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NM5507

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

ANALYSIS/MODEL COVER SHEET

Complete Only Applicable Items

1. QA: QA

Page: 1 of: 54

2. ☒ Analysis — Check all that apply

Type of Analysis:
- ☐ Engineering
- ☒ Performance Assessment
- ☐ Scientific

Intended Use of Analysis:
- ☐ Input to Calculation
- ☒ Input to another Analysis or Model
- ☐ Input to Technical Document
- ☐ Input to other Technical Products

Describe use:

To provide justification for excluding FEPs from the SZFT model.

3. ☐ Model — Check all that apply

Type of Model:
- ☐ Conceptual Model
- ☐ Abstraction Model
- ☐ Mathematical Model
- ☐ System Model
- ☐ Process Model

Intended Use of Model:
- ☐ Input to Calculation
- ☐ Input to another Model or Analysis
- ☐ Input to Technical Document
- ☐ Input to other Technical Products

Describe use:

4. Title:

Features, Events, and Processes in SZ Flow and Transport

5. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-NBS-MD-000002 REV 00

6. Total Attachments: 0

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8.	Originator	Theresa Brown	[signature]	4/24/00
9.	Checker	Bob Baca	R Baca	4/24/2000
10.	Lead/Supervisor	Bill Arnold	Bill W. Arnold	4/24/00
11.	Responsible Manager	Cliff Ho	Clifford K. Ho	4/24/00

12. Remarks:

Per Section 5.5.6 of AP-3.10Q, the responsible manager has determined that the subject AMR is not subject to AP-2.14Q review because the model does not affect a discipline or area other than the originating organization (Performance Assessment). The downstream user of the model resulting from this AMR is Performance Assessment (PA), which is also the originating organization of this work. PA leads, such as Bill Arnold and Geoff Freeze, have worked closely with the originator during the development of the model described in this AMR. Nevertheless, this AMR was sent to various Project participants to give representatives of QA, Regulatory and Licensing, and Applied Research and Testing the opportunity to read the AMR and provide informal comments.

ANALYSIS/MODEL REVISION RECORD

Complete Only Applicable Items

2. Analysis or Model Title:

Features, Events, and Processes in SZ Flow and Transport

3. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-NBS-MD-000002 REV 00

4. Revision/Change No.	5. Description of Revision/Change
00	Initial Issue

CONTENTS

TABLES

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ACRONYMS

3-D	three-dimensional
°C	degrees Celsius
AMR	Analyses/Models Report
atm	atmospheres
CO_2	carbon dioxide
Cs	cesium
d	day
D_e	effective diffusion coefficient
DOE	U.S. Department of Energy
FEPs	Features, Events, and Processes
HLW	High Level Waste
IRSR	Issue Resolution Status Report
K	Kelvin
K_c	a parameter that is the product of the sorption coefficient for the radionuclide onto the colloid and the concentration of colloids available for sorption
K_d	distribution coefficient
km	kilometer
m	meter
mg/L	milligrams per liter
mm	millimeter
N	newton
Ni	nickel
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
P	pressure
Pb	lead
pdfs	probability density functions
Pu	plutonium
Ra	radium
s	second
Sr	strontium
SZ	Saturated Zone
SZFT	Saturated Zone Flow and Transport
T	temperature
TSPA	Total System Performance Assessment
TSPA&I	Total System Performance Assessment and Integration
TSPA-SR	Total System Performance Assessment for Site Recommendation
U	uranium
USGS	Unites States Geological Survey
UZ	Unsaturated Zone
UZFT	Unsaturated Zone Flow and Transport
YMP	Yucca Mountain Project

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1. PURPOSE

This AMR is a support document to the Saturated Zone Flow and Transport Process Model Report (a downstream document to be completed subsequent to this analysis). The compilation of features, events, and processes (FEPs) that could affect the performance of the proposed repository is an ongoing process based on site-specific information and regulations. Currently, the Yucca Mountain Project (YMP) FEP database consists of 1,786 FEPs from other international databases, YMP literature, and YMP technical workshops (CRWMS M&O 1999a). The purpose of this analysis is to document the disposition, and justification for the disposition, of the 46 primary FEPs that potentially affect saturated zone (SZ) flow and transport. For a complete list of the FEPs that were considered in this analysis and their disposition see Table 7-1.

The FEPs that might be important to performance are evaluated, either as components of the Total System Performance Assessment (TSPA) or eliminated based on low probability, insignificant consequence, or regulatory guidance. This Analyses/Models Report (AMR) identifies which FEPs are considered explicitly in the TSPA (called included FEPs), summarizes how they are represented in the TSPA model, identifies FEPs that do not need to be included in the SZFT models, and provides the justification for why these FEPs are not required in the SZFT models. Some of the FEPs potentially affect other components of the TSPA and are being analyzed in other AMRs. The FEPs affecting only the SZ can be excluded from the TSPA (called excluded FEPs) based on insignificant consequence and the results of this analysis.

This analysis was conducted and documented in accordance with the development plan "Features Events and Processes in SZ Flow and Transport" (CRWMS M&O 1999b).

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2. QUALITY ASSURANCE

The quality assurance program is applicable to this AMR. Specifically, this work is governed by the requirements of procedure QAP-2-0 activity evaluation, "Conduct of Performance Assessment." All PA activities have been evaluated and determined quality affecting (CRWMS M&O 1999c).

This report was prepared in accordance with the requirements of AP-3.10Q, "Analyses and Models." Planning for this analysis is documented in the development plan (CRWMS M&O 1999b). Results of this analysis have been documented and recorded per AP-3.10Q (Attachment 1 and Section 6). All associated records (e.g., data, software, planning) have been submitted per the appropriate procedure cited in AP-3.10Q (Section 7). QA/QC verification, external to implementing procedure requirements, was performed as directed by management. Checking of this product was performed per AP-3.10Q (Section 5.5).

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3. COMPUTER SOFTWARE AND MODEL USAGE

No software routines were used in this analysis. No models were used in, or developed for, this analysis.

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4. INPUTS

There are no input data sources used in this analysis. References for supporting information are cited in the text.

4.1 DATA AND PARAMETERS

In order to evaluate the potential advective transport of particles in saturated fractures, the potential range of settling velocities of particles was compared to the range of simulated advective velocities (Section 6.2.8). This comparison allows evaluation of the uncertainty in the transport distance for particles as a function of the uncertainty in the advective velocity and the uncertainty in particle size.

Settling velocities for particles in saturated fractures were estimated based on Stokes Law using the following parameter values:

- particle diameters of 1 micron to 0.01 mm
- particle density of 2650 kg/m^3
- water density of 998.2 kg/m^3
- water viscosity of 1.005 x 10^{-3} Ns/m^2
- gravitational acceleration of 9.81 m/s^2.

The calculation of settling velocity as a function of particle diameter is used for illustrative purposes. Since the objective was to illustrate the order of magnitude of the settling velocity as a function of particle diameter, the other parameter values are held constant values. The particle diameter was varied over several orders of magnitude. Even though the other parameter values are not known with certainty, that uncertainty did not cause orders of magnitude changes in the settling velocity. Typical particle densities (for naturally occurring soil particles) are around 2.65 kg/m^3 (Freeze and Cherry 1979, p. 337), which is equivalent to the density of quartz, is used as an estimate for the colloid density. The water density and viscosity are estimated assuming water temperature of 20° C (Streeter and Wylie 1979; p. 534; Viswanath and Natarajan 1989, p. 715).

4.2 CRITERIA

The U.S. Nuclear Regulatory Commission's (NRC's) Total System Performance Assessment and Integration (TSPA&I) Issue Resolution Status Report (IRSR) (NRC 1998) establishes generic technical acceptance criteria that NRC staff consider essential to a defensible, transparent, and comprehensive assessment methodology for the repository system. These regulatory acceptance criteria apply to five fundamental elements of the DOE Total System Performance Assessment (TSPA) model for the Yucca Mountain site:

1. data and model justification (focusing on sufficiency of data to support the conceptual basis of the process model and abstractions)

2. data uncertainty and verification (focusing on technical basis for bounding assumptions and statistical representations of uncertainties and parameter variability)

3. model uncertainty (focusing on alternative conceptual models consistent with available site data)

4. model verification (focusing on testing of model abstractions using detailed process-level models and empirical observations)

5. integration (focusing on appropriate and consistent coupling of model abstractions).

The first four elements of the acceptance criteria are addressed in this AMR. Integration strictly applies to the final synthesis of process-level models and abstractions, and will be addressed separately in the Total System Performance Assessment for Site Recommendation (TSPA-SR).

This AMR was prepared to comply with NRC Issue Resolution Status Report acceptance criteria (NRC 1998) as well as the DOE interim guidance (Dyer 1999) which requires the use of specified Subparts/Sections of the proposed NRC high-level waste rule, 10 CFR Part 63 (64 FR 8640). The subparts of the proposed rule that are particularly applicable to data include: Subpart B, Section 15 (Site Characterization) and Subpart E, Section 114 (Performance Assessment). Subparts applicable to models are outlined in Subpart E, Sections 114 (Performance Assessment) and 115 (Characteristics of the Reference Biosphere and Critical Group).

The screening criteria for exclusion of an FEP are summarized as follows:

- Exclude based on low probability if the FEP has a less than 1 in 10,000 chance of occurrence over 10,000 years.

- Exclude based on low consequence if omission of the FEP does not significantly change the expected annual dose.

- Exclude on a regulatory basis if the FEP is not included in certain regulatory assumptions.

The NRC regulatory requirements that apply to this analysis are:

- **10 CFR 63 Sec. 63.114**
  (d) Consider only events that have at least one chance in 10,000 of occurring over 10,000 years.

  (e) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes of the geologic setting in the performance assessment. Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

- **40 CFR 197 Sec. 197.40**
  The DOE's performance assessments should not include consideration of processes or events that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal. The NRC may change this limit

to exclude slightly higher probability events. In addition, with the NRC's approval, DOE's performance assessments need not evaluate, in detail, the impacts resulting from any processes and events or sequences of processes and events with a higher chance of occurrence if the results of the performance assessments would not be changed significantly.

4.3 CODES AND STANDARDS

This section is not applicable to this analysis. There are no known standards or codes for this type of analysis.

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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 PARAMETER VALUES AND UNCERTAINTY

It is assumed that the parameter values, and uncertainty in those values, used in the TSPA models include the effects and uncertainty introduced by the included FEPs (Section 6.1). This assumption needs to be verified based on the parameter values and support for those values (CRWMS M&O 2000a). This is a general assumption that is made throughout Section 6.1.

One case in particular will require some effort to verify that the effects of the included FEPs are reflected in the uncertainty and variability in the parameter values. It is assumed in this analysis (Section 6.1.7) that the effect of uncertain and variable groundwater composition, due to chemical, geochemical and biochemical reactions, on contaminant transport is accounted for through the uncertainty in the K_d for each element, effective diffusion coefficient, and colloid facilitated transport model parameter values (CRWMS M&O 2000a).

5.2 WATER TABLE DECLINE

It is assumed for the analysis of large-scale dissolution (Section 6.2.2) that under future climates the water table will not drop as low as the carbonate aquifer. This is a reasonable assumption given the depth of the carbonate aquifer below the water table [more than 700 meters given the approximate thickness of the volcanic units below the water table based on lithologic logs from drill hole UE-25 p#1 and water table elevations in USW H-4 (CRWMS M&O 1998a, Figure 3.5-3 and Table 5.3-66)] and the lack of any significant groundwater withdrawal in a twenty kilometer radius of the proposed repository (D'Agnese et al. 1997, pp. 8, 21 and 49-50). This assumption does not require further verification.

5.3 WATER TABLE RISE

The probability and potential effects of water table rise on the unsaturated zone (UZ) are being evaluated in a separate AMR (CRWMS M&O 2000b). It is assumed, in this report, that the effects of water table rise on UZ flow and transport processes (e.g., shorter travel path through the UZ) will be represented as variability in timing and rate of contaminant transport to the SZ (Section 6.2.4). This would affect the values input to the TSPA model but would not require alteration of the SZFT model. This is a reasonable assumption, but it requires verification based on the results of the UZ FEP AMR (CRWMS M&O 2000b).

In this analysis, only the effects of water table rise on the modeled SZFT are evaluated. In that evaluation (Section 6.2.4) it is assumed that potential changes in transport pathways due to water table rise will be evaluated by performing sensitivity analyses with the calibrated SZFT model.

5.4 PARTICLE TRANSPORT

Transport of waste particles larger than colloids is a FEP that is being evaluated for the UZ (CRWMS M&O 2000b) as well as the SZ (Section 6.2.8). While it is unlikely that particles larger than colloids will be transported through the unsaturated zone, it is assumed for this report that if these particles are included in the UZFT model, they will be simulated conservatively using the UZ colloid transport model. This assumption requires verification based on the results of the repository and UZ transport modeling.

This assumption is also used in the evaluation of the effect of increased solubility limits (Section 6.2.5). The only way for an increase in solubility in the SZ to increase the dissolved contaminant mass is for the contaminants to be present in the SZ as particles. Colloidal transport provides a faster transport pathway than solute transport. If all particle transport can be conservatively modeled using the colloid transport model, there is no potential negative impact to increasing the solubility limits in the SZ.

5.5 THERMAL HYDRAULIC EFFECTS IN THE UZ

The thermal hydraulic effects of the repository are being evaluated in a separate AMR (CRWMS M&O 2000c (*FEPs Report for the Near Field Environment*)). In the analyses of the potential thermal hydraulic effects of the repository on the SZFT system (Sections 6.2.11 and 6.2.6) it is assumed that when all the effects of high temperatures in the waste are considered, repository-induced thermal effects will delay contaminant transport to the SZ.

This assumption requires verification based on the AMR for thermal hydrology and coupled processes (CRWMS M&O 2000c (*FEPs Report for the Near Field Environment*)) and the UZ FEPs analyses (CRWMS M&O 2000b).

5.6 RADIONUCLIDE ACCUMULATION IN SOILS

Radionuclide accumulation in soils is listed in the FEP database as potentially impacting the SZ (CRWMS M&O 1999a). Since the discharge of contaminated groundwater occurs at the compliance point, accumulation in soils does not alter the SZFT model (Section 6.3.2). Radionuclide accumulation in soils affects the modeled, potential exposure and dose. Hence, for this analysis (Section 6.2.9), it is assumed that this process will be included in the exposure model. This assumption requires verification based on the exposure model features.

5.7 TECTONIC EFFECTS

Since the potential effects of tectonic activity on contaminant transport are being evaluated in a separate AMR (CRWMS M&O 2000d), we are forced to make assumptions regarding the disposition of the tectonic FEPs in order to proceed with the TSPA model development and implementation (Section 6.2.10). It is assumed that potentially significant tectonic effects on UZFT will be reflected in the input parameter values supplied for the SZFT model from the UZFT model output. This assumption requires verification based on the results of the tectonics AMR (CRWMS M&O 2000d) and subsequent UZ transport modeling. It is also assumed that the future fracture systems will produce flowing intervals in the SZ that are similar to the existing system. This assumption requires verification based on the analysis of the potential effects of future tectonic activity (CRWMS M&O 2000d).

5.8 IGNEOUS ACTIVITY EFFECTS

The potential effects of igneous activity on contaminant transport are being evaluated in a separate AMR along with the tectonic FEPs (CRWMS M&O 2000d). As noted previously, we are forced to make assumptions regarding the disposition of these FEPs in order to proceed with the TSPA model development and implementation. With regard to each of the Igneous FEPs it is assumed for this analysis (Section 6.2.12) that one or more of the following apply:

1. the probability of igneous activity, of sufficient scale (or in a specific location along the transport pathway) to significantly alter SZFT, is below the regulatory screening criteria,
2. hydrothermal effects of igneous activity would delay contaminant transport through the UZ to the SZ, or
3. igneous FEPs have no negative impact on SZFT.

This assumption requires verification based on the analysis of the probability and potential effects of volcanic activity on the entire system (CRWMS M&O 2000d).

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6. ANALYSIS

6.1 INCLUDED FEPS

Screening Argument

The FEPs listed in Table 6-1 are potentially important to the results of the SZFT model and consequently may have a significant effect on the expected annual dose. Hence, the screening decision for these FEPs is to include them in the TSPA nominal scenario.

Table 6-1. Included SZ FEPs

YMP FEP Database ID#	Name
1.4.07.01.00	Water management activities
1.4.07.02.00	Wells
2.2.07.12.00	Saturated groundwater flow
2.2.07.13.00	Water-conducting features in the saturated zone
2.2.07.15.00	Advection and dispersion
2.2.07.16.00	Dilution of radionuclides in groundwater
2.2.07.17.00	Diffusion in the saturated zone
2.2.08.08.00	Matrix diffusion in geosphere
2.2.08.01.00	Groundwater chemistry/composition in UZ and SZ
2.2.08.03.00	Geochemical interactions in the geosphere
2.2.10.06.00	Thermo-chemical alteration
2.2.08.06.00	Complexation in the geosphere
2.2.09.01.00	Microbial activity in geosphere
2.2.08.02.00	Radionuclide transport occurs in a carrier plume in the geosphere
2.2.08.09.00	Sorption in the UZ and SZ
2.2.08.10.00	Colloid transport in the geosphere
2.2.08.11.00	Distribution and release of nuclides from the geosphere
2.2.10.03.00	Natural geothermal effects
2.2.12.00.00	Undetected features
3.1.01.01.00	Radioactive decay and ingrowth
2.2.03.01.00	Stratigraphy
2.2.03.02.00	Rock properties of host rock and other units

The following subsections summarize the disposition of the included FEPs within the TSPA models.

6.1.1 Water Management Activities (1.4.07.01.00) and Wells (1.4.07.02.00)

6.1.1.1 YMP Primary FEP Descriptions

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.

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.

6.1.1.2 FEP Disposition in TSPA Models

Water management activities and wells are included explicitly in the exposure model as a volume of water consumed (directly and indirectly) by the hypothetical, regulatory mandated exposed community (64 FR 8640). Groundwater use is based on current practices in the vicinity of Yucca Mountain (CRWMS M&O 2000f). The groundwater system in the vicinity of the hypothetical community's well system is modeled using a mixing cell and assuming that all the contaminants discharged at the twenty-kilometer boundary are intercepted by the community's wells (CRWMS M&O 2000e (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)). The average annual contaminant concentration in well water is calculated at a specified location for a volume of water consistent with current usage (CRWMS M&O 2000f).

The effects of existing wells and water management activities on the saturated flow system are not modeled explicitly, but are included implicitly since the flow model is calibrated using existing hydraulic head data (Faunt 1999).

The potential effect, of future wells or changes in water management practices, on the SZFT system is not evaluated as per Regulatory guidance (Dyer 1999, Sec.115(b)):

> *(2) The behaviors and characteristics of the farming community shall be consistent with current conditions of the region surrounding Yucca Mountain site. Changes over time in the behaviors and characteristics of the critical group including, but not necessarily limited to, land use, lifestyle, diet, human physiology, or metabolics; shall not be considered.*

6.1.2 Saturated Groundwater Flow (2.2.07.12.00)

6.1.2.1 YMP Primary 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.

6.1.2.2 FEP Disposition in TSPA Models

Advective transport via saturated flow in fractures is evaluated in the TSPA as the primary mode of contaminant transport from the repository to the receptor. The SZFT model simulates flow in a saturated system. The TSPA model assumes steady-state saturated flow that obeys Darcy's Law. Groundwater flux is modeled as a function of the hydraulic conductivity of the porous medium, hydraulic gradient, and the cross-sectional area through which flow occurs. The model boundary conditions are specified heads along the sides, with no flow at the bottom and specified flux (recharge) at the top boundary. Parameters influencing groundwater flow include recharge, permeability, temperature, and porosity (CRWMS M&O 2000e (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)).

6.1.3 Water-Conducting Features (2.2.07.13.00)

6.1.3.1 YMP Primary FEP Description

Geologic features in the saturated zone may affect groundwater flow by providing preferred pathways for flow.

6.1.3.2 FEP Disposition in TSPA Models

Fracture flow is an explicit feature of the TSPA SZ flow and transport model. The SZFT model simulates saturated flow and advective transport through flowing intervals, a subset of water-conducting features within the fracture system (CRWMS M&O 1999d). In the TSPA model, retardation of contaminant transport in the flowing interval occurs by contaminant diffusion out of the fractures into the matrix pores, with sorption on the matrix (CRWMS M&O 2000e (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)). Parameters used to represent the flowing interval include: flowing interval spacing, anisotropy, porosity, and permeability. Parameters influencing the simulated transport through the fractures include: the groundwater specific discharge, dispersivity, colloid concentrations, colloid retardation, element sorption coefficients and effective diffusion coefficient. The uncertainty in the effective model parameter values, given the uncertainty and variability in groundwater specific discharge, flowing interval spacing, anisotropy, porosity, dispersivity, colloid concentration, colloid retardation, solute sorption and diffusion, is evaluated using Monte Carlo simulation and uncertain parameter values (CRWMS M&O 2000a and CRWMS M&O 2000e (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)). The flowing interval permeability for each cell of the SZFT model is fixed based on calibration of the site-scale model to measured hydraulic heads and the specific discharge at the north, east and west boundaries. The targeted values of discharge are based on the distribution of flux in the calibrated regional model (D'Agnese et al. 1997, CRWMS M&O 1999e). Recharge rates and the distribution of recharge are fixed. Recharge is based on a composite of the UZ site-scale model, calibration of the regional SZ flow model to measured hydraulic heads and estimates of recharge along Fortymile Wash (Zyvoloski 1999).

6.1.4 Advection And Dispersion (2.2.07.15.00)

There are two secondary FEPs encompassed in the primary FEP evaluated in this section. These secondary FEPs are described as Far-field Transport Hydrodynamic Dispersion (2.2.07.15.02) and Solute Transport (2.2.07.15.04).

6.1.4.1 YMP Primary FEP Description

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

6.1.4.2 FEP Disposition in TSPA Models

Advection and dispersion are processes included in the SZ transport model. Transport in the fracture system is modeled with the FEHM code, which implements a numerical approximation of the three-dimensional advection-dispersion equation. Diffusion out of the fracture system into the porous matrix and equilibrium sorption within the matrix system are also simulated. A semi-analytical solution to the diffusion equation is implemented in the FEHM code (CRWMS M&O 2000e (*Type Curve Calculations Mass Transport in Parallel Fractures Used in Particle-Tracking Scheme in the Saturated Zone*)).

The results of the SZ transport model are translated into breakthrough curves. These breakthrough curves represent the uncertainty and potential variability (due to heterogeneities) in the transport rate and the length of the advective transport pathway. Uncertainty in the specified flux and hydraulic conductivity are treated explicitly using 3 separate simulations. The values of flux for the three simulations are based on the results of an expert elicitation (CRWMS M&O 2000a, CRWMS M&O 1998b). The high- and low-flux cases are used to bound the potential effects of the uncertainty in hydraulic gradient, aquifer conductivity, and recharge on this model parameter value. Monte Carlo analyses are used to evaluate the uncertainties in the flowing interval spacing and porosity, effective diffusion coefficients, and dispersivities (CRWMS M&O 2000a).

6.1.5 Dilution of Radionuclides in Groundwater (2.2.07.16.00)

6.1.5.1 YMP Primary 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

6.1.5.2 FEP Disposition in TSPA Models

Dilution as a result of pumping is explicitly included in the TSPA exposure model. The 3-D SZFT model is used to estimate the flux of contaminants into the volume of water consumed in the regulatory mandated exposure scenario. The convolution integral is used to estimate the activity of each isotope at the boundary. The average concentrations in the water consumed by the hypothetical community are calculated using a mixing cell model (64 FR 8640, part 63.115; CRWMS M&O 2000f; and CRWMS M&O 1998c, Chapter 8, section 8.3.4).

6.1.6 Diffusion (2.2.07.17.00) and Matrix Diffusion (2.2.08.08.00)

6.1.6.1 YMP Primary FEP Description

Molecular diffusion processes may affect radionuclide transport in the saturated zone.

6.1.6.2 FEP Disposition in TSPA Models

Diffusion is included in the SZ transport model (CRWMS M&O 2000e (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)). Within the rock matrix, diffusion is the only modeled contaminant transport mechanism. The diffusion coefficient is also used in the calculation of the dispersivity term (CRWMS M&O 2000a). Diffusion is assumed to obey Fick's law as a function of the effective molecular diffusion coefficient for the porous matrix and the concentration gradient. A semi-analytic solution to the diffusion equation is implemented in the FEHM code (CRWMS M&O 2000e (*Type Curve Calculations Mass Transport in Parallel Fractures Used in Particle-Tracking Scheme in the Saturated Zone.*)). The concentration gradient and the change in the gradient over time and distance along the transport pathway is a function of solubility, flowing-interval porosity, flowing-interval spacing, and effective diffusion coefficient. Monte Carlo analyses are used to evaluate the uncertainties in the flowing interval spacing, porosity, effective diffusion coefficients, and dispersivities (CRWMS M&O 1999d; CRWMS M&O 2000a).

6.1.7 Groundwater Chemistry FEPs (2.2.08.01.00, 2.2.08.03.00, 2.2.10.06.00, 2.2.09.01.00)

The following FEPs are grouped together in this analysis as FEPs related to the variability and uncertainty in groundwater chemistry and the potential effects on contaminant transport in the saturated zone:

- Groundwater Chemistry/Composition in UZ and SZ (2.2.08.01.00)
- Geochemical Interactions in the Geosphere (2.2.08.03.00)
- Thermo-chemical Alteration (2.2.10.06.00)
- Complexation in the Geosphere (2.2.08.06.00)
- Microbial activity in Geosphere (2.2.09.01.00)

Geochemical Interactions in the Geosphere includes three secondary FEPs: Alteration/Weathering of Flowpaths (2.2.08.03.08), Precipitation and Dissolution (2.2.08.03.09) and Groundwater Chemistry (2.2.08.03.18).

6.1.7.1 YMP Primary FEP Descriptions

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.

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.

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.

Complexing agents such as humic and fulvic acids present in natural groundwater could affect radionuclide transport.

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.

6.1.7.2 FEP Disposition in TSPA Models

The uncertainty in the groundwater composition and its effect on contaminant transport is modeled implicitly through the uncertainty in the K_d value for each element, effective diffusion coefficient, and the colloid-facilitated transport process model (CRWMS M&O 2000a). It is assumed that the range of values used for each parameter accounts for all these potential effects.

Other changes in the SZ groundwater chemistry are not included in the SZFT models because they would not increase the simulated dose (see Sections 6.2.2, 6.2.5 and 6.3.3).

6.1.8 Radionuclide Transport in a Carrier Plume (2.2.08.02.00)

6.1.8.1 YMP Primary FEP Description

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.

6.1.8.2 FEP Disposition in TSPA Models

Radionuclide solute and colloid transport are modeled as occurring in a carrier plume. No credit is taken for chemical changes within the plume that would decrease the transport rate (e.g., potential decrease in solubility in the SZ due to mixing of contaminated water with uncontaminated water or changes in pH).

6.1.9 Sorption in the UZ and SZ (2.2.08.09.00)

6.1.9.1 YMP Primary FEP Description

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.

6.1.9.2 FEP Disposition in TSPA Models

Sorption in the SZ is modeled using a linear equilibrium isotherm. The uncertainty in sorption is evaluated by treating K_d as an uncertain parameter in a Monte Carlo analysis. Sorption is modeled for contaminants that diffuse into the matrix, but no credit is taken for sorption of solutes in the flowing intervals (CRWMS M&O 2000a). Transport of contaminants that are irreversibly sorbed on colloids is evaluated using a colloid source concentration and colloid retardation coefficient (CRWMS M&O 2000a).

6.1.10 Colloid Transport in the Geosphere (2.2.08.10.00)

6.1.10.1 YMP Primary FEP Description

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

6.1.10.2 FEP Disposition in TSPA Models

Colloid transport is included explicitly in the SZFT model as an abstraction of the colloid process model (CRWMS M&O 2000g). The process model is used to justify the range and probability distribution for the colloid parameter values used in the SZFT model.

The model for colloid-facilitated transport used in TSPA-SR describes two different mechanisms: irreversible sorption of radionuclides onto colloids (also called irreversible colloids for brevity) and reversible sorption of radionuclides onto colloids (also called reversible colloids for brevity). Irreversible colloids represent radionuclides that are embedded or permanently bound to colloids; the model therefore assigns these radionuclides the transport properties of colloids. Retardation is by chemical filtration as estimated by field and laboratory tests and, in volcanic strata, the radionuclides/colloids are restricted to fractures.

Reversible colloids represent radionuclides that are sorbed or temporarily bound to colloids. The concept behind the model for these radionuclides is that they spend some amount of time associated with the colloids (as defined by the K_c parameter—the product of the sorption coefficient for the radionuclide onto the colloid and the concentration of colloids available for sorption) and some amount of time as solute. When the radionuclides are associated with the colloids, they are restricted to the fractures (in the volcanic strata). When the radionuclides dissociate, they are free to undergo matrix diffusion and sorption onto matrix minerals. Filtration of reversible colloids is not considered because even if the colloids filter, the radionuclides are free to dissociate and continue migrating. To simplify what could easily be an intractable problem, only one K_c value is used in the SZFT model for TSPA-SR. This value is based on sorption of Am onto waste-form colloids in a low ionic-strength groundwater—a combination of factors which should maximize the K_c and thus maximize the mobility of the radionuclides.

Reversible colloids are also called "pseudo colloids." Irreversible colloids contain as a subset the "true colloids." Although microbial colloids are not specifically included in the SZFT model, they are a type of irreversible colloid. Thus, if the source term included microbial colloids, they would be included in the SZFT model.

6.1.11 Distribution and Release Of Nuclides (2.2.08.11.00)

6.1.11.1 YMP Primary FEP Description

Radionuclides may be released to the biosphere following groundwater transport in unsaturated and saturated zones.

6.1.11.2 FEP Disposition in TSPA Models

The release of nuclides is modeled in the exposure analysis and is based on regulatory guidance (64 FR 8640). The distribution of nuclides is modeled explicitly, incorporating the potentially significant uncertainties to evaluate the effects of those uncertainties on the simulated time, composition, and rate of release of contaminants at the designated regulatory compliance point.

6.1.12 Geothermal Effects (2.2.10.03.00)

6.1.12.1 YMP Primary FEP Description

The existing geothermal gradient, and spatial or temporal variability in that gradient, may affect groundwater flow in the unsaturated and saturated zones.

6.1.12.2 FEP Disposition in TSPA Models

The geothermal gradient is explicitly included in the 3-D SZFT model (Zyvoloski 1999). The geothermal gradient is represented in the model using fixed thermal conditions with a linear, vertical temperature gradient of 25 K/km.

6.1.13 Undetected Features (2.2.12.00.00)

This FEP encompasses one secondary FEP that applies to the SZ: Undetected Fault Connects Tuff Aquifers to Carbonate Aquifers; Providing a Fast Path (2.2.12.00.04).

6.1.13.1 YMP Primary FEP Description

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.

6.1.13.2 FEP Disposition in TSPA Models

The purpose of the FEPs process is to identify undetected features that have the potential to negatively impact the site's performance (see Section 1). Undetected features are included in SZFT model in the parameter uncertainties that are evaluated in the Monte Carlo analyses and assumptions regarding parameter values, hydrogeologic framework, and transport mechanisms. Potential (i.e., undetected) features are analyzed through a systematic process to define the potential feature and determine if its potential effects are detrimental and/or have a significant probability of occurrence. This document provides the basis for inclusion or exclusion of potential FEPs that might influence the SZ flow and transport processes.

6.1.14 Radioactive Decay and Ingrowth (3.1.01.01.00)

6.1.14.1 YMP Primary FEP Description

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.

6.1.14.2 FEP Disposition in TSPA Models

Radioactive decay is explicitly included in the convolution integral of the TSPA model (CRWMS M&O 1998c, Chapter 8, section 8.3.4). The convolution integral is solved in a subroutine of the GOLDSIM computer code. Ingrowth is accounted for in two different ways in the TSPA model. First, the initial inventory in the waste is adjusted to account for the daughter products that obviously impact the simulated dose. Second, a separate set of 1-D transport simulations is run to calculate the decay and ingrowth for the four main radionuclide chains (CRWMS M&O 2000e (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)). The 1-D simulations use pathlengths and hydraulic properties based on the 3-D analyses to estimate the effects of ingrowth on the flux of radionuclides across the twenty-kilometer boundary.

6.1.15 FEPs Related to Geologic Properties (2.2.03.01.00, 2.2.03.02.00)

Two of the SZ FEPs, Stratigraphy (2.2.03.01.00) and Rock properties of host rock and other units (2.2.03.02.00) are related to geologic properties of the system that influence groundwater flow and contaminant transport. These primary FEPs include the following secondary FEP: Rock Heterogeneity (2.2.03.02.01).

6.1.15.1 YMP Primary FEP Descriptions

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.

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.

6.1.15.2 FEP Disposition in TSPA Models

Geologic features and stratigraphic units are explicitly included in the SZFT model as cells with specific hydrologic parameter values in a configuration based on the hydrogeologic framework model created by the USGS. Uncertainty in the location of the contact between alluvium and volcanics at the southern end of the site scale model is modeled probabilistically along with the other parameters representing effective (grid-scale) hydro-geologic properties (Faunt 1999; CRWMS M&O 2000e (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*); CRWMS M&O 2000a).

6.2 FEPS NOT INCLUDED IN SZFT MODELS

There are three types of FEPs that are not included in the SZ model:

1. FEPs that would tend to decrease the simulated dose because they: increase, or would tend to increase, the contaminant travel time through the SZ (from a point below the proposed repository to the compliance point); or would increase dilution of the contaminant concentration within the SZ.

2. FEPs that would not affect the simulated dose because they do not decrease the travel time through the SZ or the dilution of contaminant concentration within the SZ.

3. FEPs that are evaluated in other AMRs and excluded from TSPA or included in other models (e.g., UZ, biosphere).

The first two categories of FEPs do not need to be included in the SZFT models; however, since these FEPs also affect the UZ or biosphere and are being analyzed in other AMRs, they cannot be excluded from the TSPA as a result of solely this analysis.

The third category of FEPs are not likely to impact dose significantly because of their low probability of occurrence or because they fit into one of the first two categories. However, these FEPs are being evaluated in other AMRs that deal specifically with disruptive events.

The following sections present the arguments for screening each of these FEPs out of the SZFT models. The disposition of these FEPs will be determined once all the FEP AMRs are complete.

6.2.1 Hydrothermal Activity (1.2.06.00.00)

6.2.1.1 YMP Primary FEP Description

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.

6.2.1.2 Screening Argument

If hydrothermal activity were to occur in the vicinity of the repository or along the transport path of the contaminant plume, relatively high-temperature groundwater would flow upward from depth due to buoyancy forces overcoming resistive viscous forces. The magnitude of the buoyancy forces and the rate of dissipation of heat (due to conductance and convection) will control the height of convective flow. As warmer, lower-density water moves upward, away from the heat source, it cools and the buoyant forces decrease. This process can create convection cells, which would affect the lateral flow of fluids. If convection occurred within the contaminant plume, away from the repository, it would cause greater mixing of waters than predominantly lateral flow. Increased mixing would enhance dilution of the contaminant plume. To simplify the TSPA model, no credit is taken for this potential dilution effect.

Hydrothermal activity in the past has resulted in alteration of rocks in Yucca Mountain, and the surrounding region large-scale alteration is associated with silicic volcanism. The most recent silicic volcanism occurred more than 10 million years ago (CRWMS M&O 1998a, Section 3.9). The alterations that potentially impact the performance of the site relate to alteration of existing zeolitic minerals to varieties with lower cation exchange capacities. These alterations occur through dehydration and complex mineral phase changes due to the dependence of mineral phase stability on temperature (Smyth 1982). Dehydration only occurs in unsaturated conditions and does not apply to the saturated zone. Laboratory studies on the sorption capacities of Yucca Mountain tuffs indicate that zeolitic samples tend to have lower sorption coefficient values for Pu, Np, and U than vitric or devitrified samples. Zeolitic samples tend to have higher sorption coefficient values for Cs, Sr and Ra, Pb, and Ni. There are no significant differences for Se sorption coefficients for the three types of tuff (Triay et al. 1997, pp. 68, 83, 84, 101and 104). To simplify the SZFT model analysis, sorption coefficient values are based on the rock type with the lowest sorption capacity (CRWMS M&O 2000a).

The TSPA model evaluates the effect of the uncertainty in the geochemical conditions through the sorption coefficient (K_d) and effective diffusion coefficient (D_e) parameter values. The uncertainty in the K_d values incorporated in the model is greater than the uncertainty caused by hydrochemical alteration of the zeolitic minerals alone, because the uncertainty has been evaluated for a wider range of geochemical conditions. As a result, the effects of hydrothermal alteration are encompassed in the uncertainty in the K_d parameter used in the TSPA SZ transport model.

D_e is also function of temperature, increasing with higher temperature (CRWMS M&O 2000a). Increasing D_e would increase the rate of transport into the matrix and therefore, increase the attenuation of the contaminant plume. To simplify the TSPA model, no credit is taken for this potential enhanced attenuation effect in the SZFT model. Exclusion of the potentially beneficial effects of this FEP from the SZFT model is conservative.

6.2.2 Large-scale Dissolution (1.2.09.02.00)

6.2.2.1 YMP Primary 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.

6.2.2.2 Screening Argument

Large-scale dissolution does not need to be included in the SZFT models because evaporites, in particular halite with a solubility of 360,000 mg/L at P=1 atmosphere and T=25°C (Freeze and Cherry 1979, p. 106), are not dominant minerals in the formations along the simulated transport pathways. Evaporites are present in playa and lake deposits within the unconsolidated Quaternary/Tertiary valley fill. These evaporites are of limited areal extent (D'Agnese et al. 1997, p. 17-18) and their dissolution would not tend to provide open channels due to the lack of cementation of the sediments.

The hydrogeologic framework model, which is based on the available geologic information from the Yucca Mountain region (D'Agnese et al. 1997 and Faunt 1999), 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, p. 106)) and the permeability of these units is primarily due to solution channels and fractures. 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 are located well below the water table and below the simulated transport pathways. Development of new, extensive dissolution cavities are highly unlikely to form 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 (e.g., solubility of quartz 12 mg/L at P=1 atm and T=25°C (Freeze and Cherry 1979, p. 106)). 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.

This argument assumes that the water table will not drop as low as the carbonate aquifer (see Section 6.2.3). This is a reasonable assumption given the depth of the carbonate aquifer below the water table [more than 700 meters given the approximate thickness of the volcanic units below the water table based on lithologic logs from drill hole UE-25 p#1 and water table elevations in USW H-4 (CRWMS M&O 1998a, Figure 3.5-3 and Table 5.3-66)] and the lack of any significant groundwater withdrawal in a twenty kilometer radius of the proposed repository (D'Agnese et al. 1997, pp. 8, 21 and 49-50).

6.2.3 Drought/Water Table Decline (1.3.07.01.00)

6.2.3.1 YMP Primary FEP Description

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.

6.2.3.2 Screening Argument

The elevation of the water table is dependent on climate-driven infiltration through the UZ to the SZ. Arid, present-day conditions are included in the future climate states assumed to occur at Yucca Mountain. Current conditions are represented in the site-scale SZ flow and transport model using infiltration, specified head boundary conditions, and permeability fields that maintain the current elevation of the water table. Conceptually, the current arid conditions or even drier conditions could cause water table decline. However, this would create longer transport pathways through the unsaturated zone and less contaminant mass transport to the saturated zone. Both of these effects would be beneficial to the performance of the site. Water table decline could eliminate spring flow, but this would not affect the site's simulated performance because the regulatory mandated distance to the critical group remains constant and the exposure pathway is via well water.

The behavior of the critical group could be a function of climatic conditions; however in this analysis the exposure scenario is based on a fixed set of hypothetical behaviors. In order to maintain that set of behaviors, drought would force the agricultural community to pump more water than under wetter conditions in order to maintain the prescribed range of crop production rates. Greater pumping coupled with decreased infiltration through the repository would lead to greater dilution of the contaminant concentration in the exposure model.

A lower water table could result in less travel through the alluvial aquifer and as a result, less sorption and retardation of the contaminant plume. This potentially negative impact should not be evaluated in isolation of the potentially beneficial impacts listed above. Uncertainty in the amount of alluvium encountered along the transport pathway is included in the SZFT model. The effect of this uncertainty on the contaminant transport rate is evaluated using stochastic simulations of the location of the northern and western boundaries of the alluvium (near the modeled exposure location, twenty kilometers from the repository) in the hydrogeologic framework model (CRWMS M&O 2000a).

Given the above rationale, the overall effects of this FEP with in the SZ are beneficial to performance. However, this FEP is not included in the SZ model for the purpose of simplifying the TSPA calculation.

6.2.4 Water Table Rise (1.3.07.02.00)

The primary FEP includes the following secondary FEP: Short Circuit of a Flow Barrier in the Saturated Zone Because of a Water Table Rise (1.3.07.02.01).

6.2.4.1 YMP Primary 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. A regionally higher water table and in change flow patterns might move discharge points closer to the repository, or flood the repository.

6.2.4.2 Screening Argument

The probability and potential effects of water table rise on the UZ are being evaluated in a separate AMR (CRWMS M&O 2000b). It is assumed, in this analysis, that the effects of water table rise on UZ flow and transport processes (e.g., increased infiltration and shorter travel path through the UZ and potential flooding of the repository) will be excluded or represented as variability in timing and rate of contaminant transport to the SZ. This would affect the values input to the TSPA model but would not require alteration of the SZFT model.

Within the SZ, regionally higher water table could increase interbasin flow, change flow patterns, increase the elevation of the water table and move groundwater discharge points closer to the repository. D'Agnese et al. (1999) evaluated the potential changes to the regional groundwater flow system using the Regional Scale flow model to simulate the system under past and future climatic conditions. The uncertainty in the effects of climate change on the magnitude and distribution of precipitation, infiltration and recharge were evaluated and then abstracted for two simulations using the regional flow model. The sensitivity analyses indicate that the gradient may increase and water levels may rise 50 to 100 meters in the vicinity of YM, but the direction of flow will remain toward the south due to anisotropy in the hydraulic conductivity. The simulated water table rise is consistent with other estimates on the magnitude of future water table rise, due to climate change. Given estimated water table elevations under past, wetter climates, the expected future water table rise at Yucca Mountain is at most 115 m (Quade et al. 1995, p. 213; Paces et al. 1993, p. 1573; and Marshall et al. 1993, p.1948).

It is not clear whether transport through strata above the current water table would significantly decrease or increase the rate of contaminant transport simulated by the site-scale SZFT model. This is due to potential position of the water table relative to the hydrologic units, the transport characteristics of those units, the effects on transport through the UZ, and the uncertainty in transport pathways with or without water table rise. It is clear that with a sufficiently large water table rise below the repository, the rate of transport at the water table would be reduced because it would place the water table in the Upper Volcanic Confining Unit (Calico Hills hydrogeologic unit) which has significantly lower hydraulic conductivities.

As contaminants are transported away from the repository, the transport rate could increase or decrease due to uncertainty in the transport pathway and the units encountered along that pathway. The net effect will depend on whether there is less or more travel through the Upper Volcanic Confining Unit and Valley-fill Aquifer. If the transport pathway encounters more of either of these two units, then the transport rate will be slower. The only factor that could increase the transport is if the transport pathway encounters less of these two units. If the transport pathways remain similar to the pathways simulated in the TSPA-VA, then the contaminant plume will encounter more alluvium. Due to greater sorption characteristics of the alluvium, it tends to be the limiting factor in transport simulations. It is assumed that potential changes in transport pathways due to water table rise will be evaluated by performing sensitivity analyses with the calibrated SZFT model.

Based on the results of the regional-scale model, which indicate the geologic framework controls transport pathways, it is likely that the particle tracks will follow the same trajectory (from the repository to the point of compliance) with and without water table rise. If this is the case, then the only potentially significant negative impact from water table rise that needs to be included in the SZFT model is increased groundwater flux. The uncertainty in groundwater flux due to climate change is included in the analysis.

6.2.5 Radionuclide Solubility Limits in the Geosphere (2.2.08.07.00)

6.2.5.1 YMP Primary FEP Description

Solubility limits for radionuclides in geosphere groundwater may be different than in the water in the waste and EBS.

6.2.5.2 Screening Argument

Increasing element solubility in the saturated zone would not affect the dissolution of the radioactive waste (in the unsaturated zone). Increasing the solubility in the SZ would lead to isotopic dilution (see Section 6.3.3) if the elements were present in the rock matrix. The only way that increasing the solubility in the saturated zone could increase the mass of contaminant transported is if the contaminants existed as particles in the SZ and those particles were transported at a slower rate than the solutes. This analysis assumes the transport of particles will be conservatively modeled using the colloid transport model. Increased solubility in the SZ would retard transport since colloidal transport provides a faster path than solute transport.

Decreasing element solubility in the SZ would lead to precipitation and further retardation of contaminant transport.

To simplify the TSPA models, no credit is taken for the potentially beneficial effects of solubility changes in the saturated zone.

6.2.6 Thermal Convection Cell Develops in SZ (2.2.10.02.00)

6.2.6.1 YMP Primary FEP Description

Thermal effects due to waste emplacement result in convective flow in the saturated zone beneath the repository.

6.2.6.2 Screening Argument

This FEP indicates that a thermal convection cell develops in the saturated zone beneath the repository because the temperatures expected to develop at the water table (up to 80° C) would be able to drive convective flow in the SZ. The concern is that thermally driven water flow in the upper tuff aquifer could increase groundwater velocities relative to the system without heat sources.

The effects of thermal gradients in the SZ should not be considered in isolation of the effects of thermal gradients in the UZ. Heat will be transported by conduction and convection, creating the possibility of a net outward gradient for fluids in the vicinity of the repository. As a result, the period of highest thermal loading, when the effect on the thermal gradient in the SZ is greatest, is likely to be the period with the least contaminant transport and infiltration through the repository because of lower hydraulic conductivity due to drying. As a result, even if significant flow is caused by the thermal gradient, the thermal effects in the unsaturated zone may inhibit rather than enhance contaminant transport. The effects of thermal loading on transport through the unsaturated zone are being evaluated separately. It is assumed for this analysis that the high temperatures in the waste will retard contaminant transport.

If the results of the UZ thermal hydraulic modeling indicate thermal conditions in the repository are likely to enhance contaminant transport to the SZ, then the SZFT model can be used to evaluate potential effects of thermal gradients on contaminant transport. The complexity of the hydrogeologic system along with the uncertainties in the hydraulic gradient, porosity, potential thermal conditions created by the repository, and the effect on transport through the UZ, make it difficult to determine if coupled thermal flow and transport will be a significant process in the SZ. There are multiple and potentially offsetting effects of temperature on contaminant transport. The thermal gradient will be steeper in water than in the rock matrix, due to the higher thermal conductivity of rock. This will tend to increase the velocity of flow in the fracture, but also maintain a component of the thermal gradient, and convective transport, directed into the rock matrix. Increased temperatures will enhance matrix diffusion and increase retardation of contaminant transport.

If large-scale convection cells develop, it could cause greater mixing of waters than more laminar, lateral flow. Increased mixing would increase dilution of the contaminant plume. To simplify the TSPA model, no credit will be taken for this potential dilution effect.

The degree of enhancement of simulated transport velocities, if any, will depend on the effects on contaminant transport in the UZ, the estimated temperature gradient in fluid-filled fractures of the SZ and the simulated advective velocity. Simulations with low porosity for the saturated tuffs produce the fastest advective transport velocities. Low porosity would produce an effective thermal conductivity closer to that of tuff than of water, resulting in flatter thermal gradients. As a result, the velocities will be less enhanced in simulations with low porosity than in those with high porosity.

The thermal gradients will dissipate with distance from the repository and over time due to conduction, convection, and cooling of the repository. If the results of the UZ analysis indicate the thermal effects of the repository retard rather than enhance contaminant transport in the UZ, then this process can be eliminated from the SZFT models based on the fact that it would not increase the simulated dose.

6.2.7 Naturally Occurring Gases in the Geosphere (2.2.11.01.00)

6.2.7.1 YMP Primary FEP Description

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.

6.2.7.2 Screening Argument

There is no evidence of large-scale gas buildup in, or flow of gas through, the SZ. There are no known oil or gas fields in the vicinity of Yucca Mountain (CRWMS M&O 1998a, Table 3.11-1c). While the elements required for a viable petroleum system are present in the Yucca Mountain region, they are unlikely to have accumulated at the repository site (CRWMS M&O 1998a, Table 3.11-1c).

Even if 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 SZFT 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 SZFT model.

Gas-generating processes associated with igneous or volcanic activity that alter the hydrologic system are evaluated separately in the AMRs for Tectonic FEPs and UZ FEPs. It is assumed that those effects are negligible or will be included in the UZ model and disruptive event analyses.

6.2.8 Suspension of Particles Larger than Colloids (2.1.09.21.00)

6.2.8.1 YMP Primary FEP Description

Groundwater flow through the waste could remove radiouclide-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 EBS by suspension.

6.2.8.2 Screening Argument

This FEP is being evaluated for the UZ (CRWMS M&O 2000b) as well as the SZ. While it is unlikely that particles larger than colloids will be transported through the unsaturated zone, it is assumed for this analysis that if these particles are included in the UZFT model, they will be simulated conservatively using the UZ colloid transport model.

The condition that particles remain in suspension in a fluid system requires that the fluid force exceed the gravitational, frictional, and electrical forces. Transport of particles in suspension requires an open pathway with fluid flow and a vertical component of fluid velocity that exceeds the settling velocity of the particle. Hjulstrom's Diagram (Krumbein and Sloss 1963, p. 203) can be used to estimate the minimum transport velocities required to initiate and maintain transport of particles in open channels. Since SZFT is taking place in flowing intervals that consist of saturated, well-connected fractures, this is a reasonable approximation. Transport velocities greater than 100 centimeters per second are required to initiate transport of particles that are very small (0.001 to approximately 0.006 microns) or very large particles (greater than 10 millimeters in diameter). Very large particles could also be eliminated from the SZFT models based on filtering arguments and fracture aperture data.

If vertical velocities of sufficient magnitude to suspend particles were generated, those particles could remain in suspension if the fracture apertures in the flowing interval are sufficiently large and one of the following is true:

- the sustained, vertical component of the velocity was greater than the settling velocity, or

- the flow velocity was sufficient to allow transport of the particle to the receptor before it settled out of solution.

If the following are assumed (see Section 4.1):

- Stokes Law applies (spherical particles in a fluid with Reynolds number less than 0.5)
- particle diameter (*d*)of 1 micron (1 x 10^{-6}m)
- particle density (Δ_p)of 2650 kg/m^3
- water density of (Δ_w)1000 kg/m^3
- water viscosity (<)of 1.005 x 10^{-3} Ns/m^2

then the order of magnitude of the settling velocity (*sv*) of the particle can be estimated using the following equation:

$$sv = \frac{gd^2(\rho_p - \rho_w)}{18\nu}.$$

When the parameter values listed above are plugged into the equation along with gravitational acceleration (*g*) of 9.81 meters per second squared, the settling velocity is on the order of 9 x 10^{-7} meters per second (0.08 m/d). The settling velocity is proportional to the square of the particle diameter; hence the settling velocity is two orders of magnitude greater for particles an order of magnitude larger (i.e., with diameters of 0.01 mm). Given the short distance a particle would have to settle (the width of a fracture) relative to the distance it would need to be transported (20 kilometers), the flow velocities required to transport the particle before it settles out of suspension are not realistic. Therefore, the sustained vertical component of the flow velocity must exceed the settling velocity of the particles for transport to occur. The existing vertical component of the advective velocities, within the fractured tuffs, is not known. However, the settling velocity of 0.08 meters per day, for a particle 1 micron in diameter, is within the range of groundwater velocities that would be estimated using the modeled specific discharge and porosities. Given the uncertainty in the groundwater velocities it is not possible to rule out particles with diameters less than 1 millimeter in diameter. Lacking information on the potential size of particles expected to reach the SZ, arguments about particle filtering are difficult to defend.

The size of the particles will influence their transport through the fractured tuffs and alluvial aquifer. The larger particles will settle faster and will not fit through as many pores as smaller colloidal size particles. As a result, colloidal transport is more likely, will be at least as fast as the simulated transport of larger particles, and will be subject to less filtering.

It is assumed that if particles larger than colloids (no matter the specified upper bound on colloid diameter) are included in the UZ transport simulations and, in those simulations, some or all of the large particles reach the SZ, they can be conservatively modeled using the colloid transport model and parameter values. If all particle transport is modeled as colloid transport, then this FEP has no consequence.

6.2.9 Radionuclide Accumulation in Soils (2.3.02.02.00)

6.2.9.1 YMP Primary FEP Description

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).

6.2.9.2 Screening Argument

Radionuclide accumulation in soils is listed in the database as potentially impacting the SZ (CRWMS M&O 1999a). Since the discharge of contaminated groundwater occurs at the compliance point, accumulation in soils does not alter the SZFT model. Radionuclide accumulation in soils affects the modeled potential exposure and dose. It is assumed that this process will be included in the biosphere model.

6.2.10 FEPs Related to Future Tectonic Activity (1.2.02.01.00, 1.2.02.02.00, 1.2.03.01.00, 1.2.10.01.00, 2.2.06.02.00, 2.2.06.03.00)

The following FEPs are dependent on the occurrence of future tectonic activity:

- Additional Fractures (1.2.02.01.00)
- Faulting (1.2.02.02.00)
- Seismic Activity (1.2.03.01.00)
- Hydrologic Response to Seismic Activity (1.2.10.01.00)
- Changes in Stress Produce Change in Permeability of Faults (2.2.06.02.00)
- Changes in Stress Alter Perched Water Zones (2.2.06.03.00).

These FEPs encompass the following secondary FEPs: Changes in Fracture Properties (1.2..02.01.01), Faulting/fracturing (1.2.02.02.05), Fault Movement Pumps Fluid from SZ To UZ (1.2.10.01.01), Fault Creep Causes Short Term Fluctuations of the Water Table (1.2.10.01.02), New Faulting Breaches Flow Barrier Controlling Large Hydraulic Gradient to the North (1.2.10.01.03), Head-Driven Flow Up from Carbonates (1.2.10.01.05), Fault Movement Connects Tuff and Carbonate Aquifers (1.2.10.01.08), Fault Establishes Pathway Through the SZ (1.2.10.01.10), Flow Barrier South Of Site Blocks Flow, Causing Water Table To Rise (1.2.10.01.13), Stress Produced Porosity Changes (2.2.06.01.01), Stress Produced Permeability

Changes (2.2.06.01.02), Stress Changes Hydrogeologic Effects (2.2.06.01.10), Aseimic Alteration of Permeability Along and Across Faults (2.2.06.02.01) and Fracture Dilation Along Faults Enhance Permeability (2.2.06.02.02).

6.2.10.1 YMP Primary FEP Descriptions

Groundwater flow in the Yucca Mountain region and transport of any released radionuclides may take place along fractures. Transmissive fractures may be existing, reactivated, or newly formed fractures. The rate of flow and the extent of transport in fractures is influenced by characteristics such as orientation, aperture, asperity, fracture length, connectivity, and the nature of any linings or infills. Generation of new fractures and reactivation of preexisting fractures may significantly change the flow and transport paths. Newly formed and reactivated fractures typically result from thermal, seismic, or tectonic events.

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.

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).

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.

Stress changes due to thermal, tectonic and seismic processes result in strains that alter the permeability along and across faults.

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

6.2.10.2 Screening Argument

These FEPs are being analyzed in a separate AMRs that deal specifically with potential future tectonic activity and the effects of that activity on the engineered and natural barriers to contaminant transport (CRWMS M&O 2000d) and the potential effects on UZFT (CRWMS M&O 2000b). Since the potential effects of tectonic activity on contaminant transport are being evaluated in separate AMRs, we are forced to make assumptions regarding the disposition of the tectonic FEPs in order to proceed with the TSPA model development and implementation. It is assumed that potentially significant tectonic effects on UZFT will be reflected in the input parameter values supplied for the SZFT model from the UZFT model output. This assumption requires verification based on the results of those AMRs (CRWMS M&O 2000d and CRWMS M&O 2000b); however it is reasonable given the results of previous analyses of the potential effects of seismic activity on the hydrologic conditions at Yucca Mountain.

Gauthier et al. (1996) analyzed the potential effects of seismic activity on contaminant transport in the SZ due to changes in water-table elevation. Their analysis 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 meters within an hour of the simulated event. The simulated system returns to steady-state conditions within 6 months. Gauthier et al. 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 transience of the simulated, seismically induced, water table rise is consistent with other estimates and observations. Numerical simulations by Carrigan et al. (1991) of tectonohydrologic coupling involving earthquakes typical of the Basin and Range province (approximately 1 meter slip) produced simulated rise of 2 to 3 meters for a water table 500 m below ground surface. Extrapolation to an event of about 4 m slip results in a transient rise of 17 meters near the fault (Carrigan et al. 1991; p. 1159). Seismic pumping due to changes in permeability along faults produces higher water table rise. Carrigan et al. (1991) 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 meters, in the fracture zone, with 1 meter of slip.

Climate change would produce water table rise of similar, or greater, magnitude and significantly longer duration. As discussed in Section 6.2.4, water table rise directly beneath the repository could alter the timing and magnitude of contaminant flux from the UZ to the SZ due to shortened pathways through the UZ. The probability and significance of the effects of tectonic induced water table rise on contaminant transport through the UZ are being evaluated separately. If there are potentially significant reductions in travel time through the UZ, those effects will be reflected in the input parameter values for the SZFT model. Within the SZ, fluctuations in water table elevation lead to mixing and greater dispersion of contaminant plumes. This would dilute contaminant concentrations. Given the short duration of tectonic induced water table rise, the effects of encountering units with different hydrologic properties for that short period of time (e.g., increases in retardation of contaminant transport in the Calico Hills hydrogeologic unit, different flow and transport pathways) are negligible relative to long-term SZFT.

Future seismic activity would redistribute strain within the system. Redistribution of strain would be likely to open new fractures and close some existing fractures (Gauthier, et al. 1996). As long as the resulting fracture system maintains the same orientation and general characteristics, there will be no net impact on the simulated contaminant transport. The SZFT model includes fractures and uncertainty in the hydraulic and transport properties of the fracture system. The uncertainty in the existing system is represented in the model using stochastic simulations of flowing interval porosity, flowing interval spacing, longitudinal dispersivity, horizontal anisotropy, and colloid retardation. The relocation of the flowing intervals within each hydrologic unit does not affect the simulated contaminant flux at the twenty-kilometer boundary. It is assumed that future fracture systems will produce flowing intervals similar to the existing system. As a result of that assumption, the uncertainty in the existing system captures the uncertainty in the future system and there is no consequence as a result of this process.

6.2.11 Repository Induced Thermal Effects (2.2.10.01.00, 2.2.10.13.00, 2.2.10.07.00, 2.2.10.08.00)

The thermal effects of the repository on the saturated zone are represented in four FEPs:

- Repository Induced Thermal Effects in the Geosphere (2.2.10.01.00)
- Density-driven Groundwater Flow (thermal) (2.2.10.13.00)
- Thermo-chemical Alteration of the Calico Hills unit (2.2.10.07.00)
- Thermo-chemical Alteration of the Saturated Zone (precipitation plugs primary porosity) (2.2.10.08.00).

6.2.11.1 Primary FEP Descriptions

Thermal effects on groundwater density may cause changes in flow in the unsaturated and saturated zones.

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.

Fracture pathways in the Calico Hills are altered by the thermal and chemical properties of the water flowing out of the repository.

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.

6.2.11.2 Screening Argument

The effects of the geothermal gradient on the hydraulic gradient are included in the SZFT model (see Section 6.1.12). The effects of thermal loading due to the repository and hydrologic response are evaluated in separate AMRs (CRWMS M&Oc). As discussed in Section 6.2.6, the effects of thermal loading in the SZ should not be evaluated independent of the effects on contaminant mobilization and transport. It is assumed for this analysis that when all the effects of high temperatures in the waste are considered, repository-induced thermal hydrologic effects will inhibit contaminant transport from the UZ to the SZ and will not have a significant negative consequence. As a result of this assumption, these FEPs do not need to be included in the SZFT model.

6.2.12 FEPs Related to Future Igneous Activity (1.2.10.02.00, 1.2.04.02.00)

The following primary FEPs, and associated secondary FEPs (1.2.04.02.01 and 1.2.04.02.02), are dependent on the occurrence of future igneous activity in the vicinity of Yucca Mountain.

- Hydrologic Response to Igneous Activity (1.2.10.02.00)
- Igneous Activity Causes Changes to Rock Properties (1.2.04.02.00)

Due to their common link to future changes in the geologic system, these FEPs are being evaluated in separate AMRs that evaluate the probability, magnitude and effects of volcanic activity on the engineered and natural barrier system (CRWMS M&O 2000d and CRWMS M&O 2000c(*FEPs Report for the Near Field Environment*)). It is assumed for this analysis that one or more of the following apply:

- the probability of igneous activity of sufficient scale, or in a specific location along the transport pathway, is below the regulatory screening criteria

- hydrothermal effects would have low or no consequences for the simulated dose due to increased retardation of contaminant transport through the UZ to the SZ, increased dilution within the SZ, or no effect on SZFT.

As a result of these assumptions, these FEPs do not need to be included in the SZFT model.

6.3 EXCLUDED FEPS

The remaining SZ FEPs are excluded from the TSPA based on low consequence. In general these are FEPs that only affect the saturated zone and:

- increase, or would tend to increase, the contaminant travel time through the SZ (from a point below the proposed repository to the compliance point) or

- would increase dilution of the contaminant concentration.

These FEPs are excluded based on the fact that they would tend to decrease the expected dose to the critical group. The following sections present the screening arguments for each of the excluded FEPs. The disposition of each FEP is described in the screening argument.

6.3.1 Density Effects on Groundwater Flow (Concentration) (2.2.07.14.00)

This FEP encompasses a secondary FEP: Saline Intrusion (2.2.07.14.01).

6.3.1.1 YMP Primary FEP Description

Spatial variation in groundwater density may affect groundwater flow.

6.3.1.2 Screening Argument

The primary FEP is based on the assertion 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). The implication of this FEP is that the plume could flow along, at the water table or within the aquifer, relatively unmixed, for considerable distance due to buoyancy effects. The potential effects of density contrasts due to thermal conditions are evaluated separately (see sections 6.1.12 and 6.2.11).

The construction of the TSPA model is such that there are no significant negative effects of density on the simulated dose due to groundwater contamination. The TSPA model calculates the concentration of contaminants in groundwater, for the purposes of calculating dose, by capturing all the contaminants that cross the regulatory boundary in the wells at the compliance point. No credit is taken for the potential, incomplete capture of the plume due to density effects. The mixing model assumes that pumping and re-distribution of well water will overcome any other potential energy gradients (e.g., thermal, chemical and gravitational) that exist in the groundwater system.

This approach 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 (e.g., 64 FR 8640), by assuming that all the particles that cross the regulatory boundary are dissolved in the prescribed volume of water, the potential dose to the hypothetical, exposed community will not be underestimated. Given that the volume of water consumed is independent of these gradients, and all the contaminants that cross the regulatory boundary are contained in that volume of water, this is a simple and conservative method for estimating the potential dose to the hypothetical, exposed community. This approach may or may not be appropriate for estimating the concentration in groundwater for assessing performance relative to concentration based standards.

6.3.2 Groundwater Discharge to Surface (2.3.11.04.00)

6.3.2.1 YMP Primary FEP Description

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.

6.3.2.2 Screening Argument

For the present day climate, groundwater discharge occurs at Franklin Lake Playa and springs at Ash Meadows (D’Agnese et al. 1999, p. 22-23), beyond the regulatory compliance point. Modeling indicates potential future spring locations are not likely to be within that twenty-kilometer radius (D’Agnese et al. 1999, p. 32). Therefore, in the TSPA model, discharge to the biosphere occurs through hypothetical wells at the compliance point and spring discharge is excluded from the SZ model for a compliance location of twenty kilometers.

6.3.3 Isotopic Dilution (3.2.07.01.00)

6.3.3.1 YMP Primary 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) will lead to a reduction of the radiological consequences.

6.3.3.2 Screening Argument

Isotopic dilution in the SZ could occur if elements that are in the waste also occur naturally. This process would dilute the concentration of radioactive contaminants and reduce the simulated dose. Isotopic dilution in the SZ is excluded based on no negative consequence.

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7. CONCLUSIONS

This document addresses the primary FEPs potentially important to SZFT modeling and presents the disposition and justification for the disposition of those FEPs. Based on this analysis, there are 22 FEPs that are already, or need to be, included in the performance assessment (Section 6.1), 14 FEPs that do not need to be included in the SZFT model based on insignificant consequence (Section 6.2), and 3 FEPs that can be excluded from the TSPA models based on insignificant consequence (Section 6.3). The manner in which FEPs are included in the TSPA model may change since the model is not final, however the results of this analysis will not change. Seven of the primary SZ FEPs are being evaluated in other AMRs and are assumed to have negligible probability of occurrence, negligible consequences or no effect on the SZFT model (Sections 6.2.11 and 6.2.12). The results of those AMRs may result in a different disposition than is assumed in this analysis. In this analysis none of the FEPs were excluded based on low probability. The secondary FEPs associated with each primary FEP were reviewed and the secondary issues are addressed in the screening arguments and disposition discussion for the excluded and included primary FEPs. The 46 primary FEPs potentially impacting SZFT and the screening results for each of those FEPs are summarized in Table 7-1.

Table 7-1. Screening Results for SZ FEPs

YMP FEP Database ID#	FEP Description	TSPA Screening Decision
1.2.02.01.00	Additional Fractures	Not included in SZFT – low consequence
1.2.02.02.00	Faulting	Not included in SZFT – low consequence
1.2.03.01.00	Seismic Activity	Not included in SZFT – low consequence
1.2.04.02.00	Igneous Activity Causes Changes to Rock Properties	Not included in SZFT - assumed low consequence or probability
1.2.06.00.00	Hydrothermal Activity	Not included in SZFT – low consequence
1.2.09.02.00	Large-Scale Dissolution	Not included in SZFT – low consequence
1.2.10.01.00	Hydrologic Response to Seismic Activity	Not included in SZFT – low consequence
1.2.10.02.00	Hydrologic Response to Igneous Activity	Not included in SZFT - assumed low consequence or probability
1.3.07.01.00	Drought/Water Table Decline	Not included in SZFT - low consequence
1.3.07.02.00	Water Table Rise	Included changes in flux, other effects not included in SZFT - assumed low consequence
1.4.07.01.00	Water Management Activities	Included
1.4.07.02.00	Wells	Included
2.1.09.21.00	Suspension of Particles Larger than Colloids	Not included in SZFT - low consequence
2.2.03.01.00	Stratigraphy	Included
2.2.03.02.00	Rock Properties of Host Rock and Other Units	Included
2.2.06.02.00	Changes in Stress Produce Change in Permeability of Faults	Not included in SZFT - low consequence
2.2.06.03.00	Changes in Stress Alter Perched Water Zones	Not included in SZFT - low consequence
2.2.07.12.00	Saturated Groundwater Flow	Included
2.2.07.13.00	Water-Conducting Features in the Saturated Zone	Included

YMP FEP Database ID#	FEP Description	TSPA Screening Decision
2.2.07.14.00	Density Effects on Groundwater Flow (Concentration)	Excluded - low consequence
2.2.07.15.00	Advection and Dispersion	Included
2.2.07.16.00	Dilution of Radionuclides in Groundwater	Included
2.2.07.17.00	Diffusion in the Saturated Zone	Included
2.2.08.01.00	Groundwater Chemistry/Composition in UZ and SZ	Included
2.2.08.02.00	Radionuclide Transport Occurs in a Carrier Plume in the Geosphere	Included
2.2.08.03.00	Geochemical Interactions in the Geosphere	Included
2.2.08.06.00	Complexation in the Geosphere	Included
2.2.08.07.00	Radionuclide Solubility Limits in the Geosphere	Not included in SZFT - low consequence
2.2.08.08.00	Matrix Diffusion in Geosphere	Included
2.2.08.09.00	Sorption in the UZ and SZ	Included
2.2.08.10.00	Colloid Transport in the Geosphere	Included
2.2.08.11.00	Distribution And Release of Nuclides from the Geosphere	Included
2.2.09.01.00	Microbial Activity in Geosphere	Included
2.2.10.01.00	Repository Induced Thermal Effects in the Geosphere	Not included in SZFT - assumed low consequence or probability
2.2.10.02.00	Thermal Convection Cell Develops in SZ	Not included in SZFT - low consequence
2.2.10.03.00	Natural Geothermal Effects	Included
2.2.10.06.00	Thermo-Chemical Alteration	Included
2.2.10.07.00	Thermo-Chemical Alteration of the Calico Hills Unit	Not included in SZFT - assumed low consequence or probability
2.2.10.08.00	Thermo-Chemical Alteration of the SZ	Not included in SZFT - assumed low consequence or probability
2.2.10.13.00	Density Driven Groundwater Flow (Thermal)	Not included in SZFT – assumed low consequence
2.2.11.01.00	Naturally-Occurring Gases in the Geosphere	Not included in SZFT - low consequence
2.2.12.00.00	Undetected Features	Included
2.3.02.02.00	Radionuclide Accumulation in Soils	Not included in SZFT - low consequence
2.3.11.04.00	Groundwater Discharge to Surface	Excluded - low consequence
3.1.01.01.00	Radioactive Decay and Ingrowth	Included
3.2.07.01.00	Isotopic Dilution	Excluded - low consequence

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8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

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