preamble to 10 CFR 63 (66 FR 55732 [156671], p. 55753) states 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 Nevada Test Site (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 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) [156605]) 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 [156605]).

4.4 CODES AND STANDARDS

This analysis report falls under the requirements outlined for *Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada* given in the 10 CFR Part 63 [156605].

5. ASSUMPTIONS

For each assumption made in this analysis, a description of where it is applied and the justification for the assumption is discussed in the following subsections.

5.1 ASHFALL LEACHING AND SZ TRANSPORT

The following assumptions are made to estimate the potential impact of leaching contaminants from ashfall on the release to the accessible environment (FEP 1.2.04.07.0B, Section 6.2.4).

A volcanic eruption occurs immediately after waste emplacement.

Justification: This is equivalent to assuming that the volcanic eruption occurs immediately after waste emplacement, thus maximizing the impact of short-lived radionuclides, with regard to the timing of the release, contributing to radionuclide exposure to the RMEI. No further verification is needed.

5.2 PROBABILITY CRITERION

The following assumption is applicable to FEPs related to seismic and igneous activity. They include FEPs 1.2.04.02.0A–Igneous activity changes rock properties (Section 6.2.3); 1.2.04.07.0B–Ash redistribution in groundwater (Section 6.2.4); 1.2.10.01.0A–Hydrologic response to seismic activity (Section 6.2.7); 1.2.10.02.0A–Hydrologic response to igneous activity (Section 6.2.8); 2.2.06.01.0A–Seismic activity changes porosity and permeability of rock (Section 6.2.16); 2.2.06.02.0A–Seismic activity changes porosity and permeability of faults (Section 6.2.17); and 2.2.06.02.0B–Seismic activity changes porosity and permeability of fractures (Section 6.2.18).

For post-closure naturally occurring FEPs, it is assumed that the probability criterion can also be expressed as an annual exceedance probability, which is defined as the probability that a specified value (such as ground motions or fault displacement) will be exceeded during one year. More specifically, a stated probability screening criterion of one chance in 10,000 in 10,000 years ($10^{-4}/10^{4}$ year) is assumed equivalent to a 10^{-8} annual-exceedance probability or annual-exceedance frequency, and a stated definition of unlikely events as having one chance in 10 in 10,000 years ($10^{-1}/10^{4}$ year) 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 (CRWMS M&O 2000, Glossary [142321]) and the following justification also is presented in that referenced document. 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 [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 of time depends only on the length of the time period. The use of this assumption is justified in *Characterize Framework for Seismicity* *and Structural Deformation at Yucca Mountain, Nevada* (CRWMS M&O 2000 [142321]), which indicates that assuming that the behavior of the earth is generally Poissonian or random is the underlying assumption in all probabilistic hazard analyses.

In other words, naturally occurring events (e.g., earthquakes, meteorite impacts) 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 natural processes that occur over long time spans, assuming annual equivalence over a 10,000-year period (a relatively short time span) is reasonable and consistent with the basis of probabilistic hazard analyses. Therefore, no further confirmation is required.

5.3 EVOLUTION OF THE GEOLOGIC SETTING AND CLIMATE

Potential and naturally occurring geologic and climatic events (but perhaps not necessarily the magnitude) have occurred at least once in the past within the geologic record used as the basis for the TSPA-LA.

<u>Justification</u>: This assumption is justified because it is consistent with the regulation used as direct input. At 10 CFR Section 63.305(c) [156605], DOE is directed to "…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."

See also the discussion on the regulatory concepts for *reference biosphere* and *geologic setting* provided in Section 4.3.3.1. Because it is required by regulation, no further confirmation is necessary.

The implication of this assumption is that any discernible impacts or processes related to past events on the site setting are presumably reflected in the present knowledge of natural processes that form the basis of the TSPA. If the subject FEP phenomena are not reflected or discernible in the data used to describe past settings, they are either of "low consequence" or "low probability" and can be excluded from consideration.

<u>Use</u>: This assumption is used throughout and is particularly germane for FEPs 1.3.07.01.0A–Water table decline (Section 6.2.9); 1.3.07.02.0A–Water table rise affects SZ (Section 6.2.10); 2.2.06.01.0A–Seismic activity changes porosity and permeability of rock (Section 6.2.16); 2.2.06.02.0A–Seismic activity changes porosity and permeability of faults (Section 6.2.17); 2.2.06.02.0B–Seismic activity changes porosity and permeability of fractures (Section 6.2.18); 2.2.08.01.0A–Chemical characteristics of groundwater in the SZ (Section 6.2.25); and 2.2.08.03.0A–Geochemical interactions and evolution in the SZ (Section 6.2.26). It is particularly germane to FEPs related to processes or phenomena that, speculatively, could affect future states of the system, but for which the magnitude and/or coupling to the effect on the repository is not well defined, or for which consequences in present time are known to be minor.

6. ANALYSIS

6.1 APPROACH

To ensure clear documentation of the treatment of potentially relevant future states of the system, the DOE has chosen to adopt a FEP analysis and scenario development process based on the methodology developed by Cranwell et al. (1990 [101234]) for the NRC. The approach is fundamentally the same as that used in many performance assessments including DOE's Waste Isolation Pilot Plant (DOE 1996 [100975]), PAs by the Nuclear Energy Agency, and by other radioactive waste programs internationally (e.g., Skagius and Wingefors 1992 [101018]). Regardless of the method chosen for the performance assessment, the FEP analysis process involves (a) the development of a FEP list, and (b) the screening of the FEPs for inclusion or exclusion.

The development of the Yucca Mountain FEP list for LA is documented in the *Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [158966] and supplemented by the KTI Letter Report *Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [165394], Section 3.2). Forty-six (46) FEPs relevant to the SZ were identified for assignment and analysis by knowledgeable SZ subject-matter experts, the results of which are presented in this analysis report. These FEPs were identified in the preliminary TSPA-LA FEP list (DTN: MO0307SEPFEPS4.000 [164527]) and were revised (see italicized changes in Table 1.2-1) during subsequent evaluation by the SZ subject-matter experts. Alternative classification and assignments of the FEPs are entirely possible but would still be based on subjective judgment. Alternative approaches for determining probabilities and consequences used as a basis for screening are discussed in Section 6.2 under the individual FEP analyses.

The NRC requires the consideration and evaluation of FEPs as part of the performance assessment activities. More specifically, the NRC regulations allow the exclusion of FEPs from the TSPA if they can be shown to be of low probability or of low consequence. The specified criteria can be summarized in the form of the two following 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) [156605]).

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) [156605]).

Additionally, the Acceptance Criteria in the *Yucca Mountain Review Plan* (NRC 2003 [163274], Section 2.2.1.2.1.3) 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. If there is a negating condition in any of the three screening criteria, the FEP is *Excluded* from the TSPA-LA model.

Evaluation of the FEPs against these screening statements may be done in any order. In practice, by-regulation criteria were examined first, and then either low probability or low consequence criteria were examined. FEPs that were retained on one criterion (e.g., regulatory guidance) were also considered against the other criteria (probability and consequence). Consequently, the application of the analyst's judgment regarding the order in which to apply the criteria does not affect the final decision. Allowing the analyst to choose the most appropriate order to apply the criteria prevents needless work, such as developing quantitative probability arguments for low-consequence events or complex consequence models for low-probability events.

Regardless of the specific approach chosen to perform the screening, the screening process is in essence a comparison of the FEP against the set of criteria specified in Section 4.3. Consequently, the outcome of the screening is independent of the particular methodology or assignments selected to perform the screening.

If applicable, alternative conceptual models and uncertainty are addressed in the supporting documentation cited in the individual FEP evaluations. For included FEPs, alternative conceptual models are incorporated into the TSPA-LA based on their development and evaluation in the supporting model report. For excluded FEPs, the discussions of the alternative conceptual models from the supporting model report are cited in the screening decision for each FEP.

6.2 ANALYSIS OF SZ FEPS

The following subsections summarize the screening of SZ FEPs. For *Included* FEPs, the TSPA disposition describes the technical basis for and the implementation of the FEP within the TSPA-LA models. For *Excluded* FEPs, the screening argument describes the technical basis relevant to the exclusion criteria. 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 of the FEP. The full technical basis for these shared FEPs is addressed collectively by all of the sharing FEP AMRs.

6.2.1 Fractures (1.2.02.01.0A)

FEP Description: Groundwater flow in the Yucca Mountain region and transport of any released radionuclides may take place along fractures. The rate of flow and the extent of transport in fractures are influenced by characteristics such as orientation, aperture, asperity, fracture length, connectivity, and the nature of any linings or infills.

Descriptor Phrases: Fractures in the SZ; Fractures (characteristics); Fractures (infills)

Screening Decision: Included

Related FEPs: 1.2.02.02.0A, 1.2.10.01.0A, 2.2.03.01.0A, 2.2.03.02.0A, 2.2.06.01.0A, 2.2.06.02.0A, 2.2.06.02.0B, 2.2.07.13.0A, 2.2.10.04.0A, 2.2.12.00.0B

TSPA Disposition:
Groundwater flow through fractures in the volcanic units is included in the Saturated Zone Flow and Transport (SZFT) model (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.2). Groundwater flow through fractures in the volcanic units is modeled in the *Site Scale Saturated Zone Flow Model* (BSC 2003 [166262], Sections 6.3.3, 6.5.1, 7, 8, and Figures 6.4-1 and 6.2-2) using an effective continuum approach (BSC 2003 [166262], Section 6.5.1) implemented in the numerical code FEHM V 2.20 (STN: 10086-2.20-00, LANL 2003 [161725]). In the SZ Transport Abstraction Model and the SZ one-dimensional (1-D) Transport Model (both discussed in BSC 2003 [167651], Section 6.5) variability in the groundwater specific discharge, due to variability in fracture permeability and orientation, is modeled by scaling the base case specific discharge flow field (BSC 2003 [166262], Section 8) with the stochastically sampled scaling parameters for groundwater specific discharge (GWSPD), and horizontal anisotropy in the volcanic units (HAVO), to stochastically produce 3-D flow fields. Additionally, the characteristics of the fracture properties such as fracture orientation, aperture size, degree of infilling, and tortuosity are modeled through the following probabilistically modeled parameters; groundwater specific discharge (GWSPD), flowing interval spacing in volcanics (FISVO), flowing interval porosity in the volcanic units (FPVO), longitudinal dispersivity (LDISP), horizontal anisotropy in the volcanic units (HAVO), colloid partitioning coefficients in the volcanics (COLVO), and the sorption coefficients onto colloids (Kd_Pu_Col, Kd_Am_Col, Kd_Cs_Col). The above parameters are described in the BSC 2003 ([167651], Sections 6.5.2.1, 6.5.2.4, 6.5.2.5, 6.5.2.9, 6.5.2.10, 6.5.2.12, and 6.5.2.15).

6.2.2 Faults (1.2.02.02.0A)

FEP Description: Numerous faults of various sizes have been noted in the Yucca Mountain Region and in the repository area in specific. Faults may represent an alteration of the rock permeability and continuity of the rock mass, alteration or short-circuiting of the flow paths and flow distributions close to the repository, and represent unexpected pathways through the repository.

Descriptor Phrases: Faults (displacement); Faults (dip-slip); Faults (strike-slip); Faults (detachment); Faults in the SZ

Screening Decision: Included

Related FEPs: 1.2.02.01.0A, 1.2.10.01.0A, 2.2.03.02.0A, 2.2.06.01.0A, 2.2.06.02.0A, 2.2.06.02.0B, 2.2.07.13.0A, 2.2.12.00.0B

TSPA Disposition:

Geologic features and hydrostratigraphic units are explicitly included in the *SZ Flow and Transport Model Abstraction* (BSC 2003 [167651], Section 6.2) in a configuration that accounts for the effects of existing faults, based on the hydrogeologic framework model (HFM). As discussed in *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.4), the HFM represents faults and other hydrogeologic features (such as zones of hydrothermal alteration) that affect SZ flow. Model configuration of these discrete features is developed in BSC 2003 ([166262], Section 6.3.2) and accounts for fault dip, strike, slip and detachment. Faults in the model area can dip at almost any angle, but most are high-angle faults. Given numerical flow model resolution, faults were treated as vertical features. Faults deemed important to flow near Yucca Mountain were modeled explicitly in the numerical SZ flow model. Important thrust faults were represented by repeating hydrogeologic units in the HFM.

The offsets of hydrostratigraphic units across major faults are incorporated into the model, and some key faults (e.g., Solitario Canyon fault, Highway 95 fault, and Fortymile Wash structure) are explicitly included as high- or low-permeability features. Model parameters, including horizontal anisotropy in the volcanic units (HAVO) and groundwater specific discharge (GWSPD), implicitly include the potential impacts of faults on groundwater flow and are modeled probabilistically to account for the uncertainty in hydrologic properties associated with faults and fractures in the volcanic units. The above two parameters are described in Sections 6.5.2.1 and 6.5.2.10 of BSC 2003 ([167651], Section 6.5.2.1 and 6.5.2.10). A more detailed description of the manner in which specific faults have been addressed is provided in the *Supplemental Discussion* for this FEP in this SZ FEP report.

Supplemental Discussion:

Faults fall under several distinct categories based on their hydrological impact on SZ flow paths and distributions (BSC 2003 [166262], Table 12). A list of the modeled faults (also denoted as features in BSC 2003 [166262], Section 6.4) aggregated under their hydrologic categories is given below. Note in the *Supplemental Discussion* of FEP 2.2.03.02A–Rock properties of host rock and other units, a list of all features, including faults, developed in BSC 2003 ([166262]) is given accompanied with a figure depicting their location.

(1) Zones of permeability enhancement parallel to faults and zones of permeability reduction perpendicular to faults

- **Crater Flat Fault**–This is a linear feature running north-south in the western half of the model, starting south of Claims Canyon and terminating near Highway 195, almost halfway between the western boundary of the Solitario Canyon. Vertically it extends from the top to the bottom of the model.
- **Solitario Canyon Fault Zone**–A north-south trending linear feature just to the west of Yucca Mountain. Vertically it extends from the top to the bottom of the model.
- **Solitario Canyon Fault, East Branch**–A north-northeast trending linear feature just to the west of Yucca Mountain. Vertically, it extends from the bottom of the model to the top of the model.

- **Solitario Canyon Fault, West Branch**–A north-northeast trending linear features just to the west of Yucca Mountain. Vertically, it extends from the bottom of the model to the top of the model.
- **Highway 95 Fault (West)**–This is a linear feature in the lower half of the western portion of the model. It is east-southeast trending. Vertically, it extends from the bottom to the top of the model.

(2) Fault Zones with enhanced permeability

- **Bare Mountain Fault**–This is a northwest- to southeast-trending linear feature in the southwestern corner of the model. Vertically, it extends from the bottom to the top of the model.
- **Imbricate Fault Zone**–This is a highly faulted area bounded in the west by the Ghost Dance fault, south by the Dune Wash, east by the Paintbrush Canyon fault, and to the north by the Drillhole Wash. Vertically, it extends from the top of the model down through the middle volcanics to the top of the undifferentiated units.

(3) Faults representing regions of lower permeability caused by hydrothermal alteration

- **Northern Zone (entire Claim Canyon, Calico Hills, and Shoshone Mt.)**–This zone is wedge-shaped, spanning almost the entire northern boundary (except the western corner of the northern boundary) and approximately the upper fourth of the eastern boundary. Vertically, it extends from the top to the bottom of the model.
- **Northern Crater Flat Zone**–This wedge-shaped zone is at the northern third of the western boundary of the model. Vertically, it extends from the top to the bottom of the model.
- **Claim Canyon Caldera**–These zones span much of the northern boundary of the model, extending south as triangular shapes and terminating north of the Yucca Wash. Vertically, it extends from the top to the bottom of the model.
- **Shoshone Mt. Zone**–These two zones are in the northeastern corner of the model. They extend from the top of the carbonate aquifer up to the top of the model. Vertically, it extends from the top to the bottom of the model.
- **Calico Hills Zone**–These two zones are near the eastern end of the model, south of the Shoshone Mountain Zones, at approximately the same northing as the Yucca Wash. Vertically, it extends from the top to the bottom of the model.

6.2.3 Igneous Activity Changes Rock Properties (1.2.04.02.0A)

FEP Description:	Igneous activity near the underground facility causes extreme changes to 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)

Screening Decision: Excluded–Low consequence

Related FEPs: 1.2.10.02.0A, 1.2.06.00.0A, 1.2.04.07.0A

Screening Argument:

Volcanism and igneous activity within the Yucca Mountain region has undergone two developmental phases. Silicic volcanism was dominant between 15 and 11 million years ago (m.y.a.), coincident with plate extension and an episode of major caldera formation in the Great Basin Region. As extension rates declined, silicic volcanism was replaced with basaltic volcanism. Basaltic volcanic caldera building and igneous activity within Yucca Mountain region commenced between 13 and 11 m.y.a. Post-caldera building igneous activity within the Yucca Mountain peaked approximately 7 m.y.a. Volcanism and igneous activity within the Yucca Mountain region is now in a relatively quiescent phase; any future igneous activity in the Yucca Mountain region will be basaltic in origin (*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*, BSC 2003 [163769], Section 6.2). The reduction in igneous activity is coupled with a reduction in basaltic intrusions within SZ stratigraphic units. Thus changes in existing SZ rock properties due to future basaltic intrusions will be less than the cumulative effect of igneous intrusions that occurred over the last 13 to 11 million years.

Basaltic intrusions due to igneous activity will typically be minimal and highly localized and thus cause minimal to localized changes in the physical properties (e.g., lower permeability of the intrusion relative to the matrix of the non-welded units) of the intruded rock. This is supported by investigations at the Grants Ridge analog sites, which indicate that basaltic intrusion produced only localized formation of volcanic glass within the contact zone (*Synthesis of Volcanism Studies for the Yucca Mountain Site Characterization Project,* CRWMS M&O 1998 [105347], Section 5, p.74 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). Investigations of basaltic intrusions at Paiute Ridge (Carter Krogh and Valentine 1996 [160928], pp. 7 through 8 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) suggest that igneous activities altered rock properties to only a few tens of centimeters to, at most, a meter perpendicular to an intruding dike. Since the SZ contains completely saturated pores, heat transfer will occur through both conduction and convection. The heat produced from the dike, which is a primary component in mineral alteration, will be transferred more efficiently away from the dike in the SZ compared to the UZ. Therefore, it is inferred that mineral alteration in the SZ due to a dike intrusion will be similar to that of the Grants Ridge analog sites, where mineral alteration is constrained to a narrow width on either side of the dike.

The limited, meter scale effects of mineral alteration, and possible change in flow paths, are insignificant when compared to the multi-kilometer scale changes in path length that results from existing considerations of uncertainty in fracture properties and flowing intervals. Flow and transport in the SZ is dominated by existing fractures, fracture clusters and fracture spacing, collectively labeled as flowing intervals in the SZFT model abstraction (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.3). The SZFT model evaluates uncertainties assigned to flowing interval properties such as horizontal anisotropy in the volcanic units, flowing interval spacing, flowing interval porosity in the volcanics, and longitudinal dispersion (BSC 2003 [167651], Table 6-8). Transport times through the SZ are quite sensitive to parameter uncertainty associated with flowing interval properties (only uncertainty in the specific discharge scaling parameter, which is meant to account for increased specific discharge due to a wetter climate, produces a greater variation in transport times). As an example, parameter uncertainty in flowing interval spacing results in transport times that vary by several thousands of years (Arnold et al. 2000 [166335]). The uncertainty incorporated in the horizontal anisotropy (which accounts for maximum and minimum stresses imposed on fracture clusters and faults and their orientation) results in transport paths varying by several kilometers (BSC 2003 [167651], Figure 6-6). Thus the incorporated parameter uncertainty in fracture and fault regional properties overwhelms any changes in SZ transport times and flows paths associated with localized changes in mineral alteration.

Given the scale of the SZFT model (18 km to the discharge point and the modeled 500-m model grid discretization) and the uncertainties in the flowing interval properties incorporated in BSC 2003 ([167651], Table 6-8), highly localized effects caused by igneous activity will not have significant impacts on the flux at the compliance boundary. As a result, any localized changes in flow or transport properties due to igneous activity (inclusive of geochemical changes) will not have a significant effect on the exposure to RMEI. A more detailed discussion of FEPs related to igneous activity is given in *Errata for Features, Events and Processes*: *Disruptive Events* (BSC 2004 [167720], Section 6.2.2). Therefore, changes in rock properties due to igneous activity can be excluded based on low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.4 Ash Redistribution in Groundwater (1.2.04.07.0B)

FEP Description: Following deposition of contaminated ash on the surface, contaminants may leach out of the ash deposit and be transported through the subsurface to the compliance point.

Descriptor Phrases: Leaching of contaminated ash; Redistribution of contaminated ash (pumping)

Screening Decision: Excluded–Low consequence

Related FEPs: 1.2.04.06.0A, 2.3.02.02.0A

Screening Argument:

The probability of a volcanic eruption intersecting the repository is approximately 1.3E-8/year (*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*, BSC 2003 [163769], Sections 7.1,7.2). The probability of such an eruption occurring during the first 10,000 years, when the dose rate is potentially significant, is approximately 1.3E-4 (see *Supplemental Discussion* for this FEP in this SZ FEP report). If a volcanic eruption were to occur within the repository entraining radioactive waste, contaminated radionuclide bearing ash deposited on the surface could leach and be transported through the UZ and SZ to the compliance point. Assuming the contents of six waste commercial spent nuclear fuel (CSNF) packages are entrained in the volcanic eruption (which is the median number of packages brought to the surface by a single volcanic eruption intersecting one drift (*Number of Waste Packages Hit by Igneous Intrusion,* BSC 2003 [161851], Attachment A)) and that all of the waste is uniformly distributed in the ash blanket on the ground surface, the resulting estimated conditional dose rate is 20.5mrem/year. The probability that a volcanic eruption will occur within the repository during the first 10,000 years of waste emplacement is 1.3E-04. The resulting probability-weighted dose rate due to leaching of radionuclides from contaminated ash becomes less than 2.66E-03 mrem/year (as calculated in the *Supplemental Discussion* for this FEP in this SZ FEP report). In addition, the conservative assumption is made that all radionuclides derived from the volcanic ash blanket are captured in the hypothetical pumping wells of the RMEI. This is consistent with the TSPA nominal class scenario model, in which radionuclide contamination of groundwater in the SZ is assumed to be completely captured in the groundwater usage of the hypothetical future farming community. This is significantly less than the probability-weighted doses resulting from other igneous pathways during this period (*Total System Performance Assessment for the Site Recommendation*, CRWMS M&O 2000 [153246], Section 4.2). The effects of non-uniform distribution of the ash blanket are addressed in the *Supplemental Discussion*. The effects of ashfall on SZ transport is excluded on the basis of low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

Supplemental Discussion:

For this screening analysis, it is assumed that the contents of six waste packages are entrained in the volcanic eruption and that all of the waste resulting from the eruption is uniformly distributed in the ash blanket on the ground surface. Six waste packages are the median number of packages brought to the surface by a single volcanic eruption intersecting one drift (BSC 2003 [161851], Attachment A). The six waste packages are assumed to contain CSNF, which is the most common type of waste package in the repository. The radionuclide inventory in the waste packages is assumed to be the average for CSNF at the time of waste emplacement. This is equivalent to assuming that the volcanic eruption occurs immediately after waste emplacement, an assumption that conservatively maximizes the impact of short-lived radionuclides. The inventories for key radionuclides in the erupted ash are shown in Table 6.2-1. The volcanic ash blanket is assumed to be entirely and evenly distributed in the 18-km region between the repository and the RMEI. This assumption maximizes the quantity of radionuclides that is available for transport via the SZ to the hypothetical pumping wells of the RMEI.

It is assumed that the radionuclides in the ash layer are entirely and immediately dissolved in the infiltrating groundwater along the 18-km flow path. It is also conservatively assumed that radionuclides are transported without radioactive decay in the SZ; however, radioactive decay is accounted for during transport from the ground surface to the water table. In addition, the conservative assumption is made that all radionuclides derived from the volcanic ash blanket are captured in the hypothetical pumping wells of the RMEI. This is consistent with the TSPA nominal scenario class model, in which radionuclide contamination of groundwater in the SZ is assumed to be completely captured in the groundwater usage of the hypothetical future farming community. The same groundwater volume that is used determine radionuclide concentrations in the TSPA-LA, 3,000 acre-ft/year (10 CFR 63 [156605], Subpart 63.332 (3)), is used to determine the expected value withdrawn from the RMEI's well in this analysis.

Transport of radionuclides from the ash blanket to the water table is conceptualized to occur by one-dimensional flow downward through alluvium. The groundwater velocity in the UZ above the water table is calculated using an average volumetric moisture content of 0.1. This is a reasonable average value for vegetated native soil in the region (Johnson et al. 2002 [165069], Figure 16) and is likely lower than what would occur under washes in which intermittent infiltration occurs. The calculation of groundwater velocity also uses an infiltration flux of 2.21 mm/year, which is the estimated recharge rate along Fortymile Wash in the upper Jackass Flats reach (*Recharge and Lateral Groundwater Flow Boundary Conditions for the Saturated Zone Site-Scale Flow and Transport Model,* BSC 2001 [164648], Table 6.1.3-1). In addition, the thickness of the UZ is assumed to be 100 m, which is an approximate value in the region near the hypothetical pumping wells, based on the depth to the water table in well NC-EWDP-19P (DTN: GS010908312332.002 [163555]). The average transport time from the ground surface to the water table for radionuclides is calculated as:

$$t = R_f \frac{z\theta_m}{q} \tag{Eq. 1}$$

where t is the average transport time [T], R_f is the retardation factor in the alluvium [-], z is the depth to the water table [L], θ_m is the moisture content [-], and q is the recharge flux [L/T]. The retardation factor for flow in the UZ is defined by Freeze and Cherry (1979 [101173], p. 404) as:

$$R_f = 1 + \frac{\rho_b K_d}{\phi} \tag{Eq. 2}$$

where ρ_b is the dry bulk density of the alluvium [M/L^3], K_d is the sorption coefficient [L^3/M], and ϕ is the total porosity of the alluvium [-]. The value of bulk density used in the analysis is 1.91 g/milliliter (ml) and the porosity is 0.3, which are the expected values (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Table 6-8). The median values for the sorption coefficients for the radionuclides, as taken from BSC 2003 ([167651], Table 6-8), are shown Table 6.2-1. Radionuclides will experience radioactive decay during transport in the UZ to the water table. The remaining activity of radionuclides after transport through the UZ, which can be derived from Domenico and Schwartz (1991 [100569], Equation 14.11), is:

$$A = A_0 (2^{-t/T_{0.5}}) \tag{Eq. 3}$$

where A is the activity at the water table [Curies], A_0 is the activity in the ash [Curies], and $T_{0.5}$ is the half-life of the radionuclide and t is the average transport time. Substituting Equations 1 and 2 into Equation 3 yields the activity of each radionuclide at the water table in Curies.

Note that radionuclides of Pu and Am are treated as irreversibly attached to colloids in the analysis presented here. Consequently, the retardation factor used is the median value for the retardation factor of colloids in alluvium (BSC 2003 [167651], Table 6-8). Radionuclides irreversibly attached to colloids migrate more rapidly than radionuclides reversibly attached to colloids, so this assumption is conservative with regard to estimated dose.

The SZ is conceptualized as a simplified one-dimensional flow system between the repository and the accessible environment as shown in Figure 6.2-1. In the simplified conceptual model of radionuclide transport in the SZ, uniform, one-dimensional flow is assumed to deliver the radionuclide mass to the hypothetical pumping wells of the RMEI at a steady rate. A transport time of 800 years, for a non-sorbing species, from the water table located just below the repository footprint, is taken from the analysis of SZ transport using the three-dimensional SZ Transport Abstraction Model (BSC 2003 [167651], Figure 6-28). The 800-year travel time is the approximate median transport time among the multiple realizations of SZ transport. The resulting idealized radionuclide mass breakthrough curve is shown in Figure 6.2-2. Note that the first radionuclide mass is released to the accessible environment at the time of first arrival at the water table (shown as time zero in Figure 6.2-2). The duration of the breakthrough curve is 800 years, at which time the most upstream of the radionuclide mass arrives. The average (and also peak) concentration of the non-sorbing radionuclide in the water supply of the hypothetical farming community is calculated by dividing the total radionuclide mass delivered to the SZ from the contaminated ash by the water usage over the 800 years. For those radionuclides that experience sorption and retardation in the SZ, the distribution of radionuclide mass arrival at 18 km is spread over a longer period of time, as indicated by the example shown in Figure 6.2-2. A retardation factor of two means that the arrival of radionuclide mass at 18 km is spread over about 1600 years and the radionuclide mass flux is one half of that for the non-sorbing species.

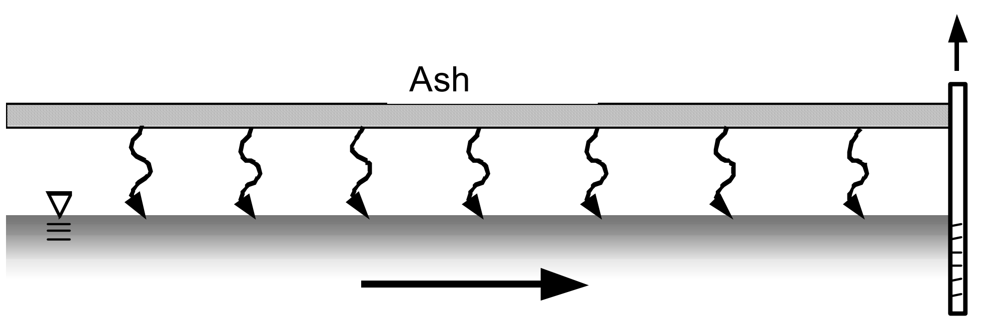

Figure 6.2-1. Cross-Section Diagram of Simplified One-Dimensional Model for Transport in the SZ of Radionuclides Leached from Volcanic Ash

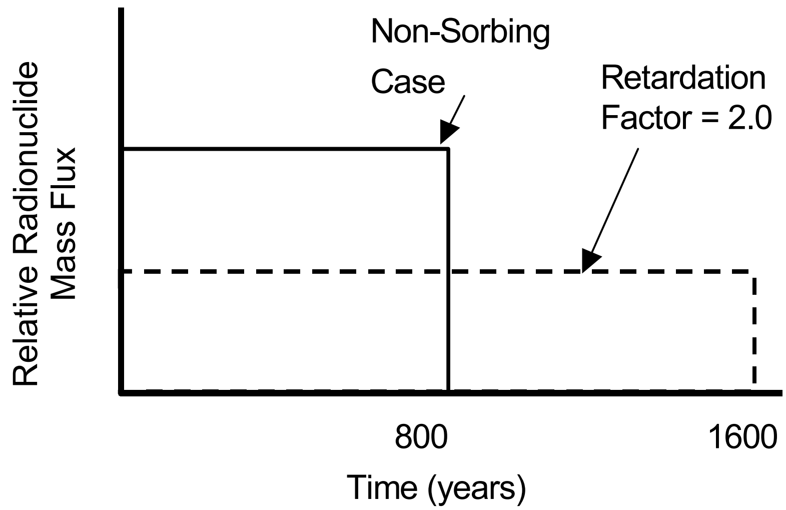

Figure 6.2-2. Example of Idealized Radionuclide Mass Breakthrough Curves at 18-km Distance Resulting from Volcanic Ash Leaching for Non-Sorbing and Sorbing Radionuclides

The estimate of dose rate from this simplified analysis is shown in Table 6.2-1. The representative volume of water for each radionuclide is calculated as the product of the expected annual groundwater usage, the 800-year travel time, and the retardation factor. The concentration is calculated by dividing the activity of the radionuclide at the water table by the representative water volume. The dose rate is calculated as the product of the average concentration and the Biosphere Dose Conversion Factor (BDCF) for each radionuclide, as shown in Table 6.2-1. Note that the values of the BDCF for these radionuclides are taken for present climatic conditions, which are higher than the values for future, wetter conditions. The resulting estimated dose is thus higher and conservative relative to estimated future conditions for most of the next 10,000 years.

The resulting estimated conditional total dose rate is 20.5 mrem/year. As shown in Table 6.2-1, the calculated dose rate from shorter-lived radionuclides (e.g., ^{90}Sr and ^{137}Cs) is zero due to decay during transport to the water table following leaching from the ash layer. The largest single contribution to the total calculated dose rate is from ^{239}Pu (21.4 mrem/year). As noted above, the dose from ^{239}Pu is probably overestimated due to the conservative assumption that Pu is transported as irreversibly attached to colloids. ^{99}Tc, ^{129}I, ^{234}U, and ^{237}Np contribute smaller but significant amounts to the total calculated dose rate.

This conditional dose rate should be weighted by the probability of the occurrence of a volcanic eruption to evaluate its potential impact on the overall exposure to RMEI. Volcanic eruptions at Yucca Mountain are unlikely; BSC 2003 ([163769], Sections 7.1, 7.2) concludes that the mean annual frequency of igneous intrusion into the repository footprint is 1.7E-08. The probability of eruption, conditioned to an intrusion, is less, 1.3E-08 (not all hypothetical igneous intrusions would result in an eruption at the repository). Adopting the 1.3E-08/year value and assuming that future igneous activity at Yucca Mountain is a Poisson process, there is approximately a

1.3E-04 probability of an eruptive igneous event at Yucca Mountain in the next 10,000 years. This event is equally likely to occur in any year during the 10,000-year period, and the probability that the event has already occurred (and that groundwater is contaminated) rises from 1.3E-08 in the first year to 1.3E-04 after 10,000 years. A rigorous approach to estimating the probability-weighted dose through time would require evaluating consequences of events at each year and summing the probability-weighted doses, as done in the TSPA-Site Recommendation (SR) for doses incurred by direct exposure to a contaminated ash layer (CRWMS M&O 2000 [153246], Section 4.2). However, it is conservative to assume that the dose rate estimated for an igneous event occurring in the first year is representative of events that might occur at any time in the first 10,000 years. In fact, the first-year event provides an upper bound on the radionuclide inventory available for later events. The probability of an eruptive igneous event occurring during the first 10,000 years is 1.3E-04, which yields a probability-weighted dose rate of approximately 2.66E-03 mrem/year for leaching of radionuclides from contaminated ash and contamination of the groundwater used by the RMEI. This is significantly less than the probability-weighted doses resulting from other igneous pathways during this period (CRWMS M&O 2000 [153246], Section 4.2).

One assumption of the simplified analysis summarized in Table 6.2-1 is that the blanket of ash is uniformly deposited on the ground surface above the aquifer. A plausible alternative scenario is that the ash could be redistributed, for example, by running water in Fortymile Wash before leaching of radionuclides. A thicker deposit of ash in one area would lead to higher concentrations of radionuclides in that area of the SZ and consequent higher peak dose rate from the production of contaminated groundwater. The increase in the estimated peak dose rate would be approximately proportional to the increased thickness of the ash deposit relative to the average thickness due to erosional and depositional processes. In other words, if the ash deposit were redistributed such that it was five times thicker at the downstream end of Fortymile Wash relative to the average ash thickness, then the peak dose rate would be about five times greater. This would be a significant increase relative to the estimated conditional dose rate of 20.5 mrem/year. However, considering the probability weighting presented above and the numerous conservative simplifying assumptions used in the analysis, this aspect of ash redistribution has low consequence to repository performance. In conclusion ashfall is excluded from the SZ on the basis of low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

Table 6.2-1. Screening Estimate of Dose from the SZ for Leaching from Volcanic Ash, Conditional on Eruptive Release

Radio-nuclide	Curies per package[a]	Curies Released	Expected K_d (ml/g)[b]	Expected R_f	Half-life (years)	Curies at water table	Water Volume (L)	Concen-tration (picoCi/L)	BDCF (mrem/yr per pCi/L)[c]	Dose Rate (mrem/yr)
C-14	6.12E+00	3.67E+01	0.0	1.0	5.73E+03	2.12E+01	2.96E+12	7.16E+00	9.06E-03	6.49E-02
Sr-90	3.48E+05	2.09E+06	210.0	1338.0	2.91E+01	0.00E+00	3.96E+15	0.00E+00	1.64E-01	0.00E+00
Tc-99	1.29E+02	7.74E+02	0.0	1.0	2.13E+05	7.36E+02	2.96E+12	2.49E+02	2.21E-03	5.50E-01
I-129	3.09E-09	1.85E+00	0.0	1.0	1.57E+07	1.85E+00	2.96E+12	6.25E-01	3.37E-01	2.11E-01
Cs-137	5.19E+05	3.11E+06	728.0	4635.9	3.00E+01	0.00E+00	1.37E+16	0.00E+00	4.87E-01	0.00E+00
U-232	2.27E-01	1.36E+00	4.6	30.3	7.20E+01	0.00E+00	8.97E+13	0.00E+00	5.78E00	0.00E+00
U-233	5.61E-04	3.37E-03	4.6	30.3	1.59E+05	1.85E-03	8.97E+13	2.06E-05	1.74E00	3.58E-05
U-234	1.10E+01	6.60E+01	4.6	30.3	2.45E+05	4.48E+01	8.97E+13	4.99E-01	1.21E00	6.04E-01
U-236	2.51E+00	1.51E+01	4.6	30.3	2.34E+07	1.50E+01	8.97E+13	1.67E-01	1.08E00	1.80E-01
U-238	2.66E+00	1.60E+01	4.6	30.3	4.47E+09	1.60E+01	8.97E+13	1.78E-01	1.08E00	1.92E-01
Np-237	3.26E+00	1.96E+01	6.4	41.7	2.14E+06	1.84E+01	1.24E+14	1.48E-01	6.92E00	1.02E+00
Pu-238	2.64E+04	1.58E+05	N/A	34.0	8.77E+01	0.00E+00	1.01E+14	0.00E+00	4.67E00	0.00E+00
Pu-239	2.71E+03	1.63E+04	N/A	34.0	2.41E+04	1.95E+02	1.01E+14	1.93E+00	9.16E00	1.77E+01
Pu-240	4.73E+03	2.84E+04	N/A	34.0	6.54E+03	2.35E-03	1.01E+14	2.33E-05	8.93E00	2.08E-04
Am-241	2.84E+04	1.70E+05	N/A	34.0	4.32E+02	0.00E+00	1.01E+14	0.00E+00	6.78E00	0.00E+00
Am-243	2.51E+02	1.51E+03	N/A	34.0	7.38E+03	8.01E-04	1.01E+14	7.93E-06	9.43E00	7.48E-05
										20.5

[a] Source: 2003 [161961], calculated from Table 21 and Attachment III.
[b] Source: BSC 2003 [167651], Table 6-8.
[c] Source: BSC 2003 [164403], Table 6.2-5.
Note that the probability of eruptive release of radionuclides is about 1.3E-8/year (BSC 2003 [163769], Section 7.2).
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6.2.5 Hydrothermal Activity (1.2.06.00.0A)

FEP Description:	Naturally-occurring high-temperature groundwater may induce hydrothermal alteration of minerals in the rocks through which the high-temperature groundwater flows.
Descriptor Phrases:	Hydrothermal alteration of the SZ
Screening Decision:	Excluded–Low consequence
Related FEPs:	1.2.04.02.0A, 1.2.10.02.0A, 2.2.10.02.0A, 2.2.08.03.0A, 2.2.10.08.0A, 2.2.10.03.0A

Screening Argument:

The presence of silica, calcite, and clay vein deposits and mineral replacement assemblages indicate the presence of past hydrothermal activity associated with both silicic and basaltic caldera building within the Basin and Range province. Evidence of hydrothermal mineral alteration is seen in the Calico Hills, Claim Canyon, and along the south Flank of Shoshone Mountain (*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada*, BSC 2003 [167211], Figure 3); all three past hydrothermal areas are not along the SZ flow path and lie north and north east of Yucca Mountain (*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*, BSC 2003 [163769], Figure 3). Hydrothermal mineral replacement is distinguished from deuteric alteration, which, as tuff cools, causes exsolving gaseous and aqueous components precipitating opal, calcite and zeolites in lithophysae and intermittent veins (*Yucca Mountain Site Description,* CRWMS M&O 2000 [151945], Section 4.9). Deuteric, not hydrothermal, mineral alteration is ubiquitous in the vicinity of Yucca Mountain. Yucca Mountain is located outside the caldera margin that encompasses Claim Canyon and Shoshone Mountain; hence it was never near this ancient hydrothermal source (BSC 2003 [163769], Figure 3).

The likelihood of future hydrothermal activity to develop within the vicinity of SZ flow paths is conditioned to future volcanic and igneous activity. Silicic volcanism was dominant between 15 and 11 million years ago (m.y.a.), coincident with plate extension and an episode of major caldera formation in the Great Basin Region. Crustal extension rates started to decline about 13 m.y.a.; this progression in crustal evolution resulted in silicic volcanism being replaced with basaltic volcanism. Basaltic volcanic caldera building and igneous activity within the Yucca Mountain region commenced between 13 and 11 m.y.a. Post-caldera building igneous activity within the Yucca Mountain peaked approximately 7 m.y.a. Igneous intrusions in the areally extensive Yucca Mountain region, once extensive in nature, are now in a relatively quiescent phase (BSC 2003 [163769], Section 6.2). Future igneous activity within the Crater Flat basin will typically cause minimal, highly localized basaltic dike-like intrusions with average widths on the order of one meter (BSC 2003 [163769], Section 6.3.2). This is supported by investigations at the Grants Ridge analog sites, which indicate that basaltic intrusion produced only localized formation of volcanic glass within the contact zone (*Synthesis of Volcanism*

Studies for the Yucca Mountain Site Characterization Project, CRWMS M&O 1998 [105347], Section 5, p.74 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). Investigations of basaltic intrusions at Paiute Ridge (Carter Krogh and Valentine 1996 [160928], pp. 7 through 8 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) suggest that igneous activities altered rock properties to only a few tens of centimeters to, at most, a meter perpendicular to an intruding dike. Associated hydrothermal activity is conditioned to these localized igneous events. It is inferred, given the lack of evidence of any past hydrothermal along the Crater Flat basin (BSC 2003 [167211], Figure 3), coupled with the relatively small widths of igneous intrusions that would intersect the SZ flow domain, that any associated hydrothermal activity produced from future igneous activity will be minimal (localized) and of low consequence to the long term and regional SZ flow paths. In summary, hydrothermal activity is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.6 Large-Scale Dissolution (1.2.09.02.0A)

FEP Description:	Dissolution can occur when any soluble mineral is removed by flowing water, and large-scale dissolution is a potentially important process in rocks that are composed predominantly of water-soluble evaporite minerals, such as salt.
Descriptor Phrases:	Large-scale dissolution in the SZ
Screening Decision:	Excluded–Low consequence
Related FEPs:	1.3.07.01.0A, 1.3.07.02.0A, 2.2.08.01.0A, 2.2.08.03.0A, 2.2.08.06.0A

Screening Argument:

Large-scale dissolution can be excluded from the Saturated Zone Flow and Transport (SZFT) models because evaporites, in particular halite with a solubility of 360,000 mg/L at P=1 atmosphere (atm) and T=25°C (Freeze and Cherry 1979 [101173], p. 106), are not dominant minerals in the formations along the simulated transport pathways. The hydrogeologic framework model, which is based on the available geologic information from the Yucca Mountain region (D'Agnese et al. 1997 [100131] and United States Geological Survey (USGS) 2003 [165176], Figures 6-2, 6-18), uses 19 hydrogeologic units to represent the geologic system. Of these hydrogeologic units, the carbonates are the most soluble in groundwater (solubility of 90-500 mg/L depending on the p_{CO_2} at P=1 atm and T=25°C (Freeze and Cherry 1979 [101173], p. 106)), and the permeability of these units is primarily due to solution channels and fractures. The transport pathways in the SZ are primarily through volcanic tuffs and alluvial material (*Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Section 6.6.2.3), which largely consists of disaggregated tuffaceous rocks (*Site-Scale Saturated Zone Transport*, BSC 2003 [166260], Attachment I and Section 8). The carbonate units are included in the SZFT model, and the assigned permeabilities are representative of the existing solution channels and fractures. The carbonate units along the SZ transport path are located well below the water table (USGS 2003

[165176], Figures 6-2 and 6-18). New extensive dissolution cavities are unlikely to develop at depths well below the water table where CO_2 has been depleted. Even if they did form, there would be no detrimental effect on the simulated performance of the site as transport occurs near the water table in the upper volcanic, lower volcanic and alluvial aquifers.

The volcanic rocks present at the water table are not readily soluble in water; their solubility is low enough that large-scale dissolution does not occur. Volcanic rocks tend to weather to clay minerals with a relatively small amount of silica going into solution. Freeze and Cherry (1979 [101173], p. 106) give the solubility of quartz 12 mg/L at P=1 atm and T=25°C. Secondary permeability in volcanic rocks is primarily due to the formation of open fractures. Fracture flow and transport are explicit features of the site-scale 3-D saturated flow and transport model.

In summary, transport of radionuclides will primarily take place in the relatively insoluble volcanic units located near the surface of the water table and well above the more soluble carbonate units where large-scale dissolution could take place. Given unusually drier climatic conditions the water table may drop to lower levels from its current potentiometric surface. While unlikely, there is mineralogical evidence that the maximum decline in the water table from current levels could be at most 300 m (see FEP 1.3.07.01.0A–Water table decline). This potential decline still retains the water table several hundreds of meters above the carbonate aquifer along the simulated SZ transport paths (USGS 2003 [165176], Figures 6-2 and 6-18). Current groundwater withdrawal rates and their effects on water table elevations in the Jackass Flats hydrographic basin (La Camera et al. 1999 [103283], pp. 17 through 22; Young 1972 [103023]) are insignificant. Based on these observations, it is concluded that future withdrawal rates will not cause the water table to drop along the transport paths to the more soluble carbonate units. In conclusion, large-scale dissolution is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.7 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
Screening Decision:	Excluded–Low consequence
Related FEPs:	1.2.02.01.0A, 1.2.02.02.0A, 2.2.06.01.0A, 2.2.06.02.0A, 2.2.06.02.0B

Screening Argument:

Water table elevations can change from a few centimeters to several tens of meters in response to seismic activity. The change in water table elevation can also affect (1) SZ flow and pathways, if the change in water table elevations are extensive enough to change the regional potentiometric surfaces, and (2) groundwater geochemistry, as the displaced water is moved into, and interacts with, rocks composed of different mineralogy. Seismic activity is caused by changes in the stress imposed on the country rock, fault and fracture formation and fault displacement. A transient change in water table elevations is associated with the passage of the seismically perturbed surface wave that passes through the region. Long-term changes in water table elevations are associated with seismically induced permanent changes in pore pressure and volume strain or permanent changes in regional permeability. In the Basin and Range Province, which includes the Yucca Mountain region, seismic activity is ultimately controlled by the more areally extensive tectonic activity, a result of broad crustal plate extension. Tectonic activity in the Yucca Mountain region is in a waning phase with the focal point moving westward (*Errata for Features, Events and Processes*: *Disruptive Events,* BSC 2004 [167720], Section 6.2.1.1). Because seismic activity is closely associated with tectonic activity, a decline in tectonic activity coincides with a decline in the frequency and intensity of seismic activity. Investigations of analog sites and numerical studies demonstrate seismic activity within the Yucca Mountain region will not change long-term (i.e., over the 10,000-year regulatory period) regional SZ groundwater flow patterns, water chemistry, and temperatures. A brief summary of these investigations is given below.

Given the predicted decline in seismic activity over a 10,000-year time frame, the Probabilistic Seismic Hazard Analysis (PSHA) expert elicitation group (*Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada,* CRWMS M&O 1998 [103731], Section 8) determined mean displacement in intact rock is less than 0.1 cm for a 1E-08 annual exceedance probability in the area between Solitario Canyon and the Ghost Dance Faults. Consequently, no significant new faults and fractures, which would have the potential to create new flow paths or significantly change the existing flow paths and flow directions, are expected in the intact rock.

Because it is unlikely a seismic event will create new faults, movement along existing faults is of primary interest. Expert elicitation from the PSHA group estimate a 2-m to 4-m mean fault displacement, at an annual-exceedance probability of 1E-8, as the upper limit for the majority of faults within the Yucca Mountain region (CRWMS M&O 1998 [103731], Section 8.2). The exception is the predicted 10-m mean displacement along the Solitario Canyon fault at an annual-exceedance probability of 1E-8, (CRWMS M&O 1998 [103731], Figure 8-3). Several investigations have been conducted to estimate the hydrologic response to a fault displacement (i.e., change in water table elevations) given predicted fault displacements. One investigation was performed by the National Research Council (NRC 1992 [105162], Chapter 5 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). This group estimated the maximum changes in water table elevations over a 10,000-year period in response to seismic activity, which presumes some degree of fault displacement. They estimated fault displacement using two modeling approaches: (1) a dislocation approach, where zones of extension on one side of a fault are balanced by compression across the fault; and (2) the more realistic ‘changes in the regional stress' approach caused by normal fault slippage in regions of extension. The regional stress approach evaluated the effect of stress on pore pressure, which is dependent on the elastic properties of the bulk rock and the mineral grains. Both models resulted in a transient change in water table elevation given a seismic event in the Yucca Mountain region. However, the extent of the rise differed for both models. Adopting the dislocation model, the maximum rise in the water table would be approximately 10 m. Results from the regional stress approach resulted in a maximum water table rise of 50 m. The later approach assumes realistically conservative rock and mineral elastic properties. The panel concluded that regardless of which approach is taken, the maximum water table rise given a seismic event would be less that 50 m. Given the Council's study, it is inferred that a 10-m slip along Solitario Canyon fault, which could implicitly impose the maximum change in volume stress strain changes on pore pressure, would result in no more than a 50-m rise in the water table (see related FEP 2.2.06.02.0A–Seismic activity changes porosity and permeability of faults).

Several other numerical studies estimate the hydrologic response due to fault displacement. Analysis performed by Gauthier et al. (1996 [100447], pp. 163 through 164) indicates that the greatest strain-induced changes in water table elevation occur with strike-slip faults. Simulations of the timing, magnitude, and duration of water table rise indicate a maximum rise of 50 m within an hour of the simulated event. The simulated system returns to steady-state conditions within 6 months. Gauthier et al. 1996 [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."

The magnitude and transient nature of the simulated, seismically induced, water table rise is consistent with other estimates and observations. Numerical simulations performed by Carrigan et al. (1991 [100967]) modeled tectonohydrologic responses based on an earthquake associated with a 1-m fault slip, which produced a simulated water table rise of 2 m to 3 m for a water table 500 m below ground surface. Extrapolation to a more hypothetical event of a 4-m slip results in a transient rise of 17 m near the fault (Carrigan et al. 1991 [100967], p. 1159).

Investigations focusing on the potentiometric hydrologic response given changes in rock properties adjacent to the fault demonstrate that the changes in water table elevation are transient and local in nature. Carrigan et al. (1991 [100967]) modeled a 100-m wide fracture zone centered on a vertical fault, such that vertical permeability was increased by three orders of magnitude. The results of that model indicate transient water table rise of up to 12 m, in the fracture zone, with 1 m of slip. These results indicate seismic pumping due to changes in permeability along faults would produce a short-term and transient water table rise and for the 10,000-year time scale, would not change regional flow directions or flow paths.

Observations of changes in water table elevation given recorded seismic events support the conclusions drawn from the above numerical studies. The United States Geological Survey (USGS) has produced an Open File Report 93-73 (O'Brien 1993 [101276]) wherein water level fluctuations at Yucca Mountain due to earthquakes in the region were analyzed. Water table fluctuations range from 90 centimeter (cm) associated with a 7.5 magnitude earthquake near Landers, California (CA) (approximately 420 km from Yucca Mountain) to 20 cm for a second quake of 6.6 magnitude near Big Bear Lake, CA (approximately 400 km from Yucca Mountain). More notably, a 5.6 magnitude quake 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 3 days following the earthquake. Water levels in that well returned to pre-quake levels over a period of about 6 months. Thus, observed changes in the water table from seismic events in the outlying vicinity are relatively minor and transient in nature.

A seismic event can alter *in-situ* rock hydrologic properties along a relatively narrow zone adjacent to the fault, labeled herein as a "zone of alteration". The zone of alteration can be on the order of a few meters to tens of meters wide adjacent to the fault (see FEPs 2.2.06.01.0A–Seismic activity changes porosity and permeability of rock and 2.2.06.02.0A–Seismic activity changes porosity and permeability of faults). The current perturbed rock properties along zones of alteration are in response to the cumulative effects of a highly active seismic past regionally imposed on the Basin and Range Province over many millennia. It is inferred, given the predicted lower frequencies of future seismic events, hydrologic properties in these zones of alterations will not be significantly altered (Detailed discussions on the effects of seismic events on rock properties are provided in BSC (2004 [167720], Sections 6.2.1.8 through 6.2.1.11).

Furthermore, flow and transport in the SZ is dominated by fault orientation and existing fractures, fracture clusters and fracture spacing, collectively labeled as flowing intervals in the Saturated Zone Flow and Transport (SZFT) model abstraction (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.3). The SZFT model evaluates uncertainties assigned to flowing interval properties such as horizontal anisotropy in the volcanic units, flowing interval spacing, flowing interval porosity in the volcanics, and longitudinal dispersion (BSC 2003 [167651], Table 6-8). Transport times through the SZ are quite sensitive to parameter uncertainty associated with flowing interval properties (only uncertainty in the specific discharge scaling parameter, which is meant to account for increased specific discharge due to a wetter climate, produces a greater variation in transport times). As an example, parameter uncertainty in flowing interval spacing results in transport times that vary by several thousands of years (Arnold et al. 2000 [166335]). The uncertainty incorporated in the horizontal anisotropy (which accounts for maximum and minimum stresses imposed on faults and fracture clusters and their orientation) results in transport paths that vary by several kilometers (BSC 2003 [167651], Figure 6-6). Thus the incorporated parameter uncertainty for fracture and fault properties, on a regional scale, overwhelms any transient changes in SZ transport times and flows paths given a localized changes in rock properties residing in the zone of alteration.

Additionally, the calibration and validation of the base case flow field is based on parameter uncertainty and model sensitivity to grid discretization. More specifically, the calibration process includes (1) spatially varying multiple flow and transport parameters such as permeability, porosity, anisotropy, faults and fault zones, and the orientation and nature of faults to measured and interpolated water levels, and (2) sensitivity of the calibrated parameters to grid size and grid resolution (*Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Sections 6.5.3.2, 6.6.1 and 7.0). Grid resolution is based on systematically running the model, then comparing results, using grids of differing resolutions (increased or decreased grid discretizations in both the horizontal and vertical direction). Given this type of exercise, the grid considered suitable for stochastic modeling is one that produces minimal differences in the model results compared to results from a grid with increased (i.e., more refined) discretization. Given this type of exercise, the appropriate grid discretization used in the SZFT model is for 500-m grid blocks (uniformly spaced) in the horizontal direction, and 10-m to 550-m non-uniformly spaced grid blocks in the vertical direction. For the TSPA-LA SZFT model, on a regional and long-term scale, the transient hydrologic response due to seismically induced changes in the relatively small and discrete "zones of alteration" is insignificant due to the parameter uncertainty incorporated into the SZ model and model scale and grid discretization (Seismic effects on rock fault properties adjacent and within faults and zones are discussed in FEP 2.2.06.02.0A–Seismic activity changes porosity and permeability of faults).

Results from the above investigations indicate the hydrologic response due to fault displacement (i.e. changes in the water table elevation) from predicted seismic events within the Yucca Mountain region will be transient and local in nature.

Lastly, the effect of a seismically induced hydrologic response on SZ groundwater chemistry will be insignificant. Groundwater isotopic and geochemical signatures within the Yucca Mountain region are indicative of groundwater flow directions and flow paths that have existed over the past 10,000 years. Geochemical analysis indicates the current SZ groundwater under the repository and along the SZ transport path is paleoclimate recharge water (*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada*, BSC 2003 [167211], Section 7.1.2). Flow and transport modeling results show good history matching with the geochemical modeled flow patterns and deduced mixing relations using hydrochemical and isotopic data (BSC 2003 [167211], Section 7.1.4). These isotopic and geochemical signatures indicate changes in groundwater temperatures and geochemistry are primarily a result of climatic events and recharge points, followed by rock-water interactions. By deduction, the large volume of paleoclimate recharge water undergoes more rock-water interactions in the UZ and SZ, and more mixing of waters from different flow systems due to climatic events, than the relatively small volume of water that contacts a seismically produced "zone of alteration." Thus, the large influx of paleoclimate recharge waters, now underneath the repository location and along the transport path, represents the maximum geochemical and temperature variability in the SZ and overshadows any minor change in groundwater geochemistry due to a transient seismically induced event.

In summary, the SZ hydrologic response due to a future seismic event is negligible over the temporal and spatial scale of concern. A seismically induced hydrologic response in the SZ will not change long-term flow directions or flow paths and will not have a significant effect on the release of radionuclides to the accessible environment. This FEP is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.8 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
Screening Decision:	Excluded–Low consequence
Related FEPs:	1.2.04.02.0A, 1.2.06.00.0A, 2.2.08.01.0A, 2.2.08.03.0A

Screening Argument:

The effects of igneous intrusions on UZ flow and flow paths, topography, surface drainage patterns, surface soil conditions and infiltration rates are addressed in the UZ FEP analysis report (*Features, Events, and Processes in UZ Flow and Transport,* BSC 2003 [164873], Section 6.7.4).

Igneous intrusions within the SZ flow domain are expected to be of low consequence to water table elevations and SZ flow patterns and flow paths for the following reasons. Several analog sites can be used to eliminate the effects of an igneous activity on SZ hydrology. The Paiute Ridge intrusive/extrusive center located in the northeastern margin of the Nevada Test Site is one example. Paleomagnetic, geochronologic, and geochemical data indicate that the complex formed during a brief magmatic pulse representing a single volcanic event (Ratcliff et al. 1994 [106634]). The vents and associated dike system formed within a north-northwest-trending extensional graben provide 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 m. Carter Krogh and Valentine's 1996 ([160928], pp. 7 and 8 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) investigation of the site suggests that (1) igneous activities altered rock properties within only a few tens of centimeters out from the rock/dike interface and at most, a meter perpendicular to an intruding dike, and (2) dike location and orientation was influenced by the orientation of the local stress field and the presence of existing faults. The anisotropic permeability in the SZ observed in the Yucca Mountain region has a maximum principal permeability direction of approximately north-northeast, which is consistent with the fault and fracture orientation (Ferrill et al. 1999 [118941], p. 1). Additionally, the dike margins are parallel and coincident with the primary direction of increased or decreased permeability. This parallel to subparallel orientation of dikes and maximum principal permeability, coupled with the expected limited affected volume of material around the dikes, indicate that dikes, even if differing in permeability, will not significantly affect groundwater flow patterns at the mountain scale.

There are several lines of evidence that support eliminating the effects of an igneous activity on long-term changes in water temperature and geochemistry. Analysis of igneous activity at Paiute Ridge (*Synthesis of Volcanism Studies for the Yucca Mountain Site Characterization Project,* CRWMS M&O 1998 [105347], Section 5, p. 57 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) indicates that thermal transfer into adjacent rock due to an igneous activity was minimal. Igneous activities at the Grants Ridge site produced only localized formation of volcanic glass within the contact zone (CRWMS M&O 1998 [105347], Section 5, p. 74 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]); evidence of any regional hydrothermal response was absent. Additionally, Kuiper (1991 [163417]) suggests if a 10-km long, 5-km deep, and 100-m wide, disc-shaped dike initially intruded into the SZ, the transient rise in the water table due to heat effects would be on the order of 25 m. Studies of natural-analog sites (CRWMS M&O 1998 [105347], Section 5, pp. 1 – 2 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) support minimal chemical and mineralogical alteration (meters to a few tens of meters of the intrusion itself) from the rock intruding dike interface due to any future igneous activity within the Yucca Mountain region. Lastly, because SZ water chemistry is dominated by the chemical and atmospheric conditions and the large volume of paleoclimate recharge waters, the small volume of igneously altered rock would have little impact on the global characteristics of SZ water chemistry (see FEPs 2.2.08.01.0A–Chemical characteristics of groundwater in the SZ and 2.2.08.03.0A–Geochemical interactions and evolution in the SZ). Thus, the regional SZ geochemistry in the Yucca Mountain vicinity will not be significantly affected by igneous activity (A more detailed discussion of FEPs related to igneous activity is given in *Errata for Features, Events and Processes*: *Disruptive Events* (BSC 2004 [167720], Section 6.2.2).

In summary, any igneous intrusions that are expected to occur in the time frame of the regulatory period will affect a relatively small volume of the SZ and are likely to have the orientation of the intrusive features or parallel to existing features. Consequently, the intrusion will not have a significant effect on rock permeabilities at the scale that affects site-wide water table elevations, SZ flow and flow paths. Therefore, the hydrologic response to igneous activity is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.9 Water Table Decline (1.3.07.01.0A)

FEP Description:	Climate change could produce decreased infiltration (e.g., an extended drought), leading to a decline in the water table in the saturated zone, which would affect the release and exposure pathways from the repository.
Descriptor Phrases:	Climate change (drier); Time-dependent infiltration (decrease); Water table elevation
Screening Decision:	Excluded–Low consequence
Related FEPs:	1.3.01.00.0A, 1.2.09.02.0A, 2.2.08.11.0A

Screening Argument:

The primary process affecting water table elevations is the cyclical and climatically driven infiltration through the UZ to the SZ (Szabo et al. 1994 [100088]). One can predict *relative* future water table elevations based on several physical lines of evidence, such as mineralogy and geochemistry and fossil, glacial and marine records. These records indicate a cyclical rise and fall of the water table coincident with the 100,000- to 150,000-year cyclical change in climate punctuated by the periodicity of smaller climate cycles ranging between 10,000 to 40,000 years (Szabo et al. 1994 [100088], Figure 6; Forester et al. 1996 [100148], p. 52). Reasoned arguments are given below for the maximum depth in which the water table could be lowered within the next 10,000 years given an unexpectedly dry climate and the effects of a much lower water table on transport times.

Geochemical and isotopic analyses (*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada*, BSC 2003 [167211], Section 7.1) indicate that SZ groundwater along the projected flow path is between 10,000 to 16,000 years old (the average mixed age), and its composition reflects recharge that occurred up until the late Pleistocene. Groundwater pressures respond much more quickly than groundwater geochemistry to changes in boundary conditions (i.e., recharge rates, inflow from adjacent boundaries). Consequently, water table elevations are more reflective of the current, interglacial, climate pressure pulse.

Present groundwater elevations in North America's Basin and Range Province (which includes the Yucca Mountain region) are reflective of current arid climatic conditions and the (time dependent) decrease in infiltration (i.e., lower recharge) of the interglacial climatic interval. The interglacial climatic interval is predicted to persist for the next 400 to 600 years. After the interglacial climatic interval, warmer and wetter monsoonal climatic conditions are predicted to persist for approximately 900 to 1400 years. It is predicted that a cooler and wetter glacial transition climatic condition will follow the brief monsoonal period and will persist for about 8,500 years (USGS 2001 [158378], Section 7). However, while not predicted in *Future Climate Analysis* (USGS 2001 [158378]), this FEP addresses variability within the interglacial climatic interval that may produce an extreme arid condition that could potentially cause the current water table to fall significantly. By investigating the geologic, fossil, and mineralogic records, one can ascertain the lower bound in which a water table could potentially fall within the next 600 years, given extremely unusual and increasingly more arid climatic conditions.

An indication of past water table elevations can be found by examining calcite crystal morphology within saturated and unsaturated fractures (Whelan et al. 1998 [108865]). Calcite crystals grown below the water table are dense and elongated, having porosities much less than 1% (Szabo et al. 1994 [100088]). Calcite crystals grown in unsaturated fractures (above the water table) are distinctly different from those grown in saturated fractures (below the water table). They are porous (1–20% porosity), free growing, short (Szabo et al. 1994 [100088]), do not fluoresce or phosphoresce, locally display orange growth banding, and have single-phase fluid inclusions (Whelan et al. 1998 [108865]). Whelan et al. (1998 [108865]) report evidence of calcite crystal growth, indicative of unsaturated conditions in fracture openings, located 100 to 300 m below the current water table. The evidence suggests the water table dropped to these levels at least once during the last 11.6 million years. Szabo et al. 1994 [100088] studied evidence of past water table fluctuations in Browns Room, a subterranean air-filled room adjacent to the Ash Meadows discharge area. Their investigations indicate the water table dropped by at least 6 m from its current level between 92,000 and 53,000 years ago. (Szabo et al. 1994 [100088] do not give estimates of how much beyond 6 m the water table may have declined.) Based on the above findings one can conclude there is a relatively low probability that the water table will decline to depths of 300 m. However, if the water table were to fall by as much as 300 m, the change in flow path and transport time that a plume would take from the repository to the 18-km compliance boundary would be of low consequence. Based on the SZ base case flow calculations, the transport path, under current and wetter climatic conditions, is confined to the Prow Pass, Bullfrog, and Tram sub-units of the Crater Flat Formation, the Upper Volcanic Confining Unit, Upper Volcanic Aquifer, Undifferentiated Valley Fill and Alluvium, with most of it going through the Bullfrog (*Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Section 6.6.2.3). The collective thicknesses of these units along the potential transport path are well over 300 m (BSC 2003 [166262], Section 6.5.3.3). The Prow Pass and Bullfrog units are the most permeable volcanic units in the flow and transport path (BSC 2003 [166262], Table 14). Lowering the water table by as much as 300 m in the volcanic units would put the potential transport path primarily in the Tram subunit and potentially in the Lower Volcanic Confining unit. The permeability of these units is several orders of magnitude lower than the Bullfrog. Therefore, if the water table was lowered by as much as 300 m, transport times would be greater than transport through the all Crater Flat sub-units.

Given the collective alluvium and valley-fill thickness of 400 to 700 m and the uncertainty in transport properties through both the undifferentiated valley fill and alluvium units, a potential lowering of the water table from its current elevation would not affect predicted transport times. The uncertainty as to whether a plume would flow in the alluvium and valley fill or the volcanic units, due to a lower water table, is implicitly captured using stochastic simulations of the location of the northern and western boundaries of the alluvial units in the *SZ Flow and Transport Model Abstraction* (BSC 2003 [167651], Section 6.5.2.2).

Additionally, a lowering of the water table would create longer transport pathways through the unsaturated zone, thus delaying and potentially reducing the total mass of radionuclides reaching the SZ, and create lower hydraulic gradients. Lower gradients in the SZ equate to slower groundwater SZ specific discharge rates, which mean longer SZ travel times to the compliance boundary.

Lastly, paleoclimate records indicate arid climatic conditions are short relative to wetter conditions. Forester et al.'s (1996 [100148], p. 52) investigations of proxy climate records indicate climatic conditions during the past 2 million years were much wetter than current climatic conditions for about 70 to 80 percent of the time. Szabo et al.'s (1994 [100088], Figure 6) analysis of Searles Lake deposits indicate extreme arid conditions have only occurred twice during the past 600,000 years, once around 290,000 years ago and between 10,000 years ago to the present. One can infer the water table is now at a low point in the 150,000- to 300,000-year climate cycle and will not significantly drop below current groundwater elevations during the 10,000-year regulatory period. Based on the above evidence, if the water table were to decline, the likelihood of it declining 140 to 300 m below its current level is very low.

Given the above rationale, it is not likely the water table will decline to levels lower than 140 to 300 m from its present position. However, if the water table were to decline to these levels, the overall effect would be to increase SZ transport travel times and thus not adversely affect repository performance. Therefore, water table decline is excluded based on low consequence because it has no adverse effects on performance.

6.2.10 Water Table Rise Affects SZ (1.3.07.02.0A)

FEP Description:	Climate change could produce increased infiltration, leading to a rise in the regional water table, possibly affecting the release and exposure pathways from the repository by altering flow and transport pathways in the SZ. A regionally higher water table and change in SZ flow patterns might move discharge points closer to the repository.
Descriptor Phrases:	Climate change (wetter); Time-dependent infiltration (increase); Water table elevation; Saturated flow and pathways in the SZ
Screening Decision:	Included
Related FEPs:	1.2.09.02.0A, 1.3.01.00.0A, 2.2.08.11.0A

Screening Argument:

The TSPA-LA implicitly models a higher water table in the SZ to reflect wetter climatic conditions (resulting in an increase in time dependent infiltration) with the use of flux multipliers. Flux multipliers are incorporated in the convolution integral method (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.5). Flux multipliers scale the base case saturated zone radionuclide breakthrough curves, effectively modeling the impacts a higher water table would have on transport times to the 18-km boundary. Three flux multipliers are used to characterize changes in water table elevations reflective of three climatic conditions. Current climatic conditions are represented by a flux multiplier of 1.0; for a monsoonal climate the multiplier is 2.7; and for a glacial transition climate the multiplier is 3.9 (BSC 2003 [167651], Table 6-5). An upper bound estimate of SZ transport times to the 18-km boundary, reflective of a higher water table produced during a glacial transition climatic condition, is conservatively bounded with the use of the 3.9 flux multiplier. The rationale supporting this assumption is given below.

SZ transport times at the 18-km boundary using the 3.9 flux multiplier method (representative of a glacial transition climate) have been compared to transport times performed on an alternative model domain. The alternative model domain method allows the water table to be 100 m higher than present conditions under the repository footprint (Section 6.4.5.1 of *Site-Scale Saturated Zone Flow Model,* (BSC 2003 [166262]), which is the upper estimate the water table would rise under the repository given a future glacial transition climatic condition. Conservative and sorbing tracer breakthrough curves (BTCs) show initial tracer breakthroughs (the leading edge of the BTC) are at least an order of magnitude greater for the alternative model method compared to breakthrough using the flux multiplier method. Additionally, BTC trailing edges for the alternative model domain are well over an order of magnitude greater compared to those derived using a flux multiplier (BSC 2003 [167208], Attachment V and Figures V-1 and V-2). The longer transport times using the alternative model are a function of several factors. The higher water table incorporated in the alternative model domain enables both types of tracers to pass through less permeable upper volcanic confining units, resulting in considerably longer path lengths and transport times. The longer transport times in the volcanic units facilitate greater matrix diffusion. Additionally, a higher water table promotes longer flow paths through the porous alluvium, equating to longer alluvium transport times. Because the flux multiplier method results in more rapid radionuclide transport relative to explicitly simulating a higher water table, this simplified representation of the effect of climate change on water table elevations conservatively estimates the effects of a higher water table on SZ transport times to the 18-km boundary.

6.2.11 Water Management Activities (1.4.07.01.0A)

FEP Description:	Water management is accomplished through a combination of dams, reservoirs, canals, pipelines, and collection and storage facilities. Water management activities could have a major influence on the behavior and transport of contaminants in the biosphere.
Descriptor Phrases:	Land use; Water use; Surface activities (water management); Radionuclide release to the biosphere (irrigation water)
Screening Decision:	Included
Related FEPs:	1.4.07.02.0A, 1.4.07.03.0A, 2.3.11.04.0A, 2.2.08.11.0A

TSPA Disposition:

For the SZ, this FEP pertains to the impacts on projected SZ flow and transport times due to the construction of future water management edifices. The effects of existing water management activities on the saturated flow system, while not directly quantifiable, are implicitly incorporated in the calibrated heads of the SZ flow model. Future water management activities, other than future well withdrawal rates specifically covered in 10 CFR Section 63.332, are presumed to be those currently in practice as stated by regulation Section 63.305 [156605], which states:

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

Water management activities are explicitly included in the biosphere models that determine irrigation intensity, fraction of overhead irrigation, and through the biosphere's "fish" and "plant" mathematical sub-models that determine the potential dose to RMEI. This FEP, and its impact on the RMEI, is discussed in the *Evaluation of Features, Events and Processes for the Biosphere Model* (BSC 2003 [165843], Section 6.2.9).

6.2.12 Wells (1.4.07.02.0A)

FEP Description: One or more wells drilled for human use (e.g., drinking water, bathing) or agricultural use (e.g., irrigation, animal watering) may intersect the contaminant plume.

Descriptor Phrases: Radionuclide release to biosphere (drinking water wells); Radionuclide release to biosphere (irrigation water wells); Water use

Screening Decision: Included

Related FEPs: 1.4.07.01.0A, 1.4.07.03.0A, 2.2.07.16.0A, 2.3.11.04.0A, 2.2.07.12.0A, 2.2.08.11.0A

TSPA Disposition:

The effects of wells on the dose to members of the RMEI are included through the volume of radionuclide-affected groundwater used by that group (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Sections 6.2). The groundwater system in the vicinity of the hypothetical community's well system is modeled assuming that all the contaminants discharged at the 18-km boundary are intercepted by the community's wells. The total volume extracted from all wells (which includes wells used for agricultural, domestic, irrigation, drinking water) to be used by the farming community will not exceed 3,000 acre-feet per year (in accordance with 10 CFR Part 63 Subpart 63.332 (3) [156605]). The volume of extracted well water used to determine the concentration of radionuclides is 3,000 acre-feet per year.

6.2.13 Transport of Particles Larger Than Colloids in the SZ (2.1.09.21.0B)

FEP Description: Particles of radionuclide-bearing material larger than colloids could be entrained in suspension and then be transported in water flowing through the SZ.

Descriptor Phrases: Groundwater rinse in the SZ; Gravitational settling of colloids in the SZ

Screening Decision: Excluded–Low consequence

Related FEPs: 2.2.08.10.0A

Screening Argument:

This FEP deals with particles larger than 1 μm, the upper limit in colloidal size particles that could potentially transport radionuclide-bearing material. Because radionuclide bearing particles larger than 1 μm are not considered to move from the waste packages through the Engineered Barrier System (EBS) and UZ, these large particles would first have to be formed in the SZ, then transported downstream to the compliance boundary. Two processes, precipitation and colloid accretion and flocculation, could contribute to the formation of large radionuclide bearing particles. Once formed, these larger particles could be entrained (i.e., rinsed) in the groundwater downstream for some distance before filtering or settling.

Horizontal flow is the dominant flow component along the potential SZ transport path. Large particles will be carried, horizontally, along contorted flow paths, encountering varying fracture widths, fracture asperities and orientations, and less mobile regions. A large particle will bump and grind along this less than ideal flow path, losing energy due to frictional forces to the point where its velocity will be reduced such that it will settle out or be filtered. It is only possible for the smallest of large particles (i.e., slightly larger than a colloid) to be sustained along the entire 18-km flow path if the upward vertical component of the pore water velocity exceeds the particle's settling velocity (*sv*). An estimation of a particle's *sv* is derived using Stokes' Law:

$$sv = \frac{gL^2(D_p - D_w)}{18V} \tag{Eq. 4}$$

and the following inputs:

1. Particle diameter (L) of 1 micron (1E-06 m).
2. Particle density (P_d) of 2500 kilogram (kg)/m^3 (*Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary,* BSC 2003 [166845], Section 5.10 & 6.3.1).
3. Water density of (D_w) - 1000 kg/m^3 at 20ºC (Streeter and Wylie 1979 [145287], p. 534).
4. Water dynamic viscosity (V) of 1.005E-03 Ns/m^2 at 20ºC (Viswanath and Natarajan 1989 [129867], p. 715).
5. Acceleration of gravity (g) - 9.81 m/s^2.

Using the above inputs (appropriate for 20ºC), the *sv* order of magnitude is 8E-07 m/s (0.08 m/d). Thus, to keep the smallest of "large" particles sustained along the entire path length, the upward vertical component of the pore water velocity must exceed the *sv* of 8E-07 m/s. This is unlikely for several reasons.

Most "particles larger than colloids" will have a *sv* greater than the 8E-07 m/s, since:

1. Minor increases in temperature cause a large increase in *sv*, enabling relatively small particles to settle more readily. The temperature range for Yucca Mountain SZ waters is

approximately 20 to 55ºC, with the majority of temperatures within the upper 20 to lower 30ºC (*Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Section 7.4). The temperature dependent density and viscosity of water for this temperature range will result in a higher *sv*. It is viscosity that varies most with temperature. Consequently, the variability in *sv* would most dramatically be increased due to the large variability in viscosity.

2. Most particles will be "larger" than the upper bound diameter for colloids (1 μm) and thus have a higher *sv* than that used in Equation 4.

3. Using Stokes' Law to calculate sustainability of particles in an "open" solution presumes particle settling is unhindered as it moves horizontally, which is not the case in porous media. SZ flow is not along open and unhindered flow paths. In the volcanics SZ flow is primarily through the Crater Flat group (consisting of the Bullfrog, Tram, and Prow Pass units), the Upper Volcanic Aquifer, and the Upper Volcanic Confining Unit, with the majority of SZ flow going through the Bullfrog unit (BSC 2003 [166262], Section 6.6.2.2). In the Crater Flat group the SZ flow passes through fractured zones consisting of rubblized and brecciated material producing large variability in permeability. On a regional scale, fracture permeability in the Bullfrog, Tram and Prow Pass units ranges over 3 orders of magnitude (BSC 2003 [166262], Section 6.6.1.4). Locally, this variability is even greater. This leads to variability in the magnitude of the vertical component of pore/fracture water velocity. Thus a large particle, if suspended when transported downstream, will encounter low permeability and rubblized zones where the vertical flow vector is less than the *sv*. In these locations large particles will settle out.

4. A calculation of the upward vertical component in two known SZ locations show the *sv* is not exceeded as follows:

    a. The difference between the Carbonate Aquifer head measurements (752.4 m at UE-25p#1) and shallower measurements in the same area (730.2 m at UE-25c#1, UE-25c#2, UE-25c#3) is about 20 m (BSC 2003 [166262], Table 13). The elevation differences are -410 m for UE-25p#1 and about 500 m average for c#1, c#2, c#3. This gives an average vertical gradient of 20 m/910 m or 0.022. The confining unit between the Carbonate aquifer and the Bullfrog unit (a primary flow path) has a mean permeability value of 1E-15 m^2 (BSC 2003 [166262], Figure 37), converting to hydraulic conductivity (at 20ºC) gives 10^{-10} m/s. Multiplying by the vertical gradient gives 2.2E-12 m/s for the specific discharge. If the effective porosity is 0.01 (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.5.2.), the calculated upward velocity is 2.2E-10 m/s, which is less than calculated *sv.*

    b. The difference between the alluvium head measurement at NC-EWDP 19D and NC-EWDP 19P is 5.3 m (USGS 2004 [168473], Table 6-1); the elevation difference between these 2 wells is 293 m, yielding a gradient of .018 (5.3 m/293 m). The mean permeability value for the alluvium is 2E-13 m^2 (BSC 2003

[166262], Table 23), which converted to hydraulic conductivity (at 20ºC) gives 5.1×10^{-06} m/s. Multiplying this by the vertical gradient gives a specific discharge of 4.56E-8 m/s. For the alluvium the mean effective porosity is 0.18 (BSC 2003 [167651], Table 6-8); multiplying mean porosity by specific discharge gives the upward vertical velocity of 2.54E-7 m/s, which is less than the calculated *sv*.

5. Laboratory and field measurements on Yucca Mountain tuffs indicate that colloid filtering and settling is a mechanism that removes colloid size particles from solution (*Saturated Zone Colloidal Transport,* BSC 2003 [162729], Sections 6.4.2 and 6.5). Laboratory experiments performed on 30-cm length core tubes demonstrated that colloids "stick" and settle along fracture surfaces, especially in those fractures oriented horizontally and parallel to the flow direction. Results from these laboratory experiments are supported with field observations. At the Nevada Test Site, a five-order decrease in Pu colloid concentrations was observed in ER-20-5 wells for colloids formed as a result of the BENHAM underground nuclear tests. The ER-20-5 wells are located several kilometers downstream from the test area (Kersting et al. 1999 [103282]). Physical filtering was the process attributed to the loss of colloid mass downstream. Because filtering occurs for colloidal size particles, this process will be exacerbated for larger particles.

Transport of particles larger than colloids is screened out on low consequence because (1) no radionuclide bearing particles larger than colloids are introduced into the SZ from the UZ (*Features, Events, and Processes in UZ Flow and Transport,* BSC 2003 [164873], Section 6.3.4), (2) large particles will not be suspended for great distances along the flow paths given the variable vertical velocity component that would be encountered along the transport path, and (3) the highly variable size, shape, orientation, and roughness of the "transporting" fracture voids promote both settling and filtering. Transport of particles larger than colloids is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.14 Stratigraphy (2.2.03.01.0A)

FEP Description:	Stratigraphic information is necessary information for the performance assessment. This information should include identification of the relevant rock units, soils and alluvium, and their thickness, lateral extents, and relationships to each other. Major discontinuities should be identified.
Descriptor Phrases:	Rock properties in the SZ; Hydrologic properties in the SZ
Screening Decision:	Included
Related FEPs:	1.2.02.01.0A, 2.2.03.02.0A, 2.2.07.12.0A, 2.2.07.13.0A, 2.2.08.01.0A, 2.2.12.00.0B

TSPA Disposition:

The stratigraphic (i.e., hydrologic) nature of the rock as it affects flow and transport is incorporated into the TSPA-LA site-scale flow and transport models (BSC 2003 [166262], Section 6.2). The primary hydrogeologic subdivisions are based on and coincide with (1) common permeability and porosity characteristics (on a regional scale) of the rock and (2) whether the rock's primary mode of origin is volcanic, clastic, sedimentary (carbonates), or alluvial in nature (BSC 2003 [166262], Section 6.3.2). The hydrogeologic subdivisions employed for the TSPA-LA are a synthesis of the Hydrogeologic Framework Model (HFM) (USGS 2003 [165176]) and the calibrated *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.5.3). In all, there are 19 hydrogeologic units employed in the formulation of the base case SZ flow model (BSC 2003 [166262], Section 6.5.3.1), the base case transport model (*Site-Scale Saturated Zone Transport,* BSC 2003 [167208], Section 6.3), and the SZ flow and transport abstraction (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.3).

The 19 hydrogeologic units can be grouped into five basic SZ hydrogeologic subdivisions: the upper volcanic aquifer, upper volcanic confining unit, lower volcanic aquifer, lower volcanic confining unit, and lower carbonate aquifer (BSC 2003 [166262], Section 6.3.2). In SZ base case flow model (BSC 2003 [166262], Sections 6.3.2 and 6.5.3.4), major discontinuities between the 19 hydrostratigraphic units are implemented by including 17 discrete features. These features reflect the degree of fracturing, faulting, fault orientation, and mineralogical alteration of glassy materials to zeolites and clay minerals. In the hydrogeologic units where flow and transport is expected to take place (the alluvium units and Units 15 through Units 11 for the volcanic units (BSC 2003 [166262], Section 6.6.2.2)), variability in transport properties between the major hydrogeologic units is implemented using a range of sampled parameters assigned to each unit for a particular realization (BSC 2003 [167651], Section 6.5.2). How the physical properties of stratigraphic units are modeled is discussed in FEP 2.2.03.02.0A–Rock properties of host rock and other units. Further discussions of the various aspects of stratigraphy affecting flow and transport in the SZ are found in BSC 2003 ([167651], Sections 6.5.2.1 and 6.5.2.2, and Table 6-3), and BSC 2003 ([167208], Section 6.3).

6.2.15 Rock Properties of Host Rock and Other Units (2.2.03.02.0A)

FEP Description:	Physical properties such as porosity and permeability of the relevant rock units, soils, and alluvium are necessary for the performance assessment. Possible heterogeneities in these properties should be considered. Questions concerning events and processes that may cause these physical properties to change over time are considered in other FEPs.
Descriptor Phrases:	Rock properties in the SZ; Hydrologic properties in the SZ
Screening Decision:	Included

Related FEPs: 1.2.02.01.0A, 1.2.02.02.0A, 2.2.03.01.0A, 2.2.07.12.0A, 2.2.08.01.0A, 2.2.07.13.0A

TSPA Disposition:

Geologic features and heterogeneous hydrostratigraphic units are explicitly included in the SZ Transport Abstraction Model (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.2) as cells with specific hydrologic parameter values in a configuration based on the hydrogeologic framework used in the *SZ Site-Scale Flow Model* (BSC 2003 [166262], Section 6.3.2). Spatial variability in rock properties is encompassed within uncertainty distributions for key parameters, such as groundwater specific discharge (GWSPD), horizontal anisotropy in volcanic units (HAVO), flowing interval spacing in volcanic units (FISVO), and sorption coefficients. Uncertainty in the location of the contact between alluvium and volcanic units at the southern end of the site-scale model is modeled probabilistically using the parameters related to the northern and western boundaries of the alluvial uncertainty zone, respectively (FPLAN and FPLAW). A more detailed description of the manner in which rock properties for specific hydrostratigraphic units are implemented is provided in the *Supplemental Discussion* for this FEP in this SZ FEP report.

Supplemental Discussion:

A base case permeability flow field is generated in the *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.5.3). Variability in permeability, due to the presence of faults and fractures, is accounted for in the base case flow model by incorporating 17 key heterogeneous features within the 19 modeled hydrostratigraphic units (BSC 2003 [166262], Sections 6.3.1 and 6.3.2). The presence of faults and fractures can either increase or decrease permeability within a unit. The SZ Transport Abstraction Model and the SZ 1-D Transport Model (both models described in BSC 2003 [167651], Section 6.5 and Table 6-2) take the base case flow model and incorporate additional uncertainty, heterogeneities, and potential changes in permeability through the stochastically sampled GWSPD (BSC 2003 [167651], Section 6.5.2.1). This results in multiple heterogeneous permeability fields. Additional uncertainty in permeability is accounted for in the SZ Transport Abstraction Model (BSC 2003 [167651], Section 6.5 and Table 6-2) through the following stochastically sampled parameters (1) horizontal anisotropy in the volcanic units (HAVO), (2) effective porosity in the alluvium units 7 and 19 (NVF7 and NVF19), (3) flowing interval spacing (FISVO), (4) flowing interval porosity (FPVO) in the volcanics, (5) alluvium bulk density (bulk density), (6) sorption coefficients (K_{dij}) for the 9 radionuclides modeled in both the alluvium and volcanic units, and (7) longitudinal dispersivity (LDISP). The above parameters are described in Sections 6.5.2.3, 6.5.2.4, 6.5.2.5, 6.5.2.7, 6.5.2.8, 6.5.2.9, and 6.5.2.10 of BSC 2003 ([167651]).

The uncertainty in rock properties to be modeled along the alluvium-volcanic contact boundary is explicitly accounted for through the probabilistically sampled parameters, FPLAW and FPLAN (BSC 2003 [167651], Section 6.5.2.2), which define the western and northern boundaries, respectively, of the alluvium (valley-fill aquifer). These parameters determine whether alluvial or volcanic rock properties will be modeled within an area along the alluvial-volcanic interface.

There are numerous broad and distinct zones in the SZ flow model, categorized as "features", which depend on their physical properties such as porosity and permeability. These zones act as either barriers or conduits to SZ groundwater flow and are directly or indirectly affected by faults, zones of mineralogical alteration along faults, or contact zones between units (BSC 2003 [166262], Section 6.5.3.4, Table 12). These zones are (1) zones of permeability enhancement parallel to faults and zones of permeability reduction perpendicular to faults, (2) fault zones with enhanced permeability, (3) contact zones between units and non-fault zones, (4) faults representing regions of lower permeability caused by hydrothermal alteration, and (5) zones of unknown features. Details of the seventeen modeled features are given the FEP 2.2.07.13.0A–Water-conducting features in the SZ.

6.2.16 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 SZ)
Related FEPs:	1.2.02.01.0A, 1.2.02.02.0A, 1.2.10.01.0A, 2.2.06.02.0A, 2.2.06.02.0B, 2.2.10.05.0A
Screening Decision:	Excluded–Low consequence

Screening Argument:

Plate tectonic activity has imparted crustal extension stresses within the Basin and Range Province (which includes the Yucca Mountain region) during the past 12 million years. The height of this activity occurred between 10 and 12 million years ago (m.y.a.) with estimated extension rates ranging between 10 and 30 mm/year (NRC 1992 [105162], Chapter 2). During this period major faults and fractures within the Yucca Mountain vicinity were created. Approximately 5 m.y.a. regional extension stresses declined to 5-10 mm/year; extension rates are still in a declining state today (NRC 1992 [105162], Chapter 2). On a local scale, regional extension rates impart local extension, compression and shear stresses on the crust depending on location, depths, and juxtaposition to parent rock units and existing faults. Release of stress results in seismic activities that create vibratory motion, faults (rupture), fault displacement, or areal redistribution of stresses not associated with specific faults. Vibratory stresses caused by seismic activity can alter the hydrologic properties of the parent rock. A seismic event can permanently affect rock hydrologic properties by (1) causing a change in pore pressures, which is usually a product of regional stress changes, or (2) an increase or decrease in permeability produced by either dilation, compression or breakage of granular structures produced from dynamic ground motion.

A seismic event is most likely to cause movement along existing faults and fractures (BSC 2004 [167720], Section 6.2.1.10) or change rock and inter-granular stresses, thus affecting rock hydrologic properties due to the creation of brecciation and gouge zones adjacent to the faults and existing fractures and possibly the production of new fractures (outside of the brecciated zone). This disturbed rock zone, labeled herein as a "zone of alteration," is correlated with the amount of fault offsets (Sweetkind et al. 1997 [100183]). Faults with 1–5 m of cumulative offset have a zone of alteration width of only 1–2 m; faults with tens of meters of offset can have a zone of alteration tens of meters wide (Sweetkind et al. 1997 [100183], pp. 66 through 71). Existing rock hydrologic properties in the zone of alteration reflect the cumulative response to cumulative displacements of a dynamic seismic past, reflective of rapid extension rates in existent 10 to 12 m.y.a. and to a lesser extent, the lower extension rates in effect today.

Expert elicitation, documented in the Probabilistic Seismic Hazard Analysis (PSHA) report, provides information that can be used to assess the effects of a seismic event on the hydrologic properties of intact rock. Of the numerous faults and seismic zones within vicinity of Yucca Mountain, the group identified nine regional and local fault displacement hazard zones they considered as most likely to contribute to maximum vibratory stresses (*Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada,* CRWMS M&O 1998 [103731], Figure 4-9).

One region of concern in the SZ flow domain is the area between Solitario Canyon and the Ghost Dance Faults, identified as Zone 8 by the PSHA group (CRWMS M&O 1998 [103731], Zone 8 in Figure 4-9), which is due west of the source point for all SZ flow paths. In this region the PSHA group assessed the mean displacement for intact rock in the vicinity of the repository to be less than 0.1 cm for a 1E-08 annual-exceedance probability (CRWMS M&O 1998 [103731], Section 8). This area encompasses the same rock type as that along the origin of the Saturated Zone Flow and Transport (SZFT) paths. Therefore, it is inferred that future seismic activity will not result in any significant new faults and fractures in the intact rock, nor will it alter the hydrologic properties in the existing 'zone of alteration' within that region that would affect SZ flow path origins. Flow path trajectories or flow velocities will not be significantly altered given predicted seismic activity within the area bounded by the Solitario Canyon and Ghost Dance Faults over the regulatory period.

The PSHA panel estimated mean fault displacement for the majority of intrablock faults in the Yucca Mountain vicinity to be between 2 to 4 m at an annual exceedance probability of 1E-8 (CRWMS M&O 1998 [103731], Section 8.2). The exceptions to this predicted range are the predicted displacements for the Solitario Canyon and Bow Ridge faults (CRWMS M&O 1998 [103731], Zones 2 and 9 in Figure 4-9). The panel predicted approximately a 10-m mean fault displacement for the Solitario Canyon fault at an annual exceedance probability of 1E-8, and a 7.5-m mean displacement for the Bow Ridge Fault at an annual exceedance probability of 1E-5 (CRWMS M&O 1998 [103731], Figures 8-2 and 8-3). These displacements will not affect SZ transport and flow paths for the following reasons.

The Solitario Canyon Fault has a cumulative displacement of approximately 260 m where it intersects the ECRB Cross-drift. With this relatively large displacement, its zone of alteration consists of approximately a 20-m brecciated and gouge zone and a seismically induced fractured area that extends tens of meters from the fault (BSC 2004 [167720], Section 6.2.1.10). The 10-m predicted displacement represents a fraction of the fault's response to multiple seismic events imposed in the region for many millennia. It is inferred, given estimated future fault displacements inclusive of the approximately 10-m displacement for the Solitario Canyon fault, the hydrologic properties in the zone of alteration will not be significantly altered from current conditions in the next 10,000 years. Detailed discussions on the effects of seismic events on rock properties are provided in BSC (2004 [167720], Sections 6.2.1.8 through 6.2.1.11).

The Bow Ridge fault is one of many faults included in the areally extensive faulted region identified as the "Imbricate Fault Zone" in the *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.5.3.4 and Table 12). The Imbricate Fault Zone is modeled in a parallelogram shaped region encompassing an area approximately 3.5 km wide and 8 km long. It includes highly fractured and brecciation zones and numerous interconnected faults, the Bow Ridge Fault being one. Due to the higher incidence of interconnected fractures and faults located in this area, the SZ flow and transport model specifically incorporates relatively higher permeabilities here (BSC 2003 [166262], Section 6.4.3.2 and Figure 7). Because the Imbricate Fault Zone is areally extensive and includes numerous faults and their attendant zones of alteration, a 7.5-m fault displacement within the Bow Ridge fault would not alter the range of effective permeabilities attributed to this region. All other displacement hazard zones identified by the PHSA group are outside of the predicted SZ flow paths and thus will not affect SZ flow paths.

An investigation conducted by the National Research Council (NRC 1992 [105162], Chapter 5 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]) looked at water table fluctuations given a predicted seismic event. Results from this report support the assumption that a future seismic event will not permanently alter the regional hydrologic properties of intact rock. The group looked at two modeling approaches in estimating the change in water table elevations given a seismically induced event: (1) a dislocation approach, where zones of extension on one side of a fault are balanced by compression across the fault, and (2) the more realistic 'changes in regional stress' approach caused by normal fault slippage in regions of extension. The regional stress approach evaluates the effect of stress on pore pressure, which is dependent on the elastic properties of the bulk rock and the mineral grains. The extent of water table fluctuations differed for both models. Adopting the dislocation model, the water table rose approximately 10 m. Adopting the regional stress approach resulted in maximum water table rise of 50 m. The latter approach assumes realistically conservative rock and mineral elastic properties. The panel concluded, regardless of what approach is taken, the maximum water table rise given a seismic event would be less that 50 m and transient in nature. Because water table fluctuations were transient for both modeling approaches, it is inferred that a future seismic event (predicted over the next 10,000 years) will not permanently alter the rock hydrologic properties (including pore pressures) on a regional scale.

Observations of water table responses to recorded seismic events support the above modeling results. The United States Geological Survey (USGS) has produced an Open File Report 93-73 (O'Brien 1993 [101276]), wherein water level fluctuations at Yucca Mountain due to earthquakes were analyzed. Fluctuations range from 90 cm related to a 7.5 magnitude earthquake near Landers, CA (approximately 420 km from Yucca Mountain), to 20 cm for a second quake of 6.6 magnitude near Big Bear Lake, CA (approximately 400 km from Yucca Mountain). More notably, a 5.6 magnitude quake 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 3 days following the earthquake. Water levels in that well returned to pre-quake levels over a period of about 6 months. Implicit in the observations, given the short duration and relatively small magnitude of seismically induced water table fluctuations, was that a seismically induced permanent change in regional rock hydrologic properties from the observed earthquakes did not occur.

As stated earlier, existing rock hydrologic properties along a fault's zone of alteration reflect the cumulative response to cumulative displacements of a dynamic seismic past. Because the Yucca Mountain region is now experiencing lower extension rates and is tectonically less active, predicted fault displacements are minor and will alter rock properties minimally compared to intact rock alterations due to the cumulative fault displacements of an active tectonic past. Furthermore, flow and transport in the SZ is dominated by existing fractures, fracture clusters and fracture spacing, collectively labeled as flowing intervals in the SZFT model (BSC 2003 [167651], Section 6.3). The SZFT model evaluates uncertainties assigned to flowing interval properties such as horizontal anisotropy in the volcanic units, flowing interval spacing, flowing interval porosity in the volcanics, and longitudinal dispersion (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Table 6-8). Transport times through the SZ are quite sensitive to parameter uncertainty associated with flowing interval properties (only uncertainty in the specific discharge scaling parameter, which is meant to account for increased specific discharge due to a wetter climate, produces a greater variation in transport times). As an example, parameter uncertainty in flowing interval spacing results in transport times that vary by several thousands of years (Arnold et al. 2000 [166335]). The uncertainty incorporated in the horizontal anisotropy (which accounts for the uncertainty in maximum and minimum *in-situ* stresses imposed on fractures and faults) results in transport paths varying by several kilometers (BSC 2003 [167651], Figure 6-6). Thus the incorporated parameter uncertainty in regional flowing interval properties overwhelms any changes in SZ transport times and flow paths associated with seismically induced changes in hydrologic properties of the rock matrix inclusive of the Bow Ridge fault in the Imbricate Fault Zone and the Solitario Canyon fault (see related FEPs 1.2.10.01.0A–Hydrologic response to seismic activity, 2.2.06.02.0A–Seismic activity changes porosity and permeability of faults, and 2.2.06.02.0B–Seismic activity changes porosity and permeability of fractures).

In summary, the expected changes in rock properties due to seismic activity are excluded based on low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.17 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 SZ)

Screening Decision: Excluded–Low consequence

Related FEPs: 1.2.02.01.0A, 1.2.02.02.0A, 1.2.10.01.0A, 2.2.06.01.0A, 2.2.06.02.0B, 2.2.10.05.0A

Screening Argument:

Fault displacement is a result of regional plate tectonic activity that imparts crustal extension stresses causing rupture of the parent rock. Within the Basin and Range Province (which includes the Yucca Mountain region) peak extension stresses occurred between 10 and 12 million years ago (m.y.a.) with extension rates between 10 and 30 mm/year (NRC 1992 [105162], Chapter 2). These rapid extension rates formed two major north trending extension belts and normal faulting zones. Approximately 5 m.y.a. regional extensional stress declined to 5–10 mm/year; extension rates are still in a declining state today (NRC 1992 [105162], Chapter 2). It is the extension stresses imposed on the areally broad Basin and Range Province that impart the extension, compression and shear stresses on the crust and determine fault development. The type of stress transmitted locally is dependent on location, depth, and juxtaposition to existing faults. These locally imposed stresses, which control existing fault hydrological properties (*Site-Scale Saturated Zone Flow Model,* BSC 2003 [166262], Section 6.3.2.10), are driven by the crustal (and now declining) extension rates. Of interest is the likelihood of future fault formation and displacement within the Yucca Mountain region.

Expert elicitation, documented in the Probabilistic Seismic Hazard Analysis (PSHA) report, provides information that can be used to assess the effects of a seismic event on fault formation. The PSHA group assessed the mean displacement in intact rock to be less than the 0.1 cm for a 1E-08 annual-exceedance probability. Consequently, no significant new faults are likely to form in the Yucca Mountain vicinity within the next 10,000 years.

A seismic event is most likely to cause movement along existing faults and could affect a fault's hydrologic properties. With the exception of the Solitario Canyon fault, the PSHA panel estimated mean fault displacement for the majority of intra-block faults in the Yucca Mountain vicinity to be between 2 to 4 m at an annual exceedance probability of 1E-8 (*Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada,* CRWMS M&O 1998 [103731], Section 8.2). At the same low exceedance probability the panel predicted a 10-m mean fault displacement the for Solitario Canyon fault (CRWMS M&O 1998 [103731], Figure 8-3). As discussed in *Errata for Features, Events and Processes: Disruptive Events* (BSC 2004 [167720], Section 6.2.1.10), the energy produced from a seismic event will be dissipated along existing faults. This energy can cause deformation and breakage of the parent rock creating brecciation and gouge zones adjacent to the faults and existing fractures and possibly the production of new fractures (outside of the brecciated zone). This disturbed rock zone, labeled herein as a “zone of alteration,” is correlated with the amount of fault offset (Sweetkind et al. 1997 [100183]). Generally, the zone of alteration adjacent to the fault is relatively narrow. Faults with 1–5 m of cumulative offset have a zone of alteration width of only 1–2 m; faults with tens of meters of offset can have zone of alteration up to tens of meters wide (Sweetkind et al. 1997 [100183], pp. 66 through 71).

Several studies have been performed to determine changes in water table elevations due to seismic induced changes in fault properties, implicitly due to fault offset. Carrigan et al. 1991 [100967] modeled a 100-m wide fracture zone centered on a vertical fault (i.e., a seismically induced altered zone) such that vertical permeability was increased by three orders of magnitude. The results of that model indicate (a short-term) transient water table rise of up to 12 m in the fracture zone with 1 m of fault slip. Their tectonohydrologic model simulated earthquakes typical of the Basin and Range Province (with approximately a 1-m slip) to produce a simulated rise of 2 m to 3 m for a water table 500 m below ground surface. Extrapolation to a 4-m slip results in a transient rise of 17 m near the fault (Carrigan et al. 1991 [100967], p. 1159).

Gauthier et al. (1996 [100447], pp. 163 through 164) analyzed the potential changes in water table elevation due to the effects of seismic activity as a result of three different types of fault displacements. For all three fault types, a 1-m displacement with a 30-km rupture length was considered. Simulations of the timing, magnitude, and duration of water table rise indicate a maximum rise of 50 m within an hour of the simulated event. The simulated system returns to steady-state conditions within 6 months. Gauthier et al. 1996 [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 simulation.”

The above studies predict short-term water table excursion given 1-m to 4-m fault slips. It is inferred that an approximately 10-m displacement along the Solitario Canyon fault will result in transient and slightly higher water table excursions. These early studies substantiate an investigation headed by the National Research Council (NRC 1992 [105162]) on the geologic and climatic processes that could affect water elevations. The council addressed the maximum level the water table could rise within the next 10,000 years given several processes, one being seismic pumping. They evaluated water table responses due to two types of seismic processes: (1) dislocation, where zones of extension on one side of a fault are balanced by compression across the fault; and (2) the more realistic ‘changes in regional stress’ approach caused by normal fault slippage in regions of extension. The regional stress approach evaluates the effect of stress on pore pressure, which is dependent on the elastic properties of the bulk rock and the mineral grains. The extent of water table fluctuations differed for both models. Adopting the dislocation model, the water table rose approximately 10 m. Adopting the regional stress approach resulted in maximum water table rise of 50 m. The later approach assumes realistically conservative rock and mineral elastic properties. The panel concluded, regardless of what approach is taken, the maximum water table rise given a seismic event would be less that 50 m and transient in nature. Because water table fluctuations were transient for both modeling approaches, it is inferred that a future seismic event (predicted over the next 10,000 years) that could result in a 10-m slip along the Solitario Canyon fault will not alter the fault's hydrologic properties.

Moreover, current Solitario Canyon fault hydrologic properties reflect the cumulative effects of a highly active tectonic and seismic past that resulted in a 260-m cumulative fault displacement where it intersects the ECRB Cross-drift (Mongano et al. 1999 [149850], pp. 48-65). With this relatively large fault displacement, its zone of alteration consists of approximately a 20-m brecciated and gouge zone and seismically induced fractured area that extends tens of meters from the fault (BSC 2004 [167720], Section 6.2.1.10). An approximately 10-m displacement of the Solitario Canyon fault (and other faults) will release local stresses accumulated along the fault plane but will not alter the large and globally extensive stresses in effect over the past 10 to 12 million years, incurred in the parent rock and embedded faults within the Yucca Mountain region (NRC 1992 [105162], Chapter 5 referenced in DTN: MO0310INPDEFEP.000 [DIRS 165880]). It is these global and areally extensive stresses imposed on the fault that determine the faults hydrologic properties. It is logically concluded the Solitario Canyon fault's hydrologic properties will be remain essentially unchanged given an approximately 10-m displacement. The fault will continue to serve as a groundwater divide between the Yucca Mountain and the Crater Flat regions (*Site-Scale Saturated Zone Flow Model,* BSC 2003 [166262], Section 6.3.2). As observed with other fault displacements, the water table could rise or decrease due to seismic response, but the fluctuation will be (at most) a few tens of meters and transient in nature.

The magnitude and transient nature of a predicted water table rise is consistent with observation of recorded seismic events. The United States Geological Survey (USGS) has produced an Open File Report 93-73 (O'Brien 1993 [101276]) wherein water table level fluctuations at Yucca Mountain due to earthquakes are analyzed. Water table fluctuations range from 90 cm, related to a 7.5 magnitude earthquake near Landers, CA (approximately 420 km from Yucca Mountain), to 20 cm for a second quake of 6.6 magnitude near Big Bear Lake, CA (approximately 400 km from Yucca Mountain). More notably, a 5.6 magnitude quake 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 3 days following the earthquake. Water levels in that well returned to pre-quake levels over a period of about 6 months. The above reports support the fact that recorded fault slippage in the Yucca Mountain region has resulted in a transient hydrologic response but has not resulted in permanent alteration of the fault's regional hydrologic properties.

Additionally, the uncertainty in the effective hydrologic properties incorporated in the SZ flow and transport model (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Table 6-8), which reflects the cumulative changes in a fault's hydrologic properties during a heightened seismically active past, coupled with the scale of the model (a grid discretized 500 m in the horizontal direction and 10 to 550 m in the vertical direction), overwhelms the changes in fault properties that would be caused by seismic events within the next 10,000 years. Flow and transport in the SZ is dominated by existing fractures, fracture clusters and fracture spacing, collectively labeled as flowing intervals in the Saturated Zone Flow and Transport (SZFT) model (BSC 2003 [167651], Section 6.3). The SZFT model evaluates uncertainties assigned to flowing interval properties such as horizontal anisotropy in the volcanic units, flowing interval spacing, flowing interval porosity in the volcanics, and longitudinal dispersion (BSC 2003 [167651], Table 6-8). Transport times through the SZ are quite sensitive to parameter uncertainty associated with flowing interval properties (only uncertainty in the specific discharge scaling parameter, which is meant to account for increased specific discharge due to a wetter climate, produces a greater variation in transport times). As an example, parameter uncertainty for flowing interval spacing results in transport times that vary by several thousands of years (Arnold et al. 2000 [166335]). The uncertainty incorporated in the horizontal anisotropy (which accounts for the uncertainty in maximum and minimum *in-situ* stresses imposed on fractures and faults) results in transport paths varying by several kilometers (BSC 2003 [167651], Figure 6-6). Thus the incorporated parameter uncertainty in regional flowing interval properties overwhelms any potential changes in a fault's hydrologic properties associated with future seismic activity (and is reflective of regional tectonic activity).

Consequently, future seismic events will not alter the range of existing fault permeability and porosity values incorporated in the SZ flow and transport model (See related FEPs 1.2.10.01.0A–Hydrologic response to seismic activity and 2.2.06.02.0B–Seismic activity changes porosity and permeability of fractures).

In summary, seismic events will have a minimal effect on the simulated flux at the compliance boundary and on the release of radionuclides to the accessible environment based on the following conclusions:

1. The energy of future seismic events will be primarily transmitted through existing fractures and faults, rather than development of new ones.

2. Changes to fault properties (which implicitly affect the fault's hydrologic properties) will tend to occur in a relatively narrow zone, and be on the order of a few meters to, at most, tens of meters wide along the length of the fault (BSC 2004 [167720], Section 6.2.1.10).

3. Current fault porosities and permeabilities reflect the effects of a seismically active past within the Yucca Mountain region. Past seismic activity is reflective of major plate extension and caldera formation phases in the Basin and Range Province, which includes the Yucca Mountain region. Seismic activity within the Yucca Mountain region is currently in a relatively quiescent period. Consequently, seismic events that will occur in the next 10,000 years will have a "relatively" low impact on existing fault hydrologic properties.

4. The uncertainty in the effective hydrologic properties incorporated in the SZ flow and transport model, coupled with the flux multiplier that effectively models wetter climatic conditions, overwhelms the changes that would be caused by small movements along existing faults.

5. Observed, seismically-induced water table fluctuations, and those simulated with numerical models, indicate future seismic events will alter water table elevations for a relatively short period of time. After a seismic event, water table elevations will return to pre-existing levels within about a 6-month period.

In conclusion, changes in fault properties in the SZ can be excluded based on low consequence because they will not significantly affect radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.18 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 SZ)
Related FEPs:	1.2.02.01.0A, 1.2.02.02.0A, 1.2.10.01.0A, 2.2.06.01.0A, 2.2.06.02.0A, 2.2.10.04.0A
Screening Decision:	Excluded–Low consequence

Screening Argument:

Fault displacement, and concomitant fracture formation, is a result of regional plate tectonic activity that imparts crustal extension stresses causing rupture of the parent rock. Within the Basin and Range Province (which includes the Yucca Mountain region) peak extension stresses were 10–30 mm/year between 10 and 12 million years ago (m.y.a.) (NRC 1992 [105162], Chapter 2). These rapid extension rates formed two major north trending extension belts and normal faulting zones. Approximately 5 m.y.a. regional extensional stress declined to 5–10 mm/year; extension rates are still in a declining state today (NRC 1992 [105162], Chapter 2). It is the extension stresses imposed on the areally broad Basin and Range Province that imparts the extension, compression and shear stresses on the crust and determine fault and concomitant fracture development and properties. The type of stress transmitted locally is dependent on location, depths, and juxtaposition to existing faults. These locally imposed stresses, which control existing fault hydrological properties (*Site-Scale Saturated Zone Flow Model,* BSC 2003 [166262], Section 6.3.2.10), are driven by the crustal (and now declining) extension rates. Concurrent with declining extension rates are declining fault and fracture development and fault displacement. Of interest is the likelihood of fracture formation within the Yucca Mountain region.

Expert elicitation documented in the Probabilistic Seismic Hazard Analysis (PSHA) report predict less than a 1-cm displacement within the vicinity of the repository host rock (between

Solitario Canyon and the Ghost Dance Faults) at a 1E-08 exceedance probability (*Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada,* CRWMS M&O 1998 [103731], Section 8). Consequently, no significant new faults and fractures are likely to form in the Yucca Mountain vicinity within the next 10,000 years. Furthermore, future seismic events are most likely to cause movement along existing faults and fractures. With the exception of the Solitario Canyon fault, the PSHA panel estimated mean fault displacement for the majority of intra-block faults in the Yucca Mountain vicinity to be between 2 to 4 m at an annual exceedance probability of 1E-8 (CRWMS M&O 1998 [103731], Section 8.2). At the same low exceedance probability the panel predicted a 10-m mean fault displacement for the Solitario Canyon fault (CRWMS M&O 1998 [103731], Figure 8-3). As discussed in *Errata for Features, Events and Processes: Disruptive Events* (BSC 2004 [167720], Section 6.2.1.10), the energy produced from a seismic event will be dissipated along existing faults. Changes in rock properties along the length of existing faults, due to the creation of brecciation and gouge zones adjacent to the fault and the production of fractures (outside of brecciated zone), are correlated with the amount of fault offsets (Sweetkind et al. 1997 [100183]). Generally, the zone of alteration adjacent to the fault (which includes fractures) is relatively narrow. Faults with 1–5 m of cumulative offset have a zone of alteration width of only 1–2 m; faults with tens of meters of offset can have zone of alteration up to tens of meters wide (Sweetkind et al. 1997 [100183], pp. 66 through 71). The Solitario Canyon Fault has a cumulative displacement of approximately 260 m where it intersects the ECRB Cross-drift; with this relatively large displacement it's zone of alteration consists of approximately a 20-m brecciated and gouge zone and seismically induced fractures that extend tens of meters from the fault (BSC 2004 [167720], Section 6.2.1.10).

Several studies have been performed to determine changes in water table elevations due to seismically induced changes in fault and fracture properties. Carrigan et al. (1991 [100967]) modeled a 100-m wide fracture zone centered on a vertical fault, such that vertical permeability was increased by three orders of magnitude. The results of that model indicate a transient water table rise of up to 12 m in the fracture zone with one meter of slip. These results indicate seismic pumping due to changes in fracture permeability along faults would produce a short-term and transient water table rise.

The above study predicts short-term water table excursion given 1- to 4-m fault slips and attendant alteration of adjacent fractures. It is inferred that an approximately 10-m displacement along the Solitario Canyon fault, and resulting changes in fracture properties, will result in transient and slightly higher water table excursions. This assumption is supported by an investigation headed by the National Research Council on the geologic and climatic processes that could affect water elevations. The council addressed the maximum level the water table could rise within the next 10,000 years given several processes, one being seismic pumping. They evaluated water table responses due to two types of seismic processes: (1) dislocation, where zones of extension on one side of a fault are balanced by compression across the fault; and (2) the more realistic 'changes in regional stress' approach caused by normal fault slippage in regions of extension. The regional stress approach evaluates the effect of stress on pore pressure, which is dependent on the elastic properties of the bulk rock and the mineral grains. The extent of water table fluctuations differed for both models. Adopting the dislocation model, the water table rose approximately 10 m. Adopting the regional stress approach resulted in maximum water table rise of 50 m. The later approach assumes realistically conservative rock and mineral elastic properties. The panel concluded that regardless of what approach is taken, the maximum water table rise given a seismic event would be less that 50 m and transient in nature. Because water table fluctuations were transient for both modeling approaches, it is inferred that a future seismic event (predicted over the next 10,000 years) that could result in changes in the regional stress field imposed on fractures, inclusive of a stresses imposed by a 10-m slip along the Solitario Canyon fault, will not alter the regional fracture hydrologic properties.

The magnitude and transient nature of a predicted water table rise is consistent with observation of recorded seismic events. The United States Geological Survey (USGS) has produced an Open File Report 93-73 (O'Brien 1993 [101276]), wherein water table level fluctuations at Yucca Mountain due to earthquakes are analyzed. Water table fluctuations range from 90 cm, related to a 7.5 magnitude earthquake near Landers, CA (approximately 420 km from Yucca Mountain), to 20 cm for a second quake of 6.6 magnitude near Big Bear Lake, CA (approximately 400 km from Yucca Mountain). More notably, a 5.6 magnitude quake 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 3 days following the earthquake. Water levels in that well returned to pre-quake levels over a period of about 6 months. The above reports support the fact that recorded seismic events in the Yucca Mountain region resulted in a transient hydrologic response. Given the observed transient responses to seismic events within the southwest portion of the Basin and Range province, it is inferred that the above seismic events did not alter regional fracture hydrologic properties.

Additionally, flow and transport in the SZ is dominated by existing fractures, fracture clusters and fracture spacing, collectively labeled as flowing intervals in the Saturated Zone Flow and Transport (SZFT) model (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.3). The SZFT model evaluates uncertainties assigned to flowing interval properties such as horizontal anisotropy in the volcanic units, flowing interval spacing, flowing interval porosity in the volcanics, and longitudinal dispersion (BSC 2003 [167651], Table 6-8). Transport times through the SZ are quite sensitive to parameter uncertainty associated with flowing interval properties (only uncertainty in the specific discharge scaling parameter, which is meant to account for increased specific discharge due to a wetter climate, produces a greater variation in transport times). As an example, parameter uncertainty in flowing interval spacing results in transport times that vary by several thousands of years (Arnold et al. 2000 [166335]). The uncertainty incorporated in the horizontal anisotropy (which accounts for the uncertainty in maximum and minimum *in-situ* stresses imposed on fractures and faults) results in transport paths varying by several kilometers (BSC 2003 [167651, Figure 6-6). Thus the incorporated parameter uncertainty in regional flowing interval properties overwhelms any changes in SZ transport times and flows paths associated with seismically induced changes in flowing interval properties.

Furthermore, existing regional stresses imposed on fracture hydrologic properties reflect the crustal extension stresses in effect today. A fracture's physical properties (orientation, length, connectivity and clustering) are reflective of a cumulative response to seismic events in existence 10 to 12 million years ago. A change in regional fracture properties, given predicted seismic activity, will be minimal relative to multiple seismic events imposed in the region for many millennia. Therefore, it is inferred, regional fracture hydrologic properties will not be significantly altered from current conditions in the next 10,000 years. As a result changes in intact fracture properties are excluded based on low consequence because they will not significantly affect radiological exposures to the RMEI or radionuclide releases to the accessible environment.

(Additional discussions on the effects of seismic events on rock properties are provided in BSC 2004 [167720], Sections 6.2.1.8, 6.2.1.9, 6.2.1.10, and 6.2.1.11.)

6.2.19 Saturated Groundwater Flow in the Geosphere (2.2.07.12.0A)

FEP Description:	Groundwater flow in the saturated zone below the water table may affect long-term performance of the repository. The location, magnitude, and direction of flow under present and future conditions and the hydraulic properties of the rock are all relevant.
Descriptor Phrases:	Saturated flow and pathways in the SZ
Related FEPs:	1.4.07.02.0A, 2.2.03.01.0A, 2.2.03.02.0A, 2.2.07.13.0A, 2.2.07.16.0A, 2.2.07.15.0A, 2.2.12.00.0B
Screening Decision:	Included

TSPA Disposition:

Steady-state, saturated, 3-D groundwater flow within the Yucca Mountain vicinity is modeled through the *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Sections 6.2 and 6.3.1) using the numerical code FEHM V 2.20 (LANL 2003 [161725], STN: 10086-2.20-00). The model domain is a 30- by 45-km region within the confines of the Death Valley groundwater basin (BSC 2003 [166262], Section 6.3.2). Inputs include faults and fault zones (BSC 2003 [166262], Section 6.3.2.10) and variable permeabilities associated with the 19 hydrostratigraphic units (FEP 2.2.03.02.0A–Rock properties of host rock and other units) identified through the Hydrogeologic Framework Model (USGS 2003 [165176]). The most significant flow units are the volcanic Crater Flat Tuff hydrogeologic (hydraulic) units and the shallow alluvial aquifer of Fortymile Wash. Flow through fractures is modeled through an effective continuum flow model (BSC 2003 [166262], Section 6.3.3).

Recharge is modeled through underflow, surface flow infiltration, and UZ infiltration components (BSC 2003 [166262], Section 6.3.2.7). The impact of future climatic conditions on flow are modeled in the *SZ Flow and Transport Model Abstraction* (BSC 2003 [167651], Section 6.5) using a convolution integral method (SZ_Convolute V 2.2 software code (STN: 10207-2.2-00, Sandia National Laboratories (SNL) 2003 [163344]) and BSC 2003 [167651], Section 6.5) that scales radionuclide breakthrough curve simulations representing current climatic conditions using representative scaling factors (BSC 2003 [167651], Section 6.5.1).

6.2.20 Water-Conducting Features in the SZ (2.2.07.13.0A)

FEP Description:	Geologic features in the saturated zone may affect groundwater flow by providing preferred pathways for flow.
Descriptor Phrases:	Fracture flow in the SZ
Screening Decision:	Included
Related FEPs:	1.2.02.01.0A, 1.2.02.02.0A, 2.2.03.01.0A, 2.2.03.02.0A, 2.2.07.12.0A, 2.2.12.00.0A, 2.2.12.00.0B

TSPA Disposition:

Faults and fractures in the volcanic units are explicitly modeled in the SZ (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651], Section 6.2) through 17 discrete geologic features incorporated in the SZ base case model (*Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Section 6.3.2). The variability and uncertainty due to the presence of fracture clusters, flowing intervals, and rubblized zones (all possible subsets of water-conducting features within the faulted and fractured system) is modeled in the SZ Transport Abstraction Model and the SZ 1-D Transport Model (both described in BSC 2003 [167651], Section 6.5.2 and Table 6-2) through the following stochastically sampled parameters: (1) groundwater specific discharge (GWSPD), (2) the flowing interval parameter (FISVO), (3) horizontal anisotropy in the volcanic units (HAVO), (4) flowing interval porosity in the volcanics (FPVO), and (5) longitudinal dispersivity (LDISP). The ranges of uncertainty in these parameters encompass the possibility of channelized flow along preferred pathways. The above parameters are described in Sections 6.5.2.1, 6.5.2.4, 6.5.2.5, 6.5.2.9, and 6.5.2.10 of BSC 2003 [167651].

There are numerous broad and distinct zones in the SZ flow model, categorized as “features” and, depending on their physical properties, act as either barriers or conduits to SZ groundwater flow. These are areas directly or indirectly affected by faults, zones of mineralogical alteration along faults, or contact zones between units (BSC 2003 [166262], Section 6.5.3.4). A more detailed description of the modeling of water conducting features in the SZ is provided in the *Supplemental Discussion* for this FEP in this SZ FEP report.

Supplemental Discussion:

There are numerous broad and distinct zones in the SZ flow model, categorized as “features”, which act as either barriers or conduits to SZ groundwater flow. These are areas directly or indirectly affected by faults, zones of mineralogical alteration along faults, or contact zones between units (BSC 2003 [166262], Section 6.5.3.4). A feature with no known association with distinct fault or fault zones is also incorporated into the Saturated Zone Flow and Transport (SZFT) model and is based on a large hydraulic gradient, which exists just north and slightly west of Yucca Mountain. There are several theories as to what is the cause of the large hydraulic gradient, but no one theory is overwhelmingly favored over others. Nevertheless, a feature (with no geologic significance) has been incorporated into the model to produce a large hydraulic gradient north of the repository.

All 17 features are distinct from the sub-horizontal geologic formations in which they reside; most are essentially vertical, with some linear in the horizontal extent, and others areally extensive (BSC 2003 [166262], Figure 19). Depending on their hydrologic impact on groundwater flow patterns, these features fall under several distinct categories. A list of the 17 features modeled in the *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Table 12), aggregated under hydrologic categories, is given below. Figure 6.2-3 is a depiction of the seventeen discrete features modeled in the SZFT model; many of these features are based on known faults and fault zones depicted on the left side of the figure.

(1) Zones of permeability enhancement parallel to faults and zones of permeability reduction perpendicular to faults

- **Crater Flat Fault**–This is a linear feature running north-south in the western half of the model, starting south of Claims Canyon and terminating near Highway 195, almost halfway between the western boundary of the Solitario Canyon. Vertically, it extends from the top to the bottom of the model.
- **Solitario Canyon Fault Zone**–A north-south trending linear feature just to the west of Yucca Mountain. Vertically it extends from the top to the bottom of the model.
- **Solitario Canyon Fault, East Branch**–A north-northeast trending linear feature just to the west of Yucca Mountain. Vertically, it extends from the bottom of the model to the top of the model.
- **Solitario Canyon Fault, West Branch**–A north-northeast trending linear features just to the west of Yucca Mountain. Vertically, it extends from the bottom of the model to the top of the model.
- **Highway 95 Fault (West)**–This is a linear feature in the lower half of the western portion of the model. It is east-southeast trending. Vertically, it extends from the bottom to the top of the model.

(2) Fault zones with enhanced permeability

- **Bare Mountain Fault**–This is a northwest- to southeast-trending linear feature in the southwestern corner of the model. Vertically, it extends from the bottom to the top of the model.
- **Imbricate Fault Zone**–This is a highly faulted area bounded in the west by the Ghost Dance fault, south by the Dune Wash, east by the Paintbrush Canyon fault, and to the north by the Drillhole Wash. Vertically, it extends from the top of the model down through the middle volcanics to the top of the undifferentiated units.

(3) Contact zones between units and non-fault zones

- **Alluvial Uncertainty Zone**–This feature represents the uncertainty zone between the alluvium and tuff boundaries. It is roughly a rectangular region to the south of Yucca Mountain in the southern half of the model. Vertically, it extends from the top of the model down through the undifferentiated units.

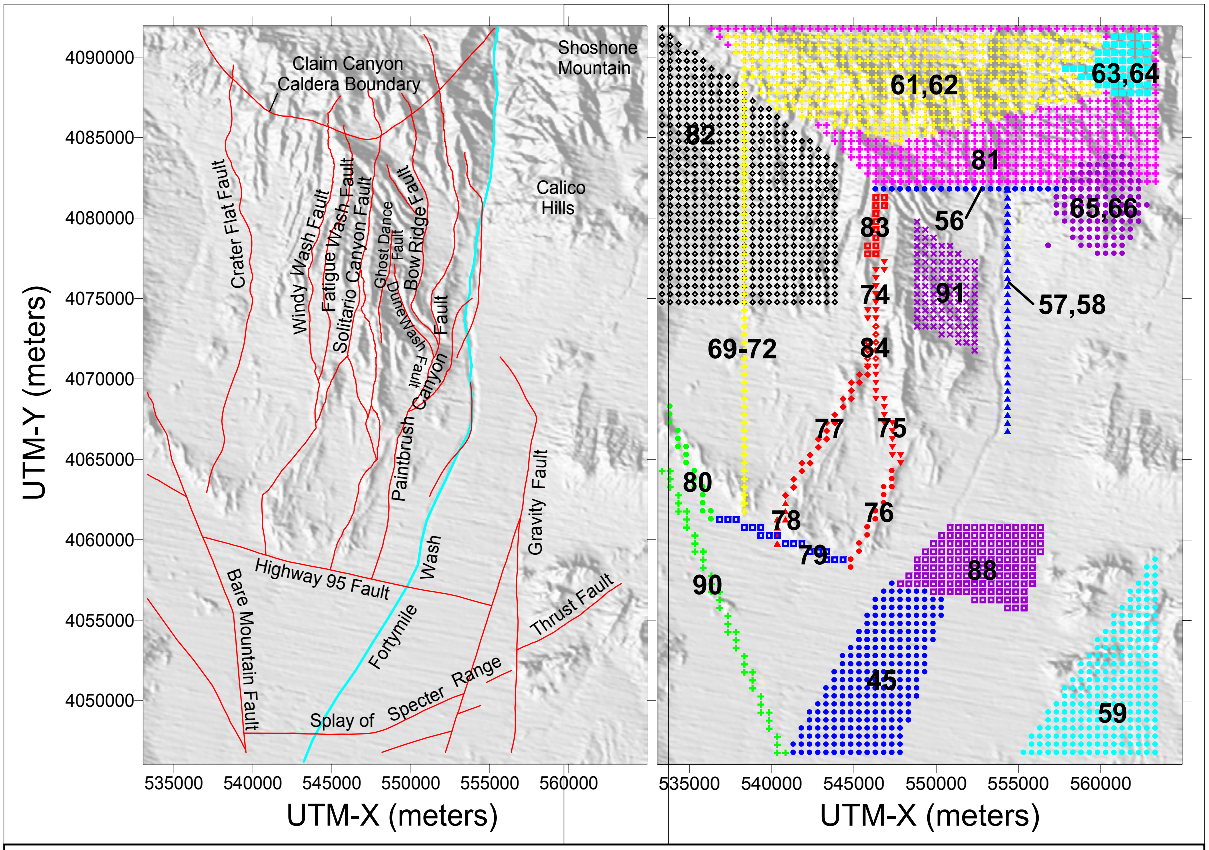
- **Spotted Range-Mine Mountain Zone**–This triangular feature is in the southeast corner of the model. Vertically, it extends from top of the model down to the bottom. A zone of enhanced permeability is associated with the Spotted Range Thrust Region.
- **Fortymile Wash Zones**–These two north-south linear features are located approximately halfway between Yucca Mountain and the eastern model boundary. Vertically, it extends from the top to the bottom of the model.
- **Lower Fortymile Wash Zone**–This quadrilateral, enhanced permeability feature encompasses the Lower Fortymile Wash part of the model. The depth of the zone includes the alluvium unit to the top of the model.

(4) Faults representing regions of lower permeability caused by hydrothermal alteration

- **Northern Zone (entire Claim Canyon, Calico Hills, and Shoshone Mt.)**–This zone is wedge-shaped, spanning almost the entire northern boundary (except the western corner of the northern boundary) and approximately the upper fourth of the eastern boundary. Vertically, it extends from the top to the bottom of the model.
- **Northern Crater Flat Zone**–This wedge-shaped zone is at the northern third of the western boundary of the model. Vertically, it extends from the top to the bottom of the model.
- **Claim Canyon Caldera**–These zones span much of the northern boundary of the model, extending south as triangular shapes and terminating north of the Yucca Wash. Vertically, it extends from the top to the bottom of the model.
- **Shoshone Mt. Zone**–These two zones are in the northeastern corner of the model. They extend from the top of the carbonate aquifer up to the top of the model. Vertically, it extends from the top to the bottom of the model.
- **Calico Hills Zone**–These two zones are near the eastern end of the model, south of the Shoshone Mountain Zones, at approximately the same northing as the Yucca Wash. Vertically, it extends from the top to the bottom of the model.

(5) Zones of unknown features

- **East-West Barrier**–This linear feature runs east-west just to the north of Yucca Mountain, starting at the western edge of Yucca Mountain and extending eastwards short of the Calico Hills. Vertically, it extends from the bottom to the top of the model. It is a permeability reduction zone.



from BSC 2003 [166262] Figure 19

DTN: GS010908314221.001 (left panel) Output DTN: LA0304TM831231.002 (right panel).

NOTE: Field data are on the left panel, and the SZ model representation is on the right panel. Numbers designate the following regions: 45 - Lower FortyMile Wash Zone; 56 - East-West Barrier Zone; 57 and 58 - Fortymile Wash Zones; 59 - Spotted Range-Mine Mountain Zone; 61 and 62 - Claim Canyon Caldera Zones; 63 and 64 - Shoshone Mountain Zones; 65 and 66 - Calico Hills Zones; 69, 70, 71, and 72 - Crater Flat Fault Zones; 74, 83, and 84 - Solitario Canyon Fault Zones; 75 and 76 - Solitario Canyon Fault Zones (East Branch); 77 and 78 - Solitario Canyon Fault Zones (West Branch); 79 - Highway 95 Fault Zone; 80 and 90 - Bare Mountain Fault Zones; 81 - Northern Zone; 82 - Northern Crater Flat Zone; 88 - Alluvial Uncertainty Zone (expected case); 91 - Imbricate Fault Zone

Figure 6.2-3. Geologic Features in the Area of the Site-Scale Flow Model (from BSC 2003 [166262], Figure 19)

6.2.21 Chemically-Induced Density Effects on Groundwater Flow (2.2.07.14.0A)

FEP Description:	Chemically induced spatial variation in groundwater density may affect groundwater flow.
Descriptor Phrases:	Density-driven flow in the SZ
Screening Decision:	Excluded–Low consequence
Related FEPs:	2.2.08.01.0A, 2.2.10.04.0A, 2.2.10.08.0A, 2.2.10.13.0A, 2.2.11.01.0A, 2.2.12.00.0B

Screening Argument:

The FEP is based on the bounding and imposed condition that a contaminant plume reaches the water table with the signature of the repository (i.e., relatively higher temperature and different solute concentrations than the groundwater at the water table). Buoyancy effects, coupled with density gradients, would cause the plume to flow along the water table surface, relatively unmixed, for a considerable distance. Density gradients tend to spread the plume laterally. These effects would all tend to hinder contaminant and radionuclide transport to the accessible environment. Consequently, the potential dose to the hypothetical and exposed community is overestimated rather than underestimated.

The TSPA-LA models calculate the concentration of contaminants in groundwater by capturing all the contaminants that cross the regulatory boundary in the wells at the compliance point. No credit is taken for partial plume capture due to density-driven flow effects. The mixing model assumes that pumping and re-distribution of well water will be far greater than any other energy gradients (e.g., thermal, chemical, and gravitational) that exist in the groundwater system. There is no modeled groundwater flow component resulting from buoyancy effects, or differences in the groundwater density due to the presence or absence of contaminants. The TSPA approach to dose modeling is predicated on the use of a prescribed volume of water. As long as that prescribed volume of water is defensible and consistent with regulations, by assuming that all the particles that cross the regulatory boundary are dissolved in the prescribed volume of water (3,000 acre-feet per year, per guidance given in 10 CFR Part 63 Subpart 63.332(3) [156605]), the potential dose to the hypothetical, exposed community will not be underestimated. Including this FEP into the TSPA-LA calculations would be beneficial to repository performance. Given that the volume of extracted water consumed is independent of density and thermal gradients, and all the contaminants that cross the regulatory boundary are contained in that volume of water, the potential dose to the hypothetical and exposed community is overestimated rather than underestimated. Therefore, this FEP is excluded based on low consequence because it has no adverse effects on performance.

6.2.22 Advection and Dispersion in the SZ (2.2.07.15.0A)

FEP Description:	Advection and dispersion processes may affect contaminant transport in the saturated zone.

Descriptor Phrases: Advection of dissolved radionuclides in the SZ; Dispersion of dissolved radionuclides in the SZ

Related FEPs: 2.2.07.12.0A, 2.2.07.16.0A, 2.2.07.17.0A, 2.2.08.08.0A, 2.2.08.10.0A

Screening Decision: Included

TSPA Disposition:

Advection and longitudinal dispersion of dissolved radionuclides are explicitly included in the conceptual and mathematical models for TSPA-LA (*Site-Scale Saturated Zone Transport,* BSC 2003 [167208], Sections 6.2, 6.3 and 6.5). The numerical code FEHM (V 2.20 STN: 10086-2.0-00, LANL 2003 [161725]) implements dispersion tensor and random walk particle tracking method. The flow field and the dispersion tensor input to this model are dependent on the nature of the geologic material and the scale of the model.

FEHM V 2.20 (STN: 10086-2.20-00, LANL 2003 [161725]) generates a mean 3-D specific discharge ("advection") flow field using calibrated permeability as input. The mean specific discharge field is output from the *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.6.2.2). The mean calibrated permeability field is scaled with the stochastically sampled scaling parameters for groundwater-specific discharge (GWSPD) and the horizontal anisotropy in volcanic units (HAVO) (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Sections 6.5.2.1 and 6.5.2.10) to produce 200 unique 3-D permeability fields. GWSPD scales permeabilities in both the volcanic and alluvium units. The range for the GWSPD scaling parameter is based on field-test analyses (discussed in *Saturated Zone In-Situ Testing,* BSC 2003 [167209]), calibration of the "mean" flow field to measured heads (discussed in BSC 2003 [166262], Section 6.5.3), and expert elicitation (discussed in *Saturated Zone Flow and Transport Expert Elicitation Project*, CRWMS M&O 1998 [100353], Section 3.2). The HAVO parameter determines the degree of anisotropy in permeability for only the volcanic units. HAVO is based on field-test analyses discussed in BSC 2003 [167209] and numerical analysis discussed in BSC 2003 [166262], Section 6.5.3. Detailed discussions of the scaling parameters GWSPD and HAVO implementation are located in BSC 2003 ([167651], Sections 6.5.2.1 and 6.5.2.10).

Uncertainty in the dispersion tensor is modeled by stochastically varying the input longitudinal dispersivity value. This approach is done using the longitudinal dispersion parameter (LDISP) (BSC 2003 [167651], Section 6.5.2.9). The range for the LDISP parameter is based on recommendations from the expert elicitation panel (CRWMS M&O 1998 [100353], Section 3.2), which were used as the basis for determining the bounds on the longitudinal dispersivity.

The transverse and vertical dispersion parameters are less than longitudinal dispersivity, not varied independently, and scaled based on the stochastically sampled LDISP value input to each flow field. Further discussions on transverse and vertical dispersion are located in BSC 2003 ([167651], Section 6.5.2.9).

6.2.23 Dilution of Radionuclides in Groundwater (2.2.07.16.0A)

FEP Description:	Dilution due to mixing of contaminated and uncontaminated water may affect radionuclide concentrations in groundwater during transport in the saturated zone and during pumping at a withdrawal well.
Descriptor Phrases:	Radionuclide dilution (in groundwater)
Screening Decision:	Included
Related FEPs:	1.4.07.02.0A, 2.2.07.12.0A, 2.2.07.15.0A, 2.2.08.09.0A, 3.2.07.01.0A

TSPA Disposition:

Dilution of radionuclides as a result of pumping is included in the TSPA-LA in two ways (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Section 6.2). First, dilution of simulated radionuclide concentrations within the contaminant plume is explicitly modeled through the transverse hydrodynamic dispersion parameter. Transverse dispersivity is a function of the stochastically sampled longitudinal dispersivity parameter (LDISP) (BSC 2003 [167651], Sections 6.7.2 and 6.5.2.9). Secondly, it is assumed in BSC 2003 ([167651], Section 6.7.2) that all the radionuclide mass crossing the 18-km regulatory boundary is captured by the pumping well of the hypothetical farming community. The volume of water (per guidance given in 10 CFR Part 63 Subpart 63.332, (3) [156605]) pumped from the hypothetical farming community is 3,000 acre-feet per year (about 3.7×10^9 liters), which is larger than the volumetric flow of contaminated groundwater crossing the 18-km boundary. Therefore, the degree of dilution is the ratio of the flux of contaminated groundwater to volume of water pumped by the hypothetical farming community.

6.2.24 Diffusion in the SZ (2.2.07.17.0A)

FEP Description:	Molecular diffusion processes may affect radionuclide transport in the SZ.
Descriptor Phrases:	Diffusion of dissolved radionuclides in the SZ
Screening Decision:	Included
Related FEPs:	2.2.08.08.0A, 2.2.07.15.0A

TSPA Disposition:

This FEP addresses diffusive transport (e.g., fracture diffusion) such as is modeled numerically as part of the hydrodynamic dispersion coefficient (part mechanical dispersion, part diffusion). Matrix diffusion (which contributes to retardation) is addressed in the FEP 2.2.08.08.0A–Matrix diffusion in the SZ. The dispersion tensor D' appearing in Equation 1 (*Site-Scale Saturated Zone Transport,* BSC 2003 [167208]) is the sum of the mechanical dispersion tensor (D) for the flow system and the coefficient of molecular diffusion (D_0) in porous media. Together, these processes are modeled using the stochastically sampled longitudinal dispersivity parameter (LDISP) (BSC 2003 [167651], Sections 6.7.2 and 6.5.2.9) and the transverse hydrodynamic dispersion parameter, which is a function of LDISP. The effects of molecular diffusion are explicitly included also in the displacement matrix given by Equation 55 in the SZ Transport Abstraction Model (BSC 2003 [167208]). The effects of molecular diffusion are thus explicitly included in the SZ transport model. These effects are significant only at low flow velocities (Bear 1972 [156269], p. 581). The specific discharge value of 0.67 m/year reported in *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.6.2.3) leads to fluid velocities on the order of 10^{-7} to 10^{-4} m/s. Combining this with the lower limit of the longitudinal dispersivity of 0.1 m given in Table 4-2 of BSC 2003 [167208], this leads to a lower limit of dispersion coefficient in excess of 10^{-8} m^2/s. The upper limit of effective diffusion coefficient for volcanics given in Table 4-2 (BSC 2003 [167208]) is $5x10^{-10}$ m^2/s. Thus, the effects of molecular diffusion, which are included in the SZ flow and transport models (BSC 2003 [167208], Section 6.2) are overshadowed by advection and dispersion.

6.2.25 Chemical Characteristics of Groundwater in the SZ (2.2.08.01.0A)

FEP Description: Chemistry and other characteristics of groundwater in the saturated zone may affect groundwater flow and radionuclide transport of dissolved and colloidal species. Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may vary spatially throughout the system as a result of different rock mineralogy.

Descriptor Phrases: Initial THC characteristics in the SZ (temperature, pH, Eh, water conc., gas conc., ionic strength); Spatially dependent chemical effects on sorption in the SZ

Screening Decision: Included

Related FEPs: 2.2.07.14.0A, 3.2.07.01.0A, 2.2.10.08.0A, 2.2.09.01.0A, 2.2.10.04.0A, 3.1.01.01.0A, 2.2.08.09.0A, 2.2.08.07.0A, 2.2.08.06.0A, 1.2.09.02.0A, 2.2.03.01.0A, 2.2.03.02.0A, 2.2.08.03.0A

TSPA Disposition:

Variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater affect sorption of radionuclides onto the rock surface and colloids, which in turn, affects the sorption coefficient, K_d, and thus, the retardation factor, R_f, for each radionuclide. In the *Site-Scale Saturated Zone Transport* model (BSC 2003 [167208], Sections 6.2 and 6.5.2.4.1), these coefficients are entered directly in the transport base case model that describes radionuclide transport via the distribution coefficients and the retardation factors (BSC 2003

[167208], Equations 56 and 57), which describe reactive transport through porous media. The effects of THC and dissolved gases within the SZ are implicitly included in the variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater. Appropriate ranges and distributions of values for K_ds are chosen based on expert elicitation (*Saturated Zone Flow and Transport Expert Elicitation Project*, CRWMS M&O 1998 [100353], Section 3.2) and laboratory and field studies for the sorption coefficient K_d (BSC 2003 [167208], Attachment I). The parameter ranges are incorporated in the model abstraction through the K_d variables KDNPVO, KDRAVO, KDSRVO, KDUVO, KDNPAL, KDRAAL, KDSRAL, KDUAL, KD_AM_VO, KD_CS_VO, KD_PU_VO, KD_AM_AL, KD_CS_AL, KD_PU_AL, the colloid retardation factor in the alluvium (CORAL), and the colloid retardation factor in volcanic units (CORVO) (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Sections 6.5.2.8 and 6.5.2.11).

Regarding the spatial and temporal dependencies of K_d, geochemical analysis indicates that current SZ groundwater under the proposed repository and along the SZ transport path is paleoclimate recharge water (*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada*, BSC 2003 [167211], Section 7.1.2). Spatial variability in the composition of the ground water reflects, in part, temporal variability in recharge when data from the Forty Mile Wash are included. Uncorrected ^{14}C ground water ages range from a few thousand years in vicinity of the Forty Mile Wash to values greater than 15,000 years under portions of the Yucca Mountain (BSC 2003 [167211], Tables 10 and 11). Using the reasonable approach that spatial variability within the recharge domain brackets the temporal variability expected to occur at a given location within the domain, the observed variability in geochemistry among the wells in the model area brackets the temporal variations expected to occur in the water composition. Additionally, significant water table rise is evidenced to have occurred under paleoclimatic conditions (*Site-Scale Saturated Zone Flow Model,* BSC 2003 [166262], Section 6.4.5.1 and BSC 2003 [167208], Attachment V). Thus, the water quality of sampled paleoclimate recharge water reflects past interactions with rock types overlying the current water table as well as the rock types along the expected transport pathways. Consequently, the range in each radionuclide K_d and effective colloidal retardation factor bracket the temporal variations in water composition given volume and time of recharge, as well as the variability in pH, Eh, mineralogy, and the number of rock sorption sites.

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6.2.26 Geochemical Interactions and Evolution in the SZ (2.2.08.03.0A)

FEP Description:	Groundwater chemistry and other characteristics, including temperature, pH, Eh, ionic strength, and major ionic concentrations, may change through time, as a result of the evolution of the disposal system or from mixing with other waters. Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties and sorption of contaminants. Effects on hydrologic flow properties of the rock, radionuclide solubilities, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time scale of concern.
Descriptor Phrases:	Time-dependent THC characteristics in the SZ (temperature, pH, Eh, water conc., gas conc., ionic strength); Time-dependent chemical effects on sorption in the SZ; Effects of precipitation/dissolution in the SZ; Effects of weathering in the SZ
Screening Decision:	Excluded–Low consequence
Related FEPs:	1.2.06.00.0A, 1.2.09.02.0A, 2.2.08.01.0A, 2.2.08.06.0A, 2.2.08.07.0A, 2.2.08.09.0A, 2.2.08.10.0A, 2.2.09.01.0A, 3.2.07.01.0A

Screening Argument:

Geochemical analysis indicates current SZ groundwater under the repository and along the SZ transport path is paleoclimate recharge water (*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada*, BSC 2003 [167211], Section 7.1.2). The paleoclimate recharge water currently undergoes rock-water interactions in the UZ and SZ and in the past has mixed with waters from flow systems having different recharge waters than those indicative of current dry climatic conditions. These waters are reflective of cooler climatic conditions and cooler recharge waters 10,000 to 16,000 years old (BSC 2003 [167211], Section 6.3). Cooler water is able to dissolve more oxygen and thus has a higher oxidation state than warmer water (i.e., the temperature dependency of Henry's Law). Compared to recharge waters reflective of current climatic conditions, paleoclimate recharge waters have higher carbon contents and higher concentrations of dissolved CO_2 gas, which also contributes to higher oxidation states (Eh potential) and a lower pH. Lower pHs and higher CO_2 concentrations equate to waters that are more aggressive and will participate in more dissolution and subsequent precipitation along the transport path compared to groundwaters originating from current climatic conditions. Consequently, resident SZ water chemistry currently encountered along the SZ transport path reflects the maximum time-dependent variability in pH and CO_2 gas concentrations. As a result, current geochemical conditions, used to derive the range in each radionuclide K_d and effective colloidal retardation factor, bracket the temporal variations in water chemistry given the volume and time of recharge, as well as the variability in pH, Eh, mineralogy, and the number of rock sorption sites (specific details pertaining to variability in Eh are discussed the *Supplemental Discussion*). Therefore, temporal changes in water geochemistry are excluded based on low consequence.

Regional Yucca Mountain SZ recharge waters mainly occur through direct infiltration through the UZ and not through surface water recharge (such as lakes and perennial rivers). Consequently, temporal changes in surface water quantities are excluded based on low consequence. Since hydrothermal activity is considered to be low consequence to regional SZ flow and flow paths in the Yucca Mountain vicinity (see FEP 1.2.06.00.0A–Hydrothermal activity), temporal geochemical changes due to an increase in geothermal (hydrothermal) activity will not affect SZ geochemistry and are therefore excluded based on low consequence.

Detailed discussions pertaining to related FEPs in groundwater chemistry as it effects transport and sorption are addressed by FEPs 2.2.08.01.0A–Chemical characteristics of groundwater in the SZ, 2.2.08.06.0A–Complexation in the SZ; 2.2.08.07.0A–Radionuclide solubility limits in the SZ; 2.2.08.09.0A–Sorption in SZ; 2.2.08.10.0A–Colloid transport in the SZ; and the following analysis and model reports: *Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada* (BSC 2003 [167211], Section 6.7); *Saturated Zone Colloid Transport* (BSC 2003 [162729], Section 6.2); and *Site-Scale Saturated Zone Transport* (BSC (2003 [167208], Attachments I, II, III, and IV). All of the above reasoned arguments support the conclusion that geochemical interactions and evolution is excluded based on low consequence to radiological exposures to the RMEI. A more detailed discussion of future geochemical interactions and evolution in the SZ is provided in the *Supplemental Discussion* for this FEP in this SZ FEP report.

Supplemental Discussion:

For the TSPA-LA transport model (BSC 2003 [167208]), it is assumed that the SZ groundwaters along the transport path are oxidizing from the UZ/SZ interface to the 18-km compliance boundary. However, there is evidence of localized reducing zones along the SZ transport pathway that may result in the reduction of redox sensitive radionuclides such as Np, Pu, Tc, and U. These radionuclides are less soluble at lower oxidation states (i.e., reducing environments) and could precipitate out of solution and accumulate in localized reduction zones. A subsequent return to oxidizing conditions within the localized reduction zones during the regulatory timeframe would favor dissolution of these precipitates back into solution, causing groundwater concentrations to increase to levels above those that were in effect prior to reaching these reduction zones.

It is not likely the local reduction zones will be oxidized during the regulatory period, nor will they increase in size. A large-scale change in oxidation state from that seen currently at Yucca Mountain is excluded on low probability and regulatory grounds. The rationale for this statement is as follows:

1. Reducing conditions were found in boreholes USW H-1, USW H-4, and UE-25b#1 (Ogard and Kerrisk 1984 [100783], Section IV, and USW WT-17 (BSC 2003 [167208], Table 4-1). The reducing agents for groundwater in these wells could be located in the

groundwater itself or in the rock matrix. Since the reducing zones are local in extent, the aquifer matrix most likely supplies most of the reduction capacity. Generally, in volcanic rocks the reduction capacity is associated with solid sulfides (e.g., pyrite), biotite, and other ferrous iron-bearing minerals. Although data points are sparse, pyrite (a reducing agent) is found deep in borehole USW H-3 in the Tram member of the Crater Flat tuff (Thordarson et al. 1984 [103200]). Predicted radionuclide flow paths are focused primarily in the Prow Pass and Bullfrog units (*Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Section 6.2.4.4). Therefore, most, if not all, of the predicted plume's flow path will pass through oxidized, and not reduced, zones. On this basis, potential changes in localized oxidation states in the SZ are excluded on low consequence.

2. The high iron contents measured in groundwater from USW WT-17 suggest that the parent rock may contain some reducing agents. However, the well history, coupled with its high organic concentrations and low Eh measurements, indicate Eh measurements from this well may not be reflective of the rock's *in-situ* redox conditions. Groundwater chemistry pumped from borehole USW WT-17 in 1998 was unique from other wells in the area. Groundwater from this well shows reducing characteristics (Eh < 0.0 mv), little or no dissolved oxygen and nitrate, and high organic carbon (up to 20 mg/L, DTN: GS980908312322.008 [145412]). One possible explanation for this unique combination is well contamination. This well was originally drilled to assess water table elevations and not as a pump test well. Consequently, it was not developed after well completion. It is possible drilling fluid, containing organic materials, had migrated from the borehole down gradient and was eventually withdrawn during the subsequent pumping event performed several years after initial drilling. This scenario would explain the low Eh, high organic carbon concentrations, and the low dissolved oxygen and nitrate concentrations. The above indicates Eh measurements in borehole USW WT-17 are suspect and do not conclusively support that reducing conditions exist in the vicinity of this borehole.

3. An alternative explanation for the reducing conditions in borehole WT-17 is that the site is located above a source of hydrocarbons in the deeper SZ (i.e., the Paleozoic aquifer). However, Yucca Mountain is considered to be an area with low hydrocarbon potential (French 2000 [107425], p. 7-11) and no hydrocarbon activity. Because regulations dictate present socio-economic practices are reflective of future practices (Section 63.305 [156605]), hydrocarbon exploration that could potentially produce a large reduction zone are not included as part of the TSPA-LA model.

4. Resident groundwaters along the projected groundwater flow path are reflective of cooler climatic conditions and cooler recharge waters 10,000 to 16,000 years old (BSC 2003 [167211], Section 6.3). Cooler water is able to dissolve more oxygen and thus has a higher oxidation state than warmer water (i.e., the temperature dependency of Henry's Law). Compared to recharge waters reflective of current climatic conditions, paleoclimate recharge waters have higher carbon contents and higher CO_2 concentrations, which also contributes to higher oxidation states and a lower pH. The above conditions promote more dissolution and subsequent precipitation than that of groundwaters

originating from current climatic conditions. Consequently, the capability of future groundwaters, reflective of the current climate pulse, to further oxidize localized reducing zones within the next 10,000 years is not a credible mechanism.

5. There is no current mechanism known to support that reducing conditions will be more extensive along the flow path than what is currently seen. The total reduction capacities in the parent rock are a function of the concentration of the rock's *in-situ* reducing agents and the volume of these reducing zones. To date, only localized reduction zones have been produced over the past several million years. It is reasonable to presume that this reduction capacity will remain localized over the relatively short 10,000-year regulatory time frame. Therefore, a significant increase in the size of these local reduction zones is not credible.

   Furthermore, the reduction capacity of the parent rock has persisted over several million years. As it has over the past several million years, the reduction capacity will continue to persist, and not be depleted, over the relatively short 10,000-year regulatory time frame. Therefore, a significant switch between reducing to oxidizing conditions in these local reduction zones is not likely to occur within the next 10,000 years.

6.2.27 Complexation in the SZ (2.2.08.06.0A)

FEP Description:	Complexing agents such as humic and fulvic acids present in natural groundwaters could affect radionuclide transport in the SZ.
Descriptor Phrases:	Complexation in the SZ
Screening Decision:	Included
Related FEPs:	1.2.09.02.0A, 2.2.08.01.0A, 2.2.08.03.0A, 2.2.08.07.0A, 2.2.09.01.0A, 3.2.07.01.0A, 2.2.08.09.0A

TSPA Disposition:

Complexing agents are included in the TSPA-LA (*Site-Scale Saturated Zone Transport,* BSC 2003 [167208], Sections 6.3 and 6.5). In the SZ inorganic complexing agents, such as carbonates are dominant, whereas organic complexing agents, such as humic and fulvic acids, are not found in significant amounts (see FEP 2.2.09.01.0A – Microbial activity in the SZ). Complexing agents can affect sorption of radionuclides onto the rock surface and colloids. The sorption coefficients K_d and K_c enter via Equations 56, 57, 76, 77, and 78 in BSC 2003 ([167208], Sections 6.5.2.4.1 and 6.5.2.5), which describe reactive transport through porous media. These effects are included in the model by choosing appropriate ranges of values for the sorption coefficients K_d and K_c as described in BSC 2003 [167208], Attachments I and II, respectively. Available data are summarized in the BSC (2003 [167208], Table 6.2-2); K_d and K_c distributions are developed on the basis of these data.

6.2.28 Radionuclide Solubility Limits in the SZ (2.2.08.07.0A)

FEP Description: Solubility limits for radionuclides may be different in saturated zone groundwater than in the water in the unsaturated zone or in the waste and EBS.

Descriptor Phrases: Radionuclide solubility (concentration) limits in the SZ

Screening Decision: Excluded–Low consequence

Related FEPs: 2.2.08.01.0A, 2.2.08.03.0A, 2.2.08.06.0A, 2.2.08.09.0A 2.2.08.10.0A, 2.2.10.04.0A, 2.2.10.08.0A, 3.1.01.01.0A, 3.2.07.01.0A

Screening Argument:

The *SZ Flow and Transport Model Abstraction* (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651]) does not implement a solubility limit for each transported radionuclide, thus allowing the radionuclide solution concentration that is introduced into SZ from the UZ to be unconstrained. The rationale supporting this position is as follows. Solubility determines the maximum concentration a constituent can reach in the aqueous phase solution; therefore it is considered a bounding property. Once a particular radionuclide reaches that maximum concentration or solubility limit, it will form a precipitate or solid. The solid can be either a pure radionuclide-bearing solid or a solid solution of two (or more) end-members. The radionuclide constituent will then be in secular equilibrium between the solid and aqueous phase. The precipitate forming solid phase will increase in mass until the concentration in the solution phase falls below the solubility limit. Once this happens, the solid phase will then "dissolve" into the aqueous phase. Thus, if a solubility limit were to be imposed into the SZ model that is lower than that implemented in the *Dissolved Concentration Limits of Radioactive Elements* (BSC 2001 [154431], Section 6.5), it would cause precipitates to form, pulling constituents out of the aqueous phase and reducing the maximum aqueous concentration capable of being transported downstream to the compliance boundary. Additionally, physical build-up of a solid phase onto mineral surfaces (due to precipitation not adsorption) can reduce permeability, increase tortuosity, and clog pores, thus increasing transport times.

In summary, introduction of a solubility limit in the SZ would be beneficial to performance. Therefore, this FEP is excluded based on low consequence because not imposing a solubility limit in the model has no adverse effects on performance.

6.2.29 Matrix Diffusion in the SZ (2.2.08.08.0A)

FEP Description: Matrix diffusion is the process by which radionuclides and other species transported in the SZ by advective flow in fractures or other pathways move into the matrix of the porous rock by diffusion. Matrix diffusion can be a very efficient retarding mechanism, especially for strongly sorbed radionuclides due to the increase in rock surface accessible to sorption.

Descriptor Phrases: Matrix diffusion in the SZ

Screening Decision: Included

Related FEPs: 2.2.07.15.0A, 2.2.07.17.0A

TSPA Disposition:

Matrix diffusion is the process by which radionuclides transported in the SZ move into the matrix of the porous rock. This process can be a very effective retarding mechanism and is explicitly included in the conceptual model of transport in the mathematical model transport Equations 56 and 57, Section 6.5.2.4.1 (*Site-Scale Saturated Zone Transport,* BSC 2003 [167208]), and in the numerical implementation of the model FEHM (V 2.20 STN: 10086-2.0-00 [161725]) through the use of the diffusion coefficient and the random-walk particle-tracking method with a semi-analytical solution.

Matrix diffusion is included in the SZ transport model abstraction (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Table 6.8) through the matrix diffusion parameter diffusion coefficient in volcanics (DCVO). The semianalytical matrix diffusion equation obeys Fick's law and incorporates concentration gradients and the temporal and spatial changes in the gradient along the transport pathway. Matrix diffusion is modeled only in the matrix portion of the volcanic units (BSC 2003 [167651], Section 6.5.2.6). The cumulative distribution function (CDF) for the DVCO is based on:

- field and laboratory diffusion experiments performed in and on volcanic tuffs located within the Yucca Mountain vicinity
- a least-squares linear empirical equation fit to diffusion experiment results and measured values for matrix porosity and permeability.

The effective matrix diffusion coefficients for diffusing radionuclides are stochastically sampled from this same CDF.

Given the inhomogeneous nature of the alluvium, flow could preferentially occur through high-permeability regions, and matrix diffusion could potentially occur into the low permeability regions of the alluvium. Data is available only from single-hole tracer tests conducted at the Alluvial Testing Complex (ATC) (*Saturated Zone In-Situ Testing*, BSC 2003 [167209], Section 6.5.4, Figures 6.5-18 through 6.5-20). Based on this available data, as a conservative approach no credit is taken for matrix diffusion into low-permeability regions within the alluvium. Similarly, no credit is taken for matrix diffusion of colloids in either the volcanics or the alluvium, because the effects would be small and would only retard transport.

6.2.30 Sorption in the SZ (2.2.08.09.0A)

FEP Description: Sorption of dissolved and colloidal radionuclides in the SZ can occur on the surfaces of both fractures and matrix in rock or soil along the transport path. Sorption may be reversible or irreversible, and it may occur as a linear or nonlinear process. Sorption kinetics and the availability of sites for sorption should be considered. Sorption is a function of the radioelement type, mineral type, and groundwater composition.

Descriptor Phrases: Sorption of dissolved radionuclides in the SZ; Sorption of colloids in the SZ

Screening Decision: Included

Related FEPs: 2.2.07.16.0A, 2.2.08.01.0A, 2.2.08.03.0A, 2.2.08.06.0A, 2.2.08.07.0A, 2.2.08.10.0A, 2.2.10.08.0A

TSPA Disposition:

Sorption of radionuclides onto rock surfaces can occur both in the volcanic rocks and the alluvium (*Site-Scale Saturated Zone Transport*, BSC 2003 [167208], Attachment I). This process is modeled through a suite of partitioning coefficients K_ds (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Section 6.5.2.8) for the radionuclides Am, Cs, Np, Pa, Pu, Ra, Th, and U (BSC 2003 [167208], Attachment I). In the volcanic rocks, sorption in the matrix is explicitly included in the retardation coefficient R_f in Equations 56b and 57 (BSC 2003 [167208], Section 6.5.2.4.1). Sorption within individual fractures is not included in the conceptual model as an extreme case; however, sorption can occur within flowing zones due to the rubblized matrix, and this effect is included in the retardation coefficient R in Equation 56a. Sorption in the alluvium is described in Equation 77 in the *Site-Scale Saturated Zone Transport* (BSC 2003 [167208]).

Radionuclides modeled as entrained "irreversible" colloids in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003 [166845], Sections 6.2 and 6.3.1) are sorbed as well. The alluvium is largely composed of disaggregated tuffaceous material, mixed with clays and other secondary minerals. Each developed radionuclide K_d distribution brackets the regional variability in K_d values due to variations in pH, Eh, water composition (representative of J-13 and UE-25 p#1 waters), mineralogy, and the number of rock sorption sites. Additionally, K_d distributions encompass the potential nonlinear behavior of the sorption processes, thus accounting for sorption kinetics (BSC 2003 [167208], Attachment I).

The volcanic units are primarily composed of zeolitic and devitrified tuffaceous materials. The alluvium is largely composed of disaggregated tuffaceous material, mixed with clays and other secondary minerals. Because radionuclides have a greater sorption affinity onto clays and secondary minerals than tuffaceous materials, alluvium K_d values are slightly higher than those for the volcanic units (BSC 2003 [167208], Attachment I) and are reflected as such in alluvium K_d distributions. Table I-4 in BSC 2003 [167208] summarizes SZ sorption model parameters.

Sorption of Dissolved Radionuclides: In the volcanic units, Np, Ra, Sr, and U sorption between the aqueous phase and the solid phase (parent rock) is modeled in the FEHM flow and transport code using the sampled parameters KDNPVO, KDRAVO, KDSRVO, KDUVO, respectively (BSC 2003 [167651], Section 6.5.2.8); sorption for the same radionuclides in the alluvium is modeled through the parameters KDNPAL, KDRAAL, KDSRAL, and KDUAL.

Sorption of Reversible Colloids: Equilibrium sorption between aqueous and solid phases and a colloidal phase is modeled for the radionuclides Am, Cs, Pa, Pu, and Th (BSC 2003 [167208], Attachment I). The sampled parameters Kd_Pu_Col and Kd_Cs_Col model Pu and Cs partitioning between the aqueous and colloidal phases, respectively. Partitioning between the aqueous and colloidal phase for the radionuclides Am, Th, and Pa is modeled through the sampled parameter Kd_Am_Col. Partitioning between the colloidal and aqueous phase is the same in both the volcanics and the alluvium. Partitioning between the aqueous and solid phase (parent rock) for each species differs between the volcanic and alluvial units. In the volcanic units, Pu and Cs aqueous- and solid-phase partitioning is modeled through the sampled parameters Kd_Pu_Vo and Kd_Cs_Vo, respectively. For Am, Th, and Pa, the same partitioning is modeled through the single sampled parameter Kd_Am_Vo. In the alluvium, Pu and Cs partitioning between aqueous and solid phases is modeled with the sampled parameters Kd_Pu_Al, Kd_Cs_Al; for Am, Pa, and Th, it is modeled through the parameter Kd_Am_Al (BSC 2003 [167651], Section 6.5.2.12.)

Sorption of Irreversible Colloids: In the volcanic units, the dispersed "advectively" transported Pu and Am colloids (*Saturated Zone Colloidal Transport,* BSC 2003 [162729], Section 6.4 and BSC 2003 [166845], Section 6.3.3.2) sorb onto fracture surfaces through a colloid retardation factor CORVO (BSC 2003 [167651], Section 6.5.2.11). In the alluvium, these same colloids are effectively sorbed via a sampled retardation factor CORAL (BSC 2003 [167651], Section 6.5.2.11).

Table 6.2-2 summarizes which radionuclides have sorption coefficients (K_d) assigned to them, their parameter name, whether they are sorbed reversibly or irreversibly to the parent rock, colloids, or both (i.e., in secular equilibrium with which surface components).

Table 6.2-2. Summary of the SZ Sampled Parameters Specific to Radionuclide (RN) Sorption

Radionuclide (RN) Partitioned Between Solution and Parent Rock (No colloid transport)			Radionuclide Partitioning Parameters Between Colloids and Parent Rock			Radionuclide Irreversibly Sorbed to Colloids	
			Sorption Between Solution and Rock Surface		Sorption Between Solution and colloids		
RN	Volcanic Units	Alluvium	Volcanic Units	Alluvium		Volcanic Units	Alluvium
Am	No	No	Yes KD_Am_VO	Yes KD_Am_AL	Yes KD_Am_Col	Yes CORVO	Yes CORAL
Cs	No	No	Yes KD_Cs_VO	Yes KD_Cs_AL	Yes KD_Cs_Col	No	No
Np	Yes KDNPVO	Yes KDNPAL	No	No	No	No	No
Pa	No	No	Yes KD_Am_VO	Yes KD_Am_AL	Yes KD_Am_Col	No	No
Pu	No	No	Yes KD_Pu_VO	Yes KD_Pu_AL	Yes KD_Pu_Col	Yes CORVO	Yes CORAL
Ra	Yes KDRAVO	Yes KDRAAL	No	No	No	No	No
Sr	Yes KDSRVO	Yes KDSRAL	No	No	No	No	No
Th	No	No	Yes KD_Am_VO	Yes KD_Am_AL	Yes KD_Am_Col	No	No
U	Yes KDUVO	Yes KDUAL	No	No	No	No	No

6.2.31 Colloidal Transport in the SZ (2.2.08.10.0A)

FEP Description: Radionuclides may be transported in groundwater in the SZ as colloidal species. Types of colloids include true colloids, pseudo colloids, and microbial colloids.

Descriptor Phrases: Advection of colloids in the SZ; Diffusion of colloids in the SZ; Sorption of colloids in the SZ

Screening Decision: Included

Related FEPs: 2.1.09.21.0B, 2.2.07.15.0A, 2.2.08.03.0A, 2.2.08.07.0A, 2.2.08.09.0A

TSPA Disposition:

The colloid-facilitated transport of radionuclides is explicitly included in the SZ Transport Abstraction Model and the SZ 1-D Transport Model (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Section 6.2). Colloids are subject to advection in the fractures of tuff units and are not assumed to diffuse into the rock matrix. Radionuclide transport in association with colloids is simulated to occur by two modes: 1) as reversibly sorbed onto colloids, and 2) as irreversibly attached to colloids (BSC 2003 [167651], Sections 6.5.2.11 and 6.5.2.12). Reversible sorption of radionuclides may occur onto any colloidal material present in the groundwater, and measurements of natural colloids in groundwater of the SZ include mineral and microbial colloids. Colloids with irreversibly attached radionuclides originate from the degradation of the glass waste form in the repository (*Waste Form and In-drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*, BSC 2003 [166845], Section 6.3.1). The parameters related to reversible sorption onto colloids are Kd_Am_Col, Kd_Pu_Col, Kd_Cs_Col, and Conc_Col. The parameters related to the retardation of colloids with irreversibly attached radionuclides are CORVO and CORAL (BSC 2003 [167651], Table 6-2).

6.2.32 Groundwater Discharge to Surface Within the Reference Biosphere (2.2.08.11.0A)

FEP Description:	Radionuclides transported in groundwater as solutes or solid materials (colloids) from the far field may discharge at specific "entry" points that are within the reference biosphere. Natural surface discharge points, including those resulting from water table or capillary rise, may be surface water bodies (rivers, lakes), springs, wetlands, holding ponds, or unsaturated soils.
Descriptor Phrases:	Radionuclide release to biosphere (surface discharge at receptor); Water table elevation
Screening Decision:	Included
Related FEPs:	1.3.07.01.0A, 1.3.07.02.0A, 1.4.07.01.0A, 1.4.07.02.0A, 2.3.11.04.0A

TSPA Disposition:

The groundwater system in the vicinity of the hypothetical community's well system is modeled such that all the contaminants discharged at the 18-km boundary are intercepted by the community's wells (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Section 6.2). Direct discharge of groundwater to the surface via springs, unsaturated soils, etc. is bounded by the simplifying assumption of complete capture of the contaminant plume in the wells.

Direct discharge points (including those resulting from water table rise to form surface water bodies (rivers, lakes), springs, wetlands, and holding ponds at the accessible environment) would first be withdrawn by a well supplying the hypothetical farming community (10 CFR 63.332 [156605]). Thus, these potential entry points to the accessible environment are implicitly included through the representative volume extracted by the hypothetical community well. Documentation as to the effects of unsaturated soils and capillary wicking on releases to the accessible environment fall under the biosphere model domain and discussed in the biosphere FEP analysis report (*Evaluation of Features, Events and Processes for the Biosphere Model,* BSC 2003 [165843], Section 6.2.14).

6.2.33 Microbial Activity in the SZ (2.2.09.01.0A)

FEP Description: Microbial activity in the SZ may affect radionuclide mobility in rock and soil through colloidal processes, by influencing the availability of complexing agents, or by influencing groundwater chemistry.

Descriptor Phrases: Microbial effects on sorption in the SZ

Screening Decision: Excluded–Low consequence

Related FEPs: 2.2.08.01.0A, 2.2.08.03.0A, 2.2.08.06.0A, 2.2.11.01.0A, 2.2.10.04.0A, 2.2.10.08.0A, 2.2.10.13.0A

Screening Argument:

Microbial activity can potentially change groundwater pH and Eh, and introduce additional complexing agents, which could affect K_d distributions. Of interest is sorption behavior of a limited number of elements, particularly U and Np, which are affected by variations in water chemistry. Microbial activity is more favorable in unsaturated conditions, where pores are less than 100% liquid saturated thus favoring vapor exchange and microbial growth resulting in the UZ including this FEP (*Features, Events, and Processes in UZ Flow and Transport* BSC 2003 [164873], Section 6.1.36). However in the SZ evidence of microbial activity is lacking, which is supported by geochemical analysis of groundwater samples taken from SZ wells within the Yucca Mountain vicinity (DTN: GS931100121347.007 [149611] and DTN: GS010308312322.003 [154734]). Results from the above analysis found little to no organic carbon in these waters. Organic carbon is a bi-product of microbial activity. It is logically concluded, because there is little organic carbon found in SZ waters, there is insignificant microbial activity in the SZ regime.

Additionally, geochemical analysis indicates current SZ groundwater along the SZ transport path is paleoclimate recharge water (*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain,* BSC 2003 [167211], Section 7.1.2), reflective of cooler climatic conditions and cooler recharge waters (BSC 2003 [167211], Section 6.3). Paleoclimate recharge waters have higher carbon contents (which are components of inorganic complexing agents) and higher concentrations of dissolved CO_2 gas. Higher CO_2 gas concentrations contribute to higher oxidation states (Eh potential) and lower pH in resident waters, resulting in solutions that are more aggressive, participate in more dissolution and precipitation along the transport path, and contribute to more surface complexing sorption sites and the production of inorganic complexing agents. Two end member groundwater compositions that could exist within the SZ, reflective of the large variability in paleoclimate recharge waters, were used in deriving the K_d distributions (water from wells UE-25p#1 and J-13, *Site-Scale Saturated Zone Transport,* BSC 2003 [167208], Attachment I). The resulting distributions used to represent the uncertainty in K_d and colloid parameter values, inclusive of U and Pu, are based on conditions in the natural system dominated by the more aggressive nature of paleoclimate recharge waters and overshadow any effects naturally occurring microbial activity would have on SZ water chemistry.

Furthermore, radionuclide bearing colloidal formation, transport, and complexation are dominated by natural inorganic ligands and inorganic constituents generated by the degradation of emplaced waste forms and not those produced by SZ microbes (*SZ Flow and Transport Model Abstraction,* BSC 2003 [167651]*,* Section 6.5.2.11 and 6.5.2.12). In conclusion, including the effects of microbial activity will not affect water chemistry used to derive K_d distribution and the presence of radionuclide bearing colloids. This FEP is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.34 Thermal Convection Cell Develops in SZ (2.2.10.02.0A)

FEP Description:	Thermal effects due to waste emplacement result in convective flow in the saturated zone beneath the repository.
Descriptor Phrases:	Thermally-driven flow (convection) in the SZ
Screening Decision:	Excluded–Low consequence
Related FEPs:	2.2.10.04.0B, 1.2.06.00.0A

Screening Argument:

A numerical model of the mountain scale effects of thermal loading on the host rock due to waste emplacement is evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498], Section 6.5). The numerical model encompasses a domain extending from the ground surface to the water table. The model assessed changes in thermal, chemical and hydrologic properties as a result of heat induced stresses on the host rock. Model results indicate that the host rock temperatures reach a high of about 103ºC at approximately 1,000 years after waste emplacement (BSC 2003 [166498], Section 6.5.10). These elevated host rock temperatures produce a heat wave, originating at the repository and propagating outwards. At the water table, temperatures peak around 2,000 years and, depending on location within the repository footprint, locally vary between at 32 to 34ºC (BSC 2003 [166498], Section 6.3.1 and Figures 6.3.1-6, 6.3.1-7). These elevated temperatures are, at most, only 0 to 4ºC above ambient water table temperatures beneath the repository. Temperatures decrease to within 1 to 2ºC of ambient levels at about 5,000 years after waste emplacement. Relative to the scale of the SZ flow domain, this small increase in water table temperatures is local and small relative to the large variability in water table temperatures along the SZ flow and transport path, which ranges between 30 to 34ºC (Fridrich et al. 1994 [100575], Figure 8). Furthermore, there are locations along the SZ transport path where ambient temperatures increase with depth, with some temperatures as high as 40 to 45ºC (measured in well UE-25-p#1; *Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Table 28). It is logically concluded that the increase in water table temperatures due to waste emplacement is a small perturbation in the SZ flow system given the large variability in groundwater temperatures along the SZ flow path. The resulting temperature perturbation will not create a thermally induced convection cell that will alter SZ flow paths.

Thermal effects will have more of an impact on flow in the near field. In *Features, Events, and Processes in UZ Flow and Transport* (BSC 2003 [164873], Section 6.8.9), it is concluded that thermal effects due to waste emplacement will have an insignificant impact on flow in the UZ (FEP 2.2.10.01.0A– Repository-induced thermal effects on flow in the UZ). In the UZ it is the potential of large-scale convection cells, driven by the vaporization and condensation cycle at the mountain scale that could potentially dominate UZ flow paths. It is logically concluded that if thermal effects on flow are excluded in the near field, then by deduction, they will have less of an impact in the far field. In conclusion, waste emplacement will not produce SZ thermal convection cells that will affect SZ flow paths; this FEP is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.35 Natural Geothermal Effects on Flow in the SZ (2.2.10.03.0A)

FEP Description:	The existing geothermal gradient, and spatial or temporal variability in that gradient, may affect groundwater flow in the unsaturated and saturated zones.
Descriptor Phrases	Natural geothermal effects on flow in the SZ
Screening Decision:	Included
Related FEPs:	1.2.06.00.0A, 2.2.10.02.0A, 2.2.10.04.0A, 2.2.10.08.0A, 2.2.10.13.0A, 2.2.11.01.0A

TSPA Disposition:

Natural geothermal effects, as they influence fluid properties, are implicitly included in the SZ site-scale flow model. Groundwater flow is simulated in the *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262]), detailed disposition in Section 6.2) using a conservation of fluid-rock energy equation in the numerical code FEHM V 2.20 (STN: 10086-2.20-00, LANL 2003 [161725]). The fluid-rock energy equation is, in part, a function of permeability, density, viscosity, and temperature (BSC 2003 [166262], Section 6.5.3.7). For temperatures that range between 20^{o}C to 100^{o}C, the density of water changes by only a few percent. In contrast, the variation in water viscosity changes by a factor of 3.3 over the same temperature range. Consequently, natural geothermal effects on groundwater flow are more effectively captured by spatially varying viscosity rather than density. The *Site-Scale Saturated Zone Flow Model* (BSC 2003 [166262], Section 6.5.3.7) assigns a specified temperature to each node, which varies with depth and is based on variable temperature measurements reported in Sass et al. (1988 [100644]). Permeability and viscosity are also assigned to each node. Temperatures are used to calculate nodal viscosities. Using the spatially varying viscosity, a fluid property, allows the calibration of hydraulic conductivity, a lumped fluid/rock property parameter. Estimated hydraulic conductivity at each node is calibrated to hydraulic head measurements, while nodal viscosities and temperatures remain fixed (BSC 2003 [166262], Section 6.5.3.7). Hydraulic heads are, in part, manifestations of multiple processes within the system, including geothermal effects. By calibrating hydraulic conductivity to hydraulic heads and keeping spatially varying temperature and viscosity fixed, geothermal effects on flow are implicitly captured.

Additionally, Bechtel SAIC Company (BSC) performed a set of heat transport and flow simulations using measured temperature values in the SZ (BSC 2003 [166262], Section 7.4). The results of the coupled thermal modeling provide a general independent validation of the SZ site-scale flow model and validate the implicit modeling of geothermal effects in SZ flow.

6.2.36 Thermo-Mechanical Stresses Alter Characteristics of Fractures Near Repository (2.2.10.04.0A)

FEP Description: Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the fracture properties (both hydrologic and mechanical) of fractures in the rock. Cooling following the peak thermal period will also change the stress field, further affecting fracture properties near the repository.

Descriptor Phrases: Thermal-mechanical effects (fractures in the UZ);
Thermal-mechanical effects (fractures in the SZ);
Thermal-mechanical effects (stress change)

Screening Decision: Excluded–Low consequence

Related FEPs: 2.2.10.13.0A, 2.2.11.01.0A, 2.2.10.08.0A, 2.2.10.04.0B, 2.2.10.03.0A, 2.2.09.01.0A, 2.2.08.07.0A, 2.2.08.01.0A, 2.2.07.14.0A, 2.2.06.02.0B, 1.2.02.01.0A,

Screening Argument:

The effects of thermal loading due to waste emplacement on fractures within the vicinity of the repository drifts are evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498], Section 6.5). The numerical model encompasses a domain extending from the ground surface to the water table. Changes in hydrologic properties as a result of heat-induced stresses on the fractures and the host rock are assessed. Results indicate the highest thermally induced stresses are in the horizontal direction and occur at approximately 100 years (BSC 2003 [166498], Section 6.5.11). Thermally induced stresses on fractures are compressive in nature below the repository and a combination of compressive and tensile in nature above the repository (BSC 2003 [166498], Sections 6.5.10 and 6.5.11). Compressive stresses transition to tensile stresses at approximately 180 m above the repository. The transition is due to a redistribution of horizontal stresses as the heat induced stress pulse encounters the unconfined and much cooler surface. Changes from compressive to tensile stresses are not seen below the repository.

Vertical and sub-vertical fractures are affected most by these compressive stresses, with many fractures closing to their residual fracture aperture widths. Horizontal fracture apertures are least affected by thermally induced mechanical stresses; under compression stresses they tend to slightly open up. Thermally induced mechanical stresses primarily affect vertical fractures residing between 150 m above and 70 m below the repository and approximately 100 m lateral to the repository plane. Model results indicate it is the vertically aligned fracture that undergoes a significant reduction in permeability in response to compressive stresses from thermal loading (BSC 2003 [166498], Section 6.5.12). Horizontal fracture permeabilities located between 140 m above and 50 m below the repository are affected by thermal-mechanical stresses, but to a significantly lesser extent (BSC 2003 [166498], Figures 6.5.12-1, 6.5.12-2, 6.5.12-3). There are little to no changes in the permeabilities of both vertical and horizontal fractures located approximately 150 m below the repository. However, if a compression pulse were to affect SZ fractures at the water table, it would most likely affect vertical to sub-vertical fractures since it is the vertical to sub-vertical fractures that are most sensitive to compression stresses. Below the repository SZ flow primarily takes place in the fractures of the volcanic units. Therefore a reduction in permeability of vertical to sub-vertical fractures will promote flow in the less permeable rock and thus increase groundwater travel times.

At 10,000 years, when the repository is well into a cooling phase, thermal-mechanical stresses do not impart significant on changes vertical fracture permeabilities beyond 50 m below the repository (BSC 2003 [166498], Figure 6.5.12-2). Because the top of the SZ is approximately 335 m below the repository (DTN: GS000808312312.007 [155270], Table S00397 001; *Total System Performance Assessment for the Site Recommendation*, CRWMS M&O 2000 [153246], Figure 3.2-10), it is inferred that the effects of the thermally induced changes in the mechanical and hydrologic properties of SZ fractures will be insignificant during the cooling phase of the thermally induced stress pulse.

In the analysis report *Features, Events, and Processes in UZ Flow and Transport* (BSC 2003 [164873], Section 6.8.12), it is concluded that thermally induced stresses would have no effect on rock properties above and below the repository, including fracture properties. Specifically, thermally induced stresses would have no global effect on UZ fracture permeabilities below the repository or at most, would cause a reduction in permeability. Consequently, this FEP was excluded in the UZ based on low consequence. Since thermo-mechanical stresses are excluded in the near field, by deduction, the thermo-mechanical stress “pulse” will have less of an impact further out in the region of the SZ.

To summarize, thermal-mechanical stresses cause little to no changes in horizontal hydrologic and mechanical properties in fractures located 50 m or more below the repository. Changes in vertical fracture properties are affected by thermal loading but are minimal at elevations 70 m below the repository. Because the top of the SZ is approximately 335 m below the repository, it is inferred that the effects of the thermal-mechanical induced stress changes will have little to no affect on SZ fractures. In conclusion, thermo-mechanical stresses imposed on fractures within the vicinity of the repository have little to no effect on SZ fractures properties. Thermo-mechanical stresses on fractures in the SZ are excluded based on low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.37 Thermo-Mechanical Stresses Alter Characteristics of Faults Near Repository (2.2.10.04.0B)

FEP Description: Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the fault properties (both hydrologic and mechanical) in and along faults. Cooling following the peak thermal period will also change the stress field, further affecting fault properties near the repository.

Descriptor Phrases: Thermal-mechanical effects (faults in the UZ);
Thermal-mechanical effects (faults in the SZ);
Thermal-mechanical effects (stress change)

Screening Decision: Excluded–Low consequence

Related FEPs 2.2.10.02.0A, 2.2.10.04.0A, 2.2.10.05.0A, 2.2.10.13.0A

Screening Argument:

For purposes of assessing the thermo-mechanical stresses on SZ faults due to waste emplacement, SZ faults can be considered as large fractures. Therefore, it is appropriate to review the impacts of thermal-mechanical stresses on fractures in order to understand similar stress effects on faults. The effects of thermal-mechanical loading due to waste emplacement on fractures within the vicinity of the repository drifts are evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498], Section 6.5). Results indicate the highest thermally induced stresses occur at approximately 100 years within the repository horizon, are horizontal in direction, and are compressive in nature below the repository (BSC 2003 [166498], Section 6.5.11). Moving away from the repository, stresses dampen. Above the repository thermally induced stresses are a combination of compressive and tensile in nature (BSC 2003 [166498], Sections 6.5.10 and 6.5.11). Compressive stresses transition to tensile stresses at approximately 180 m above the repository. Changes from compressive to tensile stresses are not seen below the repository. Model results indicate thermal-mechanical stresses induced from waste emplacement do not significantly affect SZ vertical and sub-vertical and horizontal fracture hydrologic properties (FEP 2.2.10.04.0A– Thermo-mechanical stresses alter characteristics of fractures near repository).

Faults in the SZ are further from the heat source (the repository), larger than fractures, and extend deep into the SZ. A fault's response to the same thermally induced stresses imposed on fractures will be mitigated due to their size and distance from the heat source. It is logically concluded, if thermally induced mechanical stresses will not affect fracture hydrologic properties in the SZ, then they will not affect fault properties within the SZ either.

Furthermore, thermal effects on faults in the UZ due to waste emplacement are excluded due to low consequence (*Features, Events, and Processes in UZ Flow and Transport,* BSC 2003 [164873], Section 6.8.11). Since thermo-mechanical stresses are excluded in the near field, by deduction, the thermo-mechanical stress "pulse" will have less of an impact further out in the region of the SZ and is also excluded.

In summary, thermo-mechanical stresses due to waste emplacement imposed on faults located in the SZ are excluded due to low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.38 Thermo-Mechanical Stresses Alter Characteristics of Rocks Above and Below the Repository (2.2.10.05.0A)

FEP Description: Thermal-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone.

Descriptor Phrases: Thermal-mechanical effects (rock properties in the UZ);
Thermal-mechanical effects (rock properties in the SZ);
Thermal-mechanical effects (stress change)

Screening Decision: Excluded–Low consequence

Related FEPs: 2.2.06.01.0A, 2.2.06.02.0A, 2.2.06.03.0A, 2.2.10.01.0B,
2.2.10.04.0A, 2.2.10.04.0A, 2.2.10.04.0B,

Screening Argument:

A numerical model of the mountain scale effects of thermal loading on rock properties due to waste emplacement is evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498], Section 6.5). The numerical model encompasses a domain extending from the ground surface to the water table. The model assessed changes in hydrologic properties as a result of heat-induced stresses on the host rock. Model results indicate that the largest thermally induced stresses are compressive in nature, are in the horizontal direction, and occur at the repository horizon at approximately 100 years after waste emplacement (BSC 2003 [166498], Section 6.5.11). The compression stress pulse loses strength as it moves outward from the repository. Since fractures have unconfined boundaries, a reduction in fracture apertures uses less work than a reduction of matrix porosity. Therefore it is fracture porosity (and attendant permeabilities) rather than matrix porosity, that is most affected by compressive stresses. Model results indicate vertically aligned fractures undergo a reduction in permeability in response to compressive stresses from thermal loading (BSC 2003 [166498], Section 6.5.12). Below the repository, compressive stresses primarily affect vertical to sub-vertical fractures and their permeabilities, in a region that extends approximately 100 m to 150 m directly below the repository (BSC 2003 [166498], Figure 6.5.12-3). At the water table thermal-mechanical stresses are not enough to produce a compression stress to significantly affect fracture permeability the SZ (see FEP 2.2.10.04.0A–Thermo-mechanical stresses alter characteristics of fractures near repository). Since fractures are more susceptible to thermally induced stresses and, at the water table, their hydrologic properties are not significantly affected by compressive stresses, then it is inferred neither will matrix hydrologic properties be affected by thermally induced stresses (see FEP 2.2.10.04.0A–Thermo-mechanical stresses alter characteristics of fractures near repository).

Additionally, thermal-mechanical stresses affect the near field environment to a greater extent than the far-field region, the province of the SZ. Thermo-mechanical stresses on the UZ rock properties are excluded in the UZ (BSC 2003 [164873], Section 6.8.12). By deduction, thermo-mechanical stresses will have less of an effect in the far-field and should be excluded as well.

Thermal mechanical stresses in the units above the repository is a UZ issue and outside the province of the SZ. A screening decision with respect to thermal fracturing of these units is found in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2003 [164873], Section 6.8.12).

In summary, thermo-mechanical stresses on the SZ rock properties are excluded due to low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.39 Thermo-Chemical Alteration in the SZ (Solubility, Speciation, Phase Changes, Precipitation/Dissolution) (2.2.10.08.0A)

FEP Description: Thermal effects may affect radionuclide transport directly by causing changes in radionuclide speciation and solubility in the SZ, or, indirectly, by causing changes to host rock mineralogy that affect the flow path. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.

Descriptor Phrases: Thermal-chemical effects (precipitation/dissolution in the SZ); Thermal-chemical effects (alteration in the SZ); Thermal-chemical effects (solubility limits in the SZ)

Screening Decision: Excluded–Low consequence

Related FEPs: 2.2.10.04.0A, 2.2.10.13.0A, 2.2.10.03.0A, 2.2.09.01.0A, 2.2.08.09.0A, 2.2.08.07.0A, 2.2.08.01.0A, 2.2.07.14.0A, 1.2.06.00.0A

Screening Argument:

Two primary components that affect mineral water interactions are CO_2 concentrations and pH. Of the two components, CO_2 concentrations are more sensitive to changes in temperature. Small changes in CO_2 concentrations greatly affect pH variability. Therefore, it is possible that temperature variations along the SZ flow path can result in changes in SZ rock mineralogy.

CO_2 becomes less soluble at elevated temperatures. As temperatures increase CO_2 exsolves out of solution causing pH to rise and calcite to precipitate in pores and fractures. Calcite precipitation in pores and along fractures can decrease permeability. As temperatures drop, CO_2 dissolution increases, potentially causing dissolution of calcite in pores and fractures. Calcite dissolution in fracture linings and within pore spaces can cause permeability to increase. Dissolution of CO_2 bearing minerals can occur if they come into contact with low pH waters, thus increasing permeability and porosity. Therefore, a shift to lower pH bearing waters can cause calcite bearing minerals to dissolve, resulting in an increase in porosity and permeability.

A numerical model of the mountain scale effects of thermal loading on the host rock due to waste emplacement is evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498], Section 6.5). The model encompasses a domain extending from the ground surface to the water table and assesses changes in the water chemistry and mineralogy due to thermal loading at the repository. Model results indicate the host rock temperatures at the repository reach a high of about 103ºC at approximately 1,000 years after waste emplacement (BSC 2003 [166498], Section 6.5.10). A heat wave is produced, originating at the repository and propagating outwards. These elevated temperatures cause CO_2 to exsolve out of solution above and below the repository. Just above the water table, within the repository footprint, temperatures peak around 2,000 years and locally vary between at 32 to 34ºC (BSC 2003 [166498], Section 6.3.1 and Figures 6.3.1-6, 6.3.1-7). Variability in temperature can cause significant variability in CO_2 concentrations and promote precipitation and/or dissolution of calcite in fractures and pore spaces. Modeling results indicate CO_2 concentrations just above the water table do not vary significantly during the modeled time period (BSC 2003 [166498], Figures 6.4-12 and 6.4-16). Concurrently, no significant precipitation or dissolution of calcite bearing minerals in fracture fillings is seen (BSC 2003 [166498], Section 6.4.3.3.3 and Figure 6.4-18). As such, it is logically concluded that if there is no measurable precipitation or dissolution of calcite in fracture fillings just above the water table due to thermal loading, there will be no measurable precipitation or dissolution of calcite along the SZ transport path due to thermal loading.

Model results show pH concentrations above the water table vary between 8.14 and 8.45. Variations in pH just above the water table are not accompanied with noticeable precipitation or dissolution minerals such as calcite in fracture fillings (BSC 2003 [166498], Section 6.4.3.3.1, Figures 6.4-12 and 6.4-13; and Section 6.4.3.3.2, Figures 6.4-16 and 6.4-17).

Temperatures at or above $50^{o}C$ facilitate mineral-water reactions, causing vitric and silica bearing minerals to degrade to zeolites and other secondary minerals (which include clays). Zeolites tend to have the highest porosity and sorption capacity of all the secondary minerals. These types of mineral alterations can change sorption capacity, porosity and permeability in the

SZ. Since temperatures at the water table stay within the low 30°C range, it is logically concluded there will be no alteration of silicic bearing minerals in the SZ. This is corroborated with modeling results reported in BSC 2003 ([166498]); alteration of silicate bearing minerals decreases with distance from the repository. Minimal-to-no mineral alteration is seen just above the water table (BSC 2003 [166498], Section 6.4.3.3 and Figures 6.4-20 through 6.4-24). Any mineral alteration at the water table would be degradation of silicic and vitric minerals to zeolites and other clays, which have a high sorption capacity. However, no credit is being taken for sorption onto zeolites that reside along the SZ flow path (*Site-Scale Saturated Zone Transport,* BSC 2003 [167208], Table 6.4-1). Consequently, any possible alteration of zeolites in the SZ will not affect the SZ barrier capability.

The *SZ Flow and Transport Model Abstraction* (BSC 2003 [167651]) does not implement a solubility limit for each transported radionuclide. The radionuclide concentration that is introduced into SZ from the UZ is unconstrained. Furthermore, radionuclides introduced in the UZ from the Engineered Barrier System (EBS) are also unconstrained; that is, the solubility is not reduced as radionuclides go from the higher temperature repository conditions to the UZ. Therefore, thermo-chemical alteration on radionuclide solubility will have no effect on radionuclide transport in the SZ.

In the analysis report *Features, Events, and Processes in UZ Flow and Transport* (BSC 2003 [164873], Section 6.8.14), thermal chemical effects on dissolution and precipitation in the Calico Hills units are evaluated. That analysis indicates that thermo-chemical effects are limited to the near field environment, are of short duration, and will not have a significant effect on UZ contaminant transport or the release to the accessible environment. Since thermo-chemical stresses are excluded in the near field, by deduction, the thermo-chemical alteration will have less of an impact further out in the region of the SZ and are also excluded. All of the above reasons support excluding this FEP due to low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.40 Repository-Induced Thermal Effects on Flow in the SZ (2.2.10.13.0A)

FEP Description:	Thermal effects in the geosphere could affect the long-term performance of the disposal system, including effects on groundwater flow (e.g., density-driven flow), mechanical properties, and chemical effects in the SZ.
Descriptor Phrases:	Thermal effects on flow in the SZ; Time-dependent THC characteristics in the SZ (temperature, pH, density)
Screening Decision:	Excluded–Low consequence
Related FEPs:	2.2.11.01.0A, 2.2.10.08.0A, 2.2.10.04.0A, 2.2.10.04.0B, 2.2.10.03.0A, 2.2.09.01.0A, 2.2.07.14.0A

Screening Argument:

Numerical modeling of the mountain scale effects of thermal loading on the host rock due to waste emplacement is evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003 [166498], Section 6.5). Model results indicate that the host rock temperatures at the repository will reach a high of about 103ºC at approximately 1,000 years after waste emplacement (BSC 2003 [166498], Section 6.5.10). These elevated temperatures produce a heat wave that originates at the repository and propagates outwards. Just above the water table temperatures peak around 2,000 years and, depending on location within the repository footprint, locally vary between at 32 to 34ºC (BSC 2003 [166498], Section 6.3.1 and Figures 6.3.1-6, 6.3.1-7). These elevated temperatures are, at most, only 0 to 4ºC above ambient water table temperatures beneath the repository. The model indicates that elevated temperatures decrease to within 1 to 2ºC of ambient levels at approximately 5,000 years after waste emplacement. Ambient SZ water temperatures at the water table along the transport path range between 30 and 34ºC (Fridrich et al. 1994 [100575], Figure 8). Relative to the scale of the SZ flow domain, this increase in water table temperatures is local and small relative to the large variability in water table temperatures along the SZ flow and transport path. Furthermore, SZ ambient temperatures increase with depth along the transport path, with some temperatures as high as 40 to 45ºC in units where transport takes place (measured in well UE-25p#1 *Site-Scale Saturated Zone Flow Model*, BSC 2003 [166262], Table 28), and as temperatures increase, there is a potential for CO_2 to exsolve out of solution causing pH to rise and calcite to precipitate in pores and fractures. Calcite precipitation in pores and along fractures can decrease permeability. Just above the water table, variations in both pH (ranging between 8.14 to 8.45) and CO_2 concentrations are not accompanied with noticeable precipitation or dissolution minerals such as calcite in fracture fillings (BSC 2003 [166498], Sections 6.4.3.3.1, 6.4.3.3.2, 6.4.3.3.2 and Figures 6.4-12, 6.4-13, 6.4-16, 6.4-17, and 6.4-18). It is logically concluded that if a thermal pulse emanating from the repository does not significantly increase pH and CO_2 concentrations at the water table, then there will not be a significant increase of these two components in the SZ flow domain farther away from the heat source.

Temperature dependent sorption is not modeled in the SZ. Sorption is a temperature dependent process and increases as temperature increases. An increase in groundwater temperatures would increase the sorption capacity of the transported radionuclides, thus retarding transport to the accessible environment. Since modeled radionuclide partitioning coefficients in the SZ are based on ambient SZ temperatures, an increase in sorption capacity due to an increase in SZ water temperatures would not have an adverse effect on performance.

Elevated temperatures of radionuclide bearing waters would be less dense than ambient waters. Density and temperatures gradients would promote lateral dispersion along the transport path. Lateral dispersion would reduce concentrations and thus reduce exposure to the RMEI. Therefore, temperature-induced density effects would not have an adverse effect on performance.

All of the above support the conclusion that repository-induced thermal effects on flow in the SZ can be excluded due to low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.41 Gas Effects in the SZ (2.2.11.01.0A)

FEP Description:	Pressure variations due to gas generation may affect flow patterns and contaminant transport in the SZ. Degassing could affect flow and transport of gaseous contaminants. Potential gas sources include degradation of repository components and naturally occurring gases from clathrates, microbial degradation of organic material, or deep gases in general.
Descriptor Phrases:	Gas pressure effects on flow in the SZ; Naturally occurring gases in the SZ
Screening Decision:	Excluded–Low consequence
Related FEPs:	2.2.10.04.0A, 2.2.10.13.0A, 2.2.10.03.0A, 2.2.09.01.0A, 2.2.07.14.0A

Screening Argument:

The effects of gas pressurization are excluded on several bases. There is no evidence of large-scale gas buildup in, or flow of gas through, the SZ. Additionally, no significant volumes of oil or gas have been found in the Yucca Mountain vicinity, and proven source rocks in the region are lacking (French 2000 [107425], p. 5). While the geologic elements required for a petroleum system are present in the Yucca Mountain region, stratigraphic seals (important in a viable hydrocarbon producing region) are not well developed in the Yucca Mountain area, causing the hydrocarbon potential to be classified as low (French 2000 [107425], p. 39).

In the unlikely event that gas-generating processes occur in the sedimentary rocks below the tuffs, the influence on the flow and transport pathways would tend to be highly localized. Given the coarse grid used in the flow model and the uncertainty in the flow and transport pathways incorporated in the model, undetected localized processes or features that divert flow would either be too small in scale to impact the simulations or would be accounted for in the heterogeneity and parameter uncertainties in the Saturated Zone Flow and Transport (SZFT) model. As a result, it would not have a significant effect on the effective model parameter values and therefore would not affect radionuclide release to the accessible environment.

The presence of clathrates and microbial degradation of organic components are two potential sources of gas that may affect flow and transport in the SZ. Clathrates, methane gas molecules bound in a cage-like structure made up of water molecules, form under high pressures and low temperatures. Clathrates are found in polar and deep oceanic regions (Henriet and Mienert, 1998 [166162], pp. 9-11). Exploratory drilling has the potential to penetrate clathrates fields, which could release a large volume of gas in the SZ, in turn affecting SZ flow patterns. Clathrates are not a potential hydrocarbon source in the Yucca Mountain vicinity since low-temperature, high-pressure conditions do not exist in the region, which are requisite conditions for clathrate formation.

Microbial degradation of organic components is not considered a potential gas source in the SZ. Analysis of groundwater samples taken from SZ wells within the Yucca Mountain vicinity have found little to no organic carbon (DTN: GS931100121347.007 [149611] and DTN: GS010308312322.003 [154734]). Organic carbon is a bi-product of microbial activity. It is logically concluded, because there is little organic carbon found in SZ waters, there is insignificant microbial activity in the SZ producing CO_2 gas that would affect SZ flow and transport.

Since the repository is situated in the UZ approximately 335 m above the water table (DTN: GS000808312312.007 [155270], Table S00397 001; *Total System Performance Assessment for the Site Recommendation*, CRWMS M&O 2000 [153246], Figure 3.2-10), degradation of repository components that would potentially produce gas will not affect flow and transport in the SZ. A screening decision related to gas production from repository components as it affects UZ flow and transport is found in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2003 [164873], Section 6.6.2).

In summary, the potential effects of naturally occurring gases in the geosphere can be excluded from the SZFT model based on low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

6.2.42 Undetected Features in the SZ (2.2.12.00.0B)

FEP Description:	This FEP is related to undetected features in the SZ portion of the geosphere than can affect long-term performance of the disposal system. Undetected but important features may be present, and may have significant impacts. These features include unknown active fracture zones, inhomogeneities, faults and features connecting different zones of rock, and different geometries for fracture zones.
Descriptor Phrases:	Undetected features (flow and pathways in the SZ); Undetected features (fractures in the SZ); Undetected features (faults in the SZ)
Screening Decision:	Included
Related FEPs	2.2.07.14.0A, 2.2.07.13.0A, 2.2.07.12.0A, 2.2.03.01.0A, 1.2.02.02.0A, 1.2.02.01.0A

TSPA Disposition:

Undetected features in the SZ, such as fracture zones, inhomogeneities, faults, gravel lenses and channels in the alluvium, and their potential impacts on groundwater flow are implicitly incorporated in the *SZ* Transport Abstraction Model and the SZ 1-D Transport Model through parameter distributions (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Section 6.2); both models are described in BSC 2003 ([167651], Section 6.3). The generation of multiple flow and transport realizations, using stochastically sampled key parameters as input, significantly varies flow and transport pathways in the SZ. The key parameters that implicitly model undetected features (BSC 2003 [167651], Section 6.2) are (1) groundwater specific discharge (GWSPD), (2) horizontal anisotropy in the volcanic units (HAVO), (3) flowing interval spacing in the volcanic units (FISVO) and (4) sorption coefficients (K_{dij}) for 9 radionuclides modeled in both the alluvium and volcanic units (parameters are described in BSC 2003 ([167651], Sections 6.5.2.1, 6.5.2.10, 6.5.2.4, 6.5.2.8 and Table 6-8). A more detailed description of the manner in which undetected features are implicitly captured through the use of lumped parameters is provided in the *Supplemental Discussion* for this FEP in this SZ FEP report.

Supplemental Discussion:

Modeling of natural processes is, in many instances, based on using lumped parameters. Lumped parameters are parameters that are based on empirical observations (i.e., not all processes or first order physics are explicitly understood or known). Hydraulic conductivity, permeability, and transmissivity are examples of lumped parameters. In matching hydraulic heads (a response to the system) with variable lumped parameters such as permeability, anisotropy ratios, and dispersivity (to name a few), one implicitly incorporates undetected features into the model.

Groundwater specific discharge (GWSPD) in the SZ may be enhanced due to the presence of undetected features. In the alluvium features could be undetected gravel lenses and channels, and in the volcanics these could be undetected faults and fractures or fracture clusters. Uncertainty in groundwater specific discharge in the SZ is based on data gathered from single- and multi-well hydrologic testing in the volcanic units near Yucca Mountain and field testing in the alluvium at the alluvial tracer complex (ATC). In the TSPA, the GWSPD parameter is a multiplication factor applied to all SZ permeability values and specified boundary fluxes (BSC 2003 [167651], Section 6.5.2.1) to effectively scale the simulated specific discharge and implicitly model the effects undetected features may have on groundwater specific discharge.

Additional parameters that model undetected SZ features are flowing interval porosity in the volcanic units (FPVO, longitudinal dispersivity (LDISP) incorporated in both the volcanic units and the alluvium, effective porosity in the alluvium units 7 and 19 (NV7 and NV19), alluvium bulk density (bulk density), and sorption coefficients (K_{d}) for 9 radionuclides modeled in both the alluvium and volcanic units. Additionally, in the SZ Transport Abstraction Model (BSC 2003 [167651], Section 6.5.2.2), undetected features are accounted for through the probabilistic boundaries of the alluvium uncertainty zone. The western and northern boundaries of the alluvial uncertainty zone are defined with the sampled parameters FPLAW and FPLAN. The above parameters that implicitly model undetected features are described in BSC 2003 [167651], Sections 6.5.2.1, 6.5.2.2, 6.5.2.10, 6.5.2.4, 6.5.2.5, 6.5.2.7, 6.5.2.3, 6.5.2.8, respectively.

6.2.43 Groundwater Discharge to Surface Outside the Reference Biosphere (2.3.11.04.0A)

FEP Description: Radionuclides transported in groundwater as solutes or solid materials (colloids) from the far field may discharge at specific "entry" points that are outside the reference biosphere. Natural surface discharge points, including those resulting from water table or capillary rise, may be surface water bodies (rivers, lakes), springs, wetlands, holding ponds, or unsaturated soils.

Descriptor Phrases: Radionuclide release to biosphere (surface discharge away from receptor)

Screening Decision: Excluded–by regulation

Related FEPs: 2.2.08.011.0A, 1.4.07.02.0A, 1.4.07.01.0A

Screening Argument:

Groundwater discharge to the surface outside the reference biosphere is excluded on a regulatory basis defined in 10 CFR 63 [156605] as follows. The "reference biosphere" is defined in Section 63.2 as:

> "The environment inhabited by the reasonably maximally exposed individual (RMEI)."

Section 63.312(a) specifies the location where the RMEI will reside as:

> "The reasonably maximally exposed individual is a hypothetical person who meets the following criteria:
>
> Lives in the accessible environment above the highest concentration of radionuclides in the plume of contamination."

It is only the highest dose that is calculated in the performance assessment. And by definition, the reference biosphere, where groundwater is withdrawn to calculate the dose to the RMEI, is located within the accessible environment and is above the highest radionuclide concentration of the contaminated plume. Groundwater discharge outside the reference biosphere, which by definition would have a lower radionuclide concentration than that withdrawn from the reference biosphere, is excluded by regulation.

6.2.44 Radioactive Decay and Ingrowth (3.1.01.01.0A)

FEP Description: Radioactivity is the spontaneous disintegration of an unstable atomic nucleus that results in the emission of subatomic particles. Radioactive isotopes are known as radionuclides. Radioactive decay of the fuel in the repository changes the radionuclide content in the fuel with time and generates heat. Radionuclide quantities in the system at any time are the result of the radioactive decay and the growth of daughter products as a consequence of that decay (i.e., ingrowth). Over a 10,000-year performance period, these processes will produce daughter products that need to be considered in order to adequately evaluate the release and transport of radionuclides to the accessible environment.

Descriptor Phrases: Radioactive decay and ingrowth (in the SZ)

Screening Decision: Included

Related FEPs: 3.2.07.01.0A, 2.2.08.07.0A, 2.2.08.01.0A

TSPA Disposition:

Radioactive decay during transport in the SZ is explicitly included in the convolution integral method used to couple the SZ Transport Abstraction Model with the TSPA model and in the SZ 1-D Transport Model (*SZ Flow and Transport Model Abstraction*, BSC 2003 [167651], Section 6.2; both models are described in BSC 2003 [167651], Section 6.3). Ingrowth is accounted for in two different ways in the TSPA models. First, the radionuclide mass entering the SZ at the water table is adjusted to account for the potential ingrowth of some radionuclide daughter products, resulting in a "boosting" of the initial inventory of some daughter products (BSC 2003 ([167651], Section 6.3.1). This approach is a conservative simplification that overestimates the mass of these daughter radionuclides being transported in the SZ. Second, a separate set of SZ transport simulations is run to calculate explicitly the decay and ingrowth for the four main radionuclide chains, using the SZ 1-D Transport Model (BSC 2003 [167651], Section 6.3.2 and 6.5.1.2). These two ways of accounting for ingrowth in the SZ transport simulations differ from the approach used in the UZ transport simulations because of the differing numerical methods used. The convolution integral method, as implemented in the SZ Transport Abstraction model, is not able to explicitly calculate radioactive ingrowth and transport of daughter products. Consequently, the simplified approach of daughter product source "boosting" is used for some direct daughter products, and the SZ 1-D Transport Model is used for the longer decay chains.

6.2.45 Isotopic Dilution (3.2.07.01.0A)

FEP Description: Mixing or dilution of the radioactive species from the waste with species of the same element from other sources (i.e., stable and/or naturally occurring isotopes of the same element) could lead to a reduction of the radiological consequences.

Descriptor Phrases: Radionuclide dilution (by naturally occurring isotopes)

Screening Decision: Excluded–Low consequence

Related FEPs: 2.2.08.03.0A, 2.2.08.06.0A, 2.2.08.07.0A, 2.2.08.01.0A, 2.2.07.16.0A, 3.1.01.01.0A

Screening Argument:

Isotopic dilution in the SZ could occur if elements that are in the waste also occur naturally. Prime examples of naturally occurring isotopes in SZ groundwaters are those of strontium, (^{84}S, ^{86}S ^{87}S ^{88}S), uranium (^{234}U and ^{238}U), and carbon (^{12}C and ^{13}C) (*Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada*, BSC 2003 [167211], Section 6.7.1.2). In the Saturated Zone Flow and Transport (SZFT) model the concentration of radionuclides released from the UZ to the SZ is not diluted due to the presence of naturally occurring isotopes such as those listed above. Isotopic dilution would dilute the concentration of radioactive contaminants in the groundwater withdrawn from wells in the hypothetical farming community, thus reducing radiological exposure to the RMEI. Therefore, isotopic dilution is excluded based on low consequence because it has no adverse effects on performance.

6.2.46 Recycling of Accumulated Radionuclides from Soils to Groundwater (1.4.07.03.0A)

FEP Description:	Radionuclides that have accumulated in soils (e.g., from deposition of contaminated irrigation water) may leach out of the soil and be recycled back into the groundwater as a result of recharge (either from natural or agriculturally induced infiltration). The recycled radionuclides may lead to enhanced radionuclide exposure at the receptor.
Descriptor Phrases:	Radionuclide accumulation (soil); Radionuclide release to the biosphere (recycling)
Screening Decision:	Excluded–by regulation
Related FEPs:	1.4.07.01.0A, 1.4.07.02.0A, 2.3.02.02.0A, 2.3.11.03.0A, 2.4.09.01.0B

Screening Argument:

Uptake of radionuclide bearing groundwater by agricultural wells, then recycling this water back to the groundwater due to leaching out of cultivated fields, is excluded on a regulatory basis (Economy 2004 [167914]). The rationale referenced in Economy 2004 [167914] is summarized below.

It is stated in 10 CFR 63.312 (b) [156605] that the RMEI community’s well be located within the accessible environment above the highest radionuclide concentration of the contaminated plume. The plume’s highest concentration is projected to arrive to the accessible environment along the primary groundwater flow direction at 18 km down gradient from the repository. In accordance with 10 CFR Part 63 Subpart 63.332 (3) [156605] the annual water demand of 3000 acre-feet will be used to determine the concentration of radionuclides extracted at this location. Per requirements stated in 10 CFR 63.312 (b) the RMEI partakes in the same diets and lifestyles representative of the people now residing in the farming community of Amargosa Valley. The farming community of Amargosa Valley is located approximately 12 km down gradient from the accessible environment.

In 10 CFR 63.305 (b) the regulation specifically prohibits the projection of changes in society, the biosphere (other than climate), and increases or decreases in human knowledge or technology at the time of license application submittal. Per these requirements, the location of the RMEI community, the community's everyday activities, and RMEI's water supply well be held constant through time and are consistent with current practices. Therefore, consistent with the points above, and to avoid unsupportable speculation regarding the future activities of the farming community, the following regulatory position is adopted with respect to the location of the RMEI community and the community's well.

The concentration of radionuclides in the contaminated plume is based on the RMEI's well withdrawing 3,000 acre-feet per year. The RMEI does not pump the entire 3000 acre-feet of ground water. The RMEI's well pumps only that amount of water necessary to supply drinking water for the RMEI, irrigate a small vegetable garden, and irrigate a small orchard or pasture.

The RMEI's well is located at the accessible environment. Future cultivation, farming and irrigation sites undertaken by the RMEI's community are at the same location during the time of license application submittal. That is, all water use activities undertaken by the RMEI's farming community (which includes all agricultural uses) are located approximately 12 km down-gradient from the farming community's well. This presumes the well that withdraws the representative volume of groundwater to be used in determining the RMEI dose is not engaged in center-pivot irrigation.

While the RMEI is a rural resident, it is not a subsistence farmer and does not have significant acreage under cultivation. The RMEI's well does not engage in center pivot agricultural irrigation. Because the model adopts the position that the RMEI's irrigation water is withdrawn from wells located at the 18-km accessible environment boundary, which is 12 km up-gradient from the cultivated fields located in Amargosa Valley, recycling of contaminated water will not occur and radionuclides will not accumulate in soils. In conclusion, recycling of radionuclides is excluded on the basis of inconsistency with the requirements of 10 CFR 63.305(b) and 63.312(b) (Economy 2004 [167914]).

7. CONCLUSIONS

7.1 SATURATED ZONE SCREENED FEPS

The following 46 FEPs were evaluated with respect to SZ screening criteria given in Sections 4.2.2 and 4.3. By default, a FEP will be included in the TSPA if it cannot be excluded based on the criteria. For included FEPs, the TSPA-LA Dispositions provided in Section 6.2 describe how each FEP is included in the TSPA-LA (i.e., through a parameter or TSPA model or sub-model). For excluded FEPs, the screening decision is based on the screening criteria (by regulation, low probability, low consequence) and the technical basis for exclusion is elaborated in the Screening Arguments provided in Section 6.2. Table 7.1-1 summarizes the screening arguments for excluded FEPs and the TSPA dispositions for included FEPs.

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the technical product input information quality can be confirmed by review of the DIRS database.

Table 7.1-1. Summary of SZ FEPs Screening

Section Number	LA FEP Number	FEP Name	Screening Decision
6.2.1	1.2.02.01.0A	Fractures	Included
6.2.2	1.2.02.02.0A	Faults	Included
6.2.3	1.2.04.02.0A	Igneous activity changes rock properties	Excluded Low Consequence
6.2.4	1.2.04.07.0B	Ash redistribution in groundwater	Excluded Low Consequence
6.2.5	1.2.06.00.0A	Hydrothermal activity	Excluded Low consequence
6.2.6	1.2.09.02.0A	Large-scale dissolution	Excluded Low Consequence
6.2.7	1.2.10.01.0A	Hydrologic response to seismic activity	Excluded Low Consequence
6.2.8	1.2.10.02.0A	Hydrologic response to igneous activity	Excluded Low Consequence
6.2.9	1.3.07.01.0A	Water table decline	Excluded Low Consequence
6.2.10	1.3.07.02.0A	Water table rise affects SZ	Included
6.2.11	1.4.07.01.0A	Water management activities	Included
6.2.12	1.4.07.02.0A	Wells	Included
6.2.46	1.4.07.03.0A	Recycling of accumulated radionuclides from soils to groundwater	Excluded By Regulation

Table 7.1-1. Summary of SZ FEPs Screening (Continued)

Section Number	LA FEP Number	FEP Name	Screening Decision
6.2.13	2.1.09.21.0B	Transport of particles larger than colloids in the SZ	Excluded Low Consequence
6.2.14	2.2.03.01.0A	Stratigraphy	Included
6.2.15	2.2.03.02.0A	Rock properties of host rock and other units	Included
6.2.16	2.2.06.01.0A	Seismic activity changes porosity and permeability of rock	Excluded Low Consequence
6.2.17	2.2.06.02.0A	Seismic activity changes porosity and permeability of faults	Excluded Low Consequence
6.2.18	2.2.06.02.0B	Seismic activity changes porosity and permeability of fractures	Excluded Low Consequence
6.2.19	2.2.07.12.0A	Saturated groundwater flow in the geosphere	Included
6.2.20	2.2.07.13.0A	Water-conducting features in the SZ	Included
6.2.21	2.2.07.14.0A	Chemically-induced density effects on groundwater flow	Excluded Low Consequence
6.2.22	2.2.07.15.0A	Advection and dispersion in the SZ	Included
6.2.23	2.2.07.16.0A	Dilution of radionuclides in groundwater	Included
6.2.24	2.2.07.17.0A	Diffusion in the SZ	Included
6.2.25	2.2.08.01.0A	Chemical characteristics of groundwater in the SZ	Included
6.2.26	2.2.08.03.0A	Geochemical interactions and evolution in the SZ	Excluded Low Consequence
6.2.27	2.2.08.06.0A	Complexation in the SZ	Included
6.2.28	2.2.08.07.0A	Radionuclide solubility limits in the SZ	Excluded Low Consequence
6.2.29	2.2.08.08.0A	Matrix diffusion in the SZ	Included
6.2.30	2.2.08.09.0A	Sorption in the SZ	Included
6.2.31	2.2.08.10.0A	Colloidal transport in the SZ	Included
6.2.32	2.2.08.11.0A	Groundwater discharge to surface within the reference biosphere	Included
6.2.33	2.2.09.01.0A	Microbial activity in the SZ	Excluded Low Consequence
6.2.34	2.2.10.02.0A	Thermal convection cell develops in SZ	Excluded Low Consequence
6.2.35	2.2.10.03.0A	Natural geothermal effects on flow in the SZ	Included
6.2.36	2.2.10.04.0A	Thermo-mechanical stresses alter characteristics of fractures near repository	Excluded Low Consequence
6.2.37	2.2.10.04.0B	Thermo-mechanical stresses alter characteristics of faults near the repository	Excluded Low Consequence

Table 7.1-1. Summary of SZ FEPs Screening (Continued)

Section Number	LA FEP Number	FEP Name	Screening Decision
6.2.38	2.2.10.05.0A	Thermo-mechanical stresses alter characteristics of rocks above and below the repository	Excluded Low Consequence
6.2.39	2.2.10.08.0A	Thermo-chemical alteration in the SZ (solubility, speciation, phase changes, precipitation/dissolution)	Excluded Low Consequence
6.2.40	2.2.10.13.0A	Repository-induced thermal effects on flow in the SZ	Excluded Low Consequence
6.2.41	2.2.11.01.0A	Gas effects in the SZ	Excluded Low Consequence
6.2.42	2.2.12.00.0B	Undetected features in the SZ	Included
6.2.43	2.3.11.04.0A	Groundwater discharge to surface outside the reference biosphere.	Excluded By Regulation
6.2.44	3.1.01.01.0A	Radioactive decay and ingrowth	Included
6.2.45	3.2.07.01.0A	Isotopic dilution	Excluded Low Consequence

The conclusions from this document (FEP screening decisions and supporting rationale) are considered "technical product output" with no assigned DTN. The SZ FEP screening decision, TSPA-LA disposition (for included FEPs), or screening argument (for excluded FEPs), will be incorporated in the Yucca Mountain TSPA-LA FEP database. This database will contain all Yucca Mountain FEPs considered for TSPA-LA with FEP Number, Name, Description, and relevant FEP AMRs where specific FEPs are screened. The FEP database will also contain Descriptor Phrases, Screening Decisions (Include or Exclude), Screening Arguments, and TSPA Dispositions quoted from this and all other FEP AMRs. Documentation of the FEP database will be given in an AP-3.11Q report. All FEP information, including the 46 SZ FEPs considered in this report, will be submitted to Technical Data Management System by the Yucca Mountain FEP database team as a final LA FEP DTN. These final data will be qualified as Technical Product Output from the AP-3.11Q report. The final FEP DTN will supersede all of the previous DTNs. It will then be citable by any downstream documents, such as the Safety Analysis Report (SAR) or AMR Revisions.

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