OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA
Page: 1 of: 87

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 01

6. Total Attachments: 0

7. Attachment Numbers - No. of Pages in Each:
N/A

	Printed Name	Signature	Date
8. Originator	Theresa Brown	[signature]	01/03/01
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12. Remarks:

Note: The formatting changes and additional technical information incorporated in this revision are so comprehensive that, to include change bars does not add value in identifying the extensive revisions.

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Enclosure 5

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
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 01

4. Revision/Change No.	5. Description of Revision/Change
00	Initial Issue
01	Revision to add 2 new secondary SZ FEPs, address comments by Winston and Strawn, update the text to describe the results of other FEP AMRs and change the format of section 6.2 to include the numbers for secondary FEPs, standardize callouts to include the document identifier, add subheadings and sections to address: related primary FEPs, summary of screening argument, TSPA disposition and supplemental discussion (full screening argument for lengthy evaluations) and related NRC IRSRs.

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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
HPD	High Permeability Domain (hydrologic unit designation by NAGRA)
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
LPD	Low Permeability Domain (hydrologic unit designation by NAGRA)
m	meter
mg/L	milligrams per liter
mm	millimeter
MWCF	Major Water Conducting Faults (hydrologic feature designation by NAGRA)
N	newton
NAGRA	National Cooperative for the Disposal of Radioactive Waste (Nationale Genossenschaft Fur die Lagerung Radioaktiver Abfalle) (Switzerland)
NFE	near field environment
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
WIPP	Waste Isolation Pilot Plant
YMP	Yucca Mountain Project

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 potential repository is an ongoing process based on site-specific information and regulations. Currently, the Yucca Mountain Project (YMP) FEP database consists of 1,797 entries from other international databases, YMP literature, YMP technical workshops, subject matter expert review, and external review. The origin and development of the database is given in CRWMS M&O 2000a. The purpose of this analysis is to document the disposition, and justification for the disposition, of the 47 primary FEPs that potentially affect saturated zone (SZ) flow and transport (called SZ FEPs). For a complete list of the SZ primary FEPs and the screening conclusion for each, see Table 7-1.

The FEPs that might be important to performance are evaluated, either as components of the total system performance assessment –models for the site recommendation (TSPA-SR) (CRWMS M&O 2000b) or eliminated based on low probability, low consequence, or regulatory guidance. This Analysis/Model Report (AMR) identifies which FEPs are considered explicitly in the TSPA-SR (called included FEPs) and summarizes how they are represented in the TSPA-SR models (e.g., CRWMS M&O 2000c, CRWMS M&O 2000b). This AMR also identifies SZ FEPs that do not need to be included in the TSPA-SR models (called excluded FEPs) and provides the justification for why these FEPs are not required (low consequence, low probability or regulatory guidance).

Several categories of FEPs, due to their broad range of potential impacts in the near field environment, unsaturated zone and biosphere, were analyzed in other AMRs. The results of those analyses as they pertain to the SZ are summarized in this report. FEPs related to disruptive events such as igneous activity and seismic activity are analyzed in *Disruptive Events FEPs* (CRWMS M&O 2000d). FEPs related to hydrothermal activity are analyzed in *Features, Events and Processes in UZ Flow and Transport* (CRWMS M&O 2000e)

This analysis was conducted and documented in accordance with the *Technical Work Plan for Saturated Zone Flow and Transport Modeling and Testing* (CRWMS M&O 2000f).

2. QUALITY ASSURANCE

The Quality Assurance (QA) program applies to the development of this AMR. A description of the work contained in this AMR is located in Addendum L of the *Technical Work Plan (TWP) for Saturated Zone Flow and Transport Modeling and Testing* (CRWMS M&O 2000f). The Performance Assessment Department (PAD) responsible manager has evaluated this activity in accordance with AP-2.21Q and it may be found in Addendum M of the *TWP for Saturated Zone Flow and Transport Modeling and Testing* (CRWMS 2000f). The applicable implementing procedures are defined in Section 6 of the *TWP for Saturated Zone Flow and Transport Modeling and Testing* (CRWMS M&O 2000f). The electronic control of data was accomplished in accordance with the controls specified in the Section 13 of the *TWP for Saturated Zone Flow*

and Transport Modeling and Testing (CRWMS M&O 2000f); and developed in accordance with AP-SV.1Q. The following procedures have been followed in the process of completing this report: AP-3.10Q, *Analysis and Models*; AP-3.15Q, *Managing Technical Product Inputst*; AP-SIII.3Q, *Submittal and Incorporation of Data to the Technical Data Management System*.
The list of 47 primary FEPs addressed in this AMR was derived from *The Development of Information Catalogued in REV00 of the YMP FEP Database* (CRWMS M&O 2000a). The FEPs database is maintained in accordance with applicable QA controls.

3. COMPUTER SOFTWARE AND MODEL USAGE

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

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

The nature of the FEPs Screening Arguments and TSPA Dispositions is such that cited data and values are often used to support reasoned FEP Screening Arguments or TSPA Dispositions, rather than being used as direct inputs to computational analysis or models. Consequently, conclusions and data cited in the FEPs Screening Arguments and TSPA Dispositions are largely corroborative in nature, and the FEP Screening Decisions will not be affected by any anticipated uncertainties in the cited data. Consequently, the data are not listed as inputs in this section, but are cited in the individual FEPs screening arguments and dispositions.

There are two TBV items associated with this analysis, one in the screening for the "Water Table Rise" FEP (TBV-4924) and the other for a secondary FEP "Soil leaching to groundwater" (TBV-4933). The first TBV is the result of assuming that the potential effects of water table rise due to climate change would be evaluated using sensitivity analyses of the calibrated SZ flow and transport models in the TSPA-SR analyses. The assumed sensitivity analyses have not been performed to date. Performance of the analyses described in the *TSPA Disposition* section for this FEP (Section 6.2.11) will implement the analyses necessary to include the FEP. However, performing these analyses will not alter the conclusions in this analysis (i.e., that the potential effects of this FEP should be included in the TSPA-SR analyses) and, as a result, will not impact this assessment.

The second TBV is similar to the first. It is based on the assumption that since leaching is included in the biosphere model as process that removes radionuclides from the root zone, that potential effects of leaching would be evaluated using sensitivity analyses of the dose conversion factors used in the TSPA-SR analyses. The assumed sensitivity analyses have not been performed to date. Performance of the analyses described in the *Supplemental Discussion* section for this FEP (Section 6.2.44) would provide the analyses necessary to include this secondary FEP. However, performing these analyses will not alter the conclusions in this analysis (i.e., that the potential effects of this FEP should be included in the TSPA-SR analyses) and, as a result, will not impact this assessment.

4.2 CRITERIA

The U.S. Nuclear Regulatory Commission's (NRC's) *Issue Resolution Status Report Key Technical Issue: Total System Performance Assessment and Integration* (NRC 2000) establishes generic technical acceptance criteria that NRC staff consider essential to a defensible, transparent, and comprehensive assessment methodology for the potential 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 the acceptance criteria in *Issue Resolution Status Report Key Technical Issue: Total System Performance Assessment and Integration* (NRC 2000) 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 a FEP, based on the proposed rule and interim guidance, 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 proposed NRC regulatory requirements that apply to this analysis are:

- **10 CFR 63 Sec. 63.114 (64 FR 8640)**
  (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 (64 FR 46976)**
  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.

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-SR models include the effects and uncertainty introduced by the included FEPs (Section 6.2 and Table 7-1). This analysis does not include an evaluation of whether or not the potential effects of included SZ FEPs are adequately evaluated, it documents how the potential effects are included in the current TSPA-SR models and notes instances where FEPs are not yet incorporated in the models. This is a general assumption that is made throughout Section 6.2. This assumption does not impact the results of this analysis, as the decision to include or exclude a particular FEP will not be altered based on how it is incorporated in the TSPA-SR models.

5.2 ASHFALL LEACHING AND SZ TRANSPORT

The following assumptions are made to estimate the potential impact of leaching contaminants from ashfall on the expected annual dose (Section 6.2.5).

1. The contents of ten waste packages are entrained in the volcanic eruption and that all of the waste is distributed in the ash blanket on the ground surface resulting from the eruption. This is a reasonable assumption because this is the median number of packages brought to the surface by a single volcanic eruption intersecting one drift in the Disruptive Events analysis for TSPA-SR (CRWMS M&O 2000d), and does not require further verification.
2. The ten waste packages contain commercial spent nuclear fuel (CSNF), the most common type of waste package in the potential repository. This is a reasonable assumption and does not require further verification.
3. The radionuclide inventory in the waste packages is the average for CNSF at the time of waste emplacement. This is equivalent to assuming that the volcanic eruption occurs immediately after waste emplacement, making it a conservative assumption because it maximizes the impact of short-lived radionuclides. This assumption provides a bounding estimate on the inventory for this analysis and does not require further verification.
4. The volcanic ash blanket is entirely and evenly distributed in the 20 km region between the potential repository and the critical group. This assumption is conservative because it maximizes the quantity of radionuclides that is available for transport via the SZ to the hypothetical pumping wells of the critical group. As a conservative simplifying assumption, it does not require further verification.
5. The radionuclides in the ash layer are entirely and immediately dissolved in the infiltrating groundwater along the 20 km flow path. This is a conservative simplifying assumption for this analysis because it maximizes the concentration in groundwater and does not take credit for residence time at the surface, due to limits on the dissolution rate, or radioactive decay that would occur while the contaminants reside at the surface. As with the other conservative simplifying assumptions, it does not require further verification.
6. To simplify this analysis, no credit is taken for the travel time through the UZ or for radioactive decay in the SZ. This is a conservative approximation with respect to the transport of relatively short-lived radionuclides that does not take credit for retardation and decay during transport through the UZ to the SZ. Conservative simplifying assumptions do not require further verification.
7. All radionuclides derived from the volcanic ash blanket are captured in the hypothetical pumping wells of the critical group. This is a reasonable simplifying assumption that is consistent with the TSPA-SR model that does not require further verification.

8. One-dimensional flow delivers the radionuclide mass to the hypothetical pumping wells of the critical group at a steady rate. This is a reasonable simplifying assumption that is consistent with the TSPA-SR model that does not require further verification.

9. Future igneous activity at Yucca Mountain is a Poisson process. This assumption is used to estimate the probability of an extrusive igneous event at Yucca Mountain in the next 10,000 years (CRWMS M&O 2000g). This is a reasonable assumption for evaluating the frequency of events within a specific region or the probability of occurrence of an event within a specific timeframe and location. This assumption is consistent with the TSPA-SR model and does not require further verification.

5.3 WATER TABLE DECLINE

It is assumed for the analysis of large-scale dissolution (Section 6.2.7) 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 1000 meters given the approximate elevations of the carbonate aquifer and potentiometric surface (USGS 2000, Figures 6-2 and 6-18)] and the lack of any significant water table decline due to groundwater withdrawal in the Jackass Flats hydrographic basin (La Camera et al. 1999 and Young 1972). This assumption does not require further verification.

5.4 WATER TABLE RISE

In this analysis, only the effects of water table rise on the modeled SZFT are evaluated. In that evaluation (Section 6.2.11) it is assumed that potential changes in transport pathways due to water table rise will be included in the TSPA-SR models by performing sensitivity analyses with the calibrated SZFT model. This assumption requires verification (TBV-4924).

5.5 SETTLING VELOCITY

In order to evaluate the potential advective transport of particles in saturated fractures, the potential range of settling velocities of particles was estimated using Stokes' Law (Section 6.2.14). This assumes that Stokes' Law applies to saturated groundwater flow through fractures. The estimated settling velocity is then compared to the range of simulated advective velocities. 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.

Estimation of the settling velocities for particles in saturated fractures based on Stokes' Law is a reasonable assumption because it only provides a reference value and it does not affect the conclusions of this FEP screening analysis; therefore it does not require further verification.

5.6 LEACHING TO GROUNDWATER

In this analysis, only the effects of leaching contaminants to the SZ are evaluated. In that evaluation (Section 6.2.44) it is assumed that potential effects of leaching on the expected dose will be evaluated by performing sensitivity analyses using the dose conversion factors. This assumption requires verification (TBV-4933).

6. ANALYSIS

6.1 ALTERNATIVE APPROACHES

To ensure clear documentation of the treatment of potentially relevant future states of the system, the DOE has chosen to adopt a scenario-development process based on the methodology developed by Cranwell et al. (1990) for the NRC. The approach is fundamentally the same as that used in many performance assessments. The approach has also been used by the DOE for the Waste Isolation Pilot Plant (DOE 1996), by the NEA, and by other radioactive waste programs internationally (e.g., Skagius and Wingefors 1992). Regardless of the "scenario" method chosen for the performance assessment, the initial steps in the process involve development of a FEPs list, and screening of the FEPs list for inclusion or exclusion.

The approach used to identify, analyze, and screen the FEPs (as described in CRWMS M&O 2000a) was also considered. Alternative classification of FEPs as Primary or Secondary FEPs is possible in an almost infinite range of combinations. Classification into Primary and Secondary FEPs is based primarily on redundancy and on subject matter. Subsequent assignment and analysis by knowledgeable subject-matter experts for evaluation appeared to be the most efficient methodology for ensuring a comprehensive assessment of FEPs as they relate to the TSPA. Alternative classification and assignments of the FEPs are entirely possible but would still be based on subjective judgment. Alternative approaches for determining probabilities and consequences used as a basis for screening are discussed in Section 6.2 under the individual FEP analyses.

In practice, regulatory-type criteria were examined first, and then either probabilities or consequences were examined. However, there is no prescribed order in which the screening criteria should be applied. FEPs that are retained on one criterion (e.g., regulatory guidance) were also considered against the other criteria (probability and consequence). Consequently, the application of the analyst's judgment regarding the order in which to apply the criteria does not affect the final decision. Allowing the analyst to choose the most appropriate order to apply the criteria prevents needless work, such as developing quantitative probability arguments for low-consequence events or complex, consequence models for low-probability events. For example, there is no need to develop detailed models of the response of waste packages to fault shearing, if it can be shown that fault-shearing events have a probability below the criteria threshold.

Regardless of the specific approach chosen to perform the screening, the screening process is in essence a comparison of the FEP against the criteria specified in Section 4.2. Consequently, the outcome of the screening is independent of the particular methodology or assignments selected to perform the screening.

Alternative interpretations of data as they pertain directly to the FEPs screening are provided in the Analysis and Discussion section for each FEP, as discussed below. The FEPs screening decisions may also rely on the results of analyses performed and documented as separate activities. Alternative approaches related to separate activities and analyses are addressed in the specific AMRs for those analyses and are not discussed in this AMR.

6.2 ANALYSIS OF SZ FEPS

The following subsections summarize the disposition, within the TSPA-SR models, of the SZ FEPs with the potential to have a significant effect on the expected annual dose and provide the screening arguments for FEPs that can be excluded from the SZFT models. Although some of these FEPs can be excluded from the SZFT models, they may affect the NFE, UZ or biosphere and they may be included in one or more of those TSPA-SR models. Additional categories of information, related primary FEPs (by number) and related IRSR Key Technical Issues (by abbreviation from NRC 2000, appendix B), are provided for the FEPs database.

6.2.1 Fractures (1.2.02.01.00)

FEP Description: 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.

Screening Decision and Regulatory Basis: Included (existing fractures and uncertainty in their properties)
Excluded – Low consequence (changing fracture properties)

Related Primary FEPs: 1.2.03.01.00, 1.2.04.02.00, 1.2.10.01.00, 1.2.10.02.00, 2.2.07.13.00.

IRSR Issues: USFIC5, SDS3

Screening Argument:
Existing fractures are included in TSPA as described under TSPA Disposition.

Future seismic activity would redistribute strain within the system. As noted in CRWMS M&O 2000d, (*Disruptive Events FEPS*), unless stress vectors acting on Yucca Mountain were to deviate markedly from those acting within the past few million years, it is very unlikely that the shear strength of intact rock will be exceeded in the presence of fracture sets favorably oriented to accommodate increased stress. The annual exceedance probability of fracture formation is less than 1E-08 (see CRWMS M&O 2000d (*Disruptive Events FEPS*) for the derivation of that probability). Redistribution of strain would be likely to open some and close other existing fractures. This could cause relocation of the flowing intervals and localized changes in hydraulic properties, but would not alter the orientation of those intervals. The potential effects of changes in the orientation of the fractures can be excluded because it would require the formation of new fractures, which are excluded, based on low probability. There will be no net impact on the expected annual dose due to relocation of the flowing intervals within each hydrologic unit because the location of the flowing interval does not affect the simulated contaminant flux at the twenty-kilometer boundary. Localized changes in hydraulic properties due to the opening and closing of fracture apertures would not alter the uncertainty in the effective hydraulic properties at the model grid scale (500 meter grid square). The bulk hydrologic properties should remain the same because the overall stress field should remain the same. Since changes in fracture orientation can be excluded, there will be no significant changes to the simulated flux at the compliance point, which means the expected annual dose will not change. As a result, changes in the fracture properties (secondary FEP 1.2.02.01.01), due to seismic effects, can be excluded based on low consequences.

TSPA Disposition:
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, groundwater specific discharge, longitudinal dispersivity, horizontal anisotropy, and colloid retardation.

Treatment of Secondary FEPs:
The secondary FEP, Changes in Fracture Properties (1.2.02.01.01), is a special case of the primary FEP and is subsumed in the primary FEP (included in description of the primary FEP). The secondary FEP Fracturing (1.2.02.01.02), is redundant with the primary FEP and is retained for completeness. Since these secondary FEPs are entirely incorporated in the primary FEP, the components of 1.2.02.01.02 that apply to existing fracture properties are included in the SZFT model, as described in the *TSPA Disposition* section. Secondary FEP 1.2.02.01.01 and the components of 1.2.02.01.02 that apply to changes in fracture properties are excluded as described in the *Screening Argument*.

6.2.2 Faulting (1.2.02.02.00)

FEP Description: 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 potential repository and create new pathways through the potential repository. New faults or the cavitation of existing faults may enhance the groundwater flow, thus decreasing the transport times for potentially released radionuclides.

Screening Decision and Regulatory Basis:

Included (uncertainty in the existing hydrologic properties of the system)

Excluded – Low consequence (changes to existing hydrologic properties due to additional movement along existing faults).

Excluded – Low probability (changes to existing hydrologic properties due to new faults).

Related Primary FEPs: 2.2.03.01.00, 2.2.03.02.00.

IRSR Issues: USFIC5, SDS3

Screening Argument:

Existing faults are included in TSPA as described under TSPA Disposition.

As presented in CRWMS M&O 2000d (*Disruptive Events FEPs,* Sections 6.2.19 – 6.2.20), changes in the hydrologic properties due to faulting along new faults (secondary FEP 1.2.02.02.02) can be excluded based on low probability. The annual exceedance probability for fault displacement in intact rock is less than 1E-08. Movement along existing faults (secondary FEPs 1.2.02.02.03 and 1.2.02.02.04) with an annual exceedance probability greater than 1E-08 is on the order of 0.1 to 1 centimeter and changes to hydraulic properties would tend to occur in a relatively narrow zone (on the order of a few meters to tens of meters wide) around the fault. The uncertainty in the effective hydraulic properties incorporated in the SZFT model coupled with the scale of the model (500 meter grid square) overwhelm the changes that would be caused by small (less than 1 meter) movements along existing faults. Therefore, the effects of movements along existing faults would not have a significant effect on the expected annual dose.

TSPA Disposition:

Geologic features and stratigraphic units are explicitly included in the SZFT model as cells with specific hydrologic parameter values in a configuration, that accounts for the effects of existing faults, based on the hydrogeologic framework model created by the USGS (2000). Model parameters, including horizontal anisotropy and specific discharge, are modeled probabilistically to account for the uncertainty in rock hydraulic and transport properties (USGS 2000); CRWMS M&O 2000c (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*); CRWMS M&O 2000h (*Uncertainty Distributions for Stochastic Parameters*)).

Treatment of Secondary FEPs:
The secondary FEPs, Fault generation (1.2.02.02.02), Fault activation (1.2.02.02.03) and Movements along small-scale faults (1.2.02.02.04), are special cases subsumed in the primary FEP (as can be seen in the wording of the primary FEP). The secondary FEPs, Faulting (1.2.02.02.01) and Faulting/fracturing (1.2.02.02.05), are redundant with the primary FEP. Since

all the secondary FEPs are incorporated in the primary FEP, the components of each that apply to existing faults are included in the SZFT model, as described in the *TSPA Disposition* section. The components of the secondary FEPs that relate to movement along existing faults are excluded based on low consequence, as described in the *Screening Argument* section. The secondary FEP 1.2.02.02.02, and components of the other secondary FEPs that apply to changes in existing properties due to movement along new faults, are excluded based on probability, as described in the *Screening Argument* section.

6.2.3 Seismic Activity (1.2.03.01.00)

FEP Description: 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).

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 1.2.02.01.00, 1.2.02.02.00, 1.2.10.01.00, 2.2.06.02.00.

IRSR Issues: USFIC5, SDS3

Screening Argument:

As presented in CRWMS M&O 2000d (*Disruptive Events FEPs,* Sections 6.2.19 – 6.2.20), changes in the hydrologic properties due to faulting along new faults (due to seismic activity (includes all secondary FEPs 1.2.03.01.01 – 1.2.03.01.07) can be excluded based on low probability. The annual exceedance probability for fault displacement in intact rock (i.e., the formation of new faults) is less than 1E-08. Movement along existing faults with an annual exceedance probability greater than 1E-08 is on the order of 0.1 to 1 centimeter and changes in hydraulic properties due to that movement would tend to occur in a relatively narrow zone (on the order of a few meters to tens of meters wide) around the fault. The uncertainty in the effective hydraulic properties incorporated in the SZFT model coupled with the scale of the model (500 meter grid square) overwhelm the changes that would be caused by small (less than 1 meter) movements along existing faults. The uncertainty in the effective hydraulic properties incorporated in the SZFT model is greater than the changes that would be caused by small movements along existing faults and fractures, therefore the changes in the SZ due to seismic activity would not have a significant effect on the expected annual dose (see FEPs 1.2.02.01.00 and 1.2.02.02.02.00).

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEPs, Earthquakes (1.2.03.01.03) and Seismicity (1.2.03.01.05), are specific to other locations; however the general characteristics pertinent to the YM site (e.g., seismic activity occurs) are subsumed in the primary FEP along with the secondary FEPs that are special cases of the primary FEP (Earthquakes (1.2.03.01.02)). Two of the FEPs are redundant with the primary FEP (Seismicity (1.2.03.01.04 and 1.2.03.01.06) and Seismic activity (1.2.03.01.07) and are retained in the list for completeness. The remaining secondary FEP (Earthquakes (1.2.03.01.01)) applies only to the waste package and vault and is not considered further in relation to the SZ.

Secondary FEPs that are subsumed in the primary (i.e., 1.2.03.01.02, 1.2.03.01.04, 1.2.03.01.06, 1.2.03.01.07), along with the components of 1.2.03.01.03 and 1.2.03.01.05 that apply to the primary FEP, are excluded due to low consequence as described in the *Screening Argument.*

6.2.4 Igneous Activity Causes Changes to Rock Properties (1.2.04.02.00)

FEP Description: Igneous activity near the underground facility causes extreme changes to rock hydrologic and mineralogic properties. Permeabilities of dikes and sills and the heated regions immediately around them can differ from those of country rock. Mineral alterations can also change the chemical response to contaminants.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 1.2.10.02.00

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

As indicated in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport)*, basaltic intrusions due to igneous activity typically cause minimal, highly localized physical (e.g., lower permeability of the intrusion relative to the matrix of the non-welded units which includes secondary FEPs 1.2.04.02.01, 1.2.04.02.02, 1.2.04.02.03 and 1.2.04.02.06) and mineralogical changes that would not alter the transport of contaminants (includes secondary FEP 1.2.04.02.05). Given the scale of the SZFT model (20 km to discharge point and 500 meter model grid square), advection in the flowing intervals (rather than the rock matrix) and the uncertainties in rock properties that are evaluated in the TSPA-SR SZFT model, highly localized effects will not have significant impacts on the flux at the compliance boundary and as a result will not have a significant effect on the expected annual dose. Therefore, changes in rock properties due to igneous activity can be excluded based on low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEPs, Dike provides a permeable flow path (1.2.04.02.01), Dike provides a barrier to flow (1.2.04.02.02), Volcanic activity in the vicinity produces an impoundment (1.2.04.02.03), Igneous activity causes extreme changes to rock geochemical properties (1.2.04.02.04) and Dike related fractures alter flow (1.2.04.02.06), are special cases of the primary FEP. These special cases and the redundant secondary FEPs (Intrusion (magmatic) (1.2.04.02.05) and Magmatic activity (1.2.04.02.07)) are subsumed in the primary FEP (as can be seen from the wording of the primary FEP). Since these secondary FEPs are incorporated in the primary FEP, they are excluded due to low consequence, as described in the *Screening Argument*.

6.2.5 Ashfall (1.2.04.07.00)

FEP Description: Finely-divided waste particles are carried up a volcanic vent and deposited on the surface from an ash cloud or pyroclastic flow.

Screening Decision and Regulatory Basis: Excluded - Low consequence

Related Primary FEPs: 1.2.04.06.00, 2.3.02.02.00

IRSR Issues: IA2

Screening Argument:

The potential effect of this FEP on the SZ is that once contaminated ash is deposited on the surface, the contaminants will leach out of the deposit and be transported through the UZ and SZ to the compliance point (secondary FEP 1.2.04.07.01). A simplified estimate of the potential dose from radionuclides leached into the saturated zone from contaminated volcanic ash is used in the screening analysis for this FEP. This stylized representation of radionuclide mobilization and transport in the SZ contains several conservative approximations and assumptions in order to simplify the analysis for the purpose of screening. In addition, the expected values of several parameters are assumed for the analysis (see *Supplemental Discussion* for detailed discussion of how the dose rate was estimated). The resulting estimated conditional total dose rate is 16.1 mrem/year for an event in the first year.

The dose rate is conditional upon the occurrence of the contaminated ashfall event. Hence, the conditional dose rate should be weighted by the probability of the occurrence of a volcanic eruption to evaluate its potential impact on the overall expected annual dose. The probability of a volcanic eruption during the compliance period is less than 1.6 x 1E-04 (see *Supplemental Discussion*). The probability of a volcanic eruption during the first 1,000 years, when the dose rate is potentially significant, is less than 1.6E-05. The resulting probability-weighted dose rate, due to leaching of radionuclides from contaminated ash, is less than 2.6E-04 mrem/year. This is significantly less than the probability-weighted doses resulting from other igneous pathways during this period (CRWMS M&O 2000b, (*Total System Performance Assessment for the Site Recommendation),* section 4.2), and the FEP can be excluded on the basis of low consequence to the expected annual dose.

TSPA Disposition:

Excluded from the SZ model as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEP, Soil leaching following ashfall (1.2.04.07.01), is a special case that is subsumed in the primary FEP. The secondary FEP represents the portion of the primary FEP that applies to the SZ and is the focus of this analysis. It is excluded based on low consequence as presented in the *Screening Argument* and *Supplemental Discussion.*

Supplemental Discussion

Supplemental Text for Screening Argument:

For this screening analysis, it is assumed that the contents of ten waste packages are entrained in the volcanic eruption and that all of the waste is distributed in the ash blanket on the ground surface resulting from the eruption. Ten waste packages is the median number of packages brought to the surface by a single volcanic eruption intersecting one drift in the Disruptive Events analysis for TSPA-SR (CRWMS M&O 2000b, (*Total System Performance Assessment for the Site Recommendation),* Section 3.10.2.2, Table 3.10-4). The ten waste packages are assumed to contain commercial spent nuclear fuel (CSNF), which is the most common type of waste package in the potential repository (CRWMS M&O 2000i, (*Inventory Abstraction*), Table I-1). The radionuclide inventory in the waste packages is assumed to be the average for CNSF at the time of waste emplacement. This is equivalent to assuming that the volcanic eruption occurs immediately after waste emplacement, an assumption that conservatively maximizes the impact of short-lived radionuclides. The volcanic ash blanket is assumed to be entirely and evenly distributed in the 20 km region between the potential repository and the critical group. This assumption maximizes the quantity of radionuclides that is available for transport via the SZ to the hypothetical pumping wells of the critical group.

The SZ is conceptualized to consist of a simplified one-dimensional flow system between the potential repository and the accessible environment as shown in Figure 6-1 of this document (ANL-NBS-MD-000002). It is assumed that the radionuclides in the ash layer are entirely and immediately dissolved in the infiltrating groundwater along the 20 km flow path. Furthermore, it is assumed that the travel time through the UZ for the dissolved radionuclides is negligible and that the radionuclides are introduced in the recharge to the SZ at time zero of the analysis. This is a very conservative approximation with respect to the transport of relatively short-lived radionuclides (e.g., ^{90}Sr, ^{137}Cs, and ^{238}Pu), which would probably experience significant retardation and decay during transport through the UZ to the SZ. It is also conservatively assumed that radionuclides are transported without radioactive decay in the SZ. In addition, the conservative assumption is made that all radionuclides derived from the volcanic ash blanket are captured in the hypothetical pumping wells of the critical group. The expected value of groundwater usage of 1938 acre-ft/year is used in the analysis (CRWMS M&O 2000j, (*Biosphere Process Model Report*), Table 12).

In the simplified conceptual model of radionuclide transport in the SZ uniform, one-dimensional flow is assumed to deliver the radionuclide mass to the hypothetical pumping wells of the critical group at a steady rate. A transport time of 800 years, for a non-sorbing species, from the potential repository is taken from the analysis of SZ transport using the three-dimensional SZ site-scale flow and transport model (CRWMS M&O 2000c, (*Input and Results of the Base Case Saturated Zone Flow and Transport Model for TSPA*), Figure 11). The 800 year travel time is the time at which about 80% of the radionuclide mass arrives at 20 km in the expected-value simulation. The resulting idealized radionuclide mass breakthrough curve is shown in Figure 6-2 of this document (ANL-NBS-MD-000002). Note that the first radionuclide mass arrives at time zero because of the assumed instantaneous travel through the UZ and the duration of the breakthrough curve is 800 years, at which time the most upstream of the radionuclide mass arrives. The average (and also peak) concentration of the non-sorbing radionuclide in the water supply of the hypothetical farming community is calculated by dividing the total radionuclide mass delivered to the SZ from the contaminated ash by the water usage over the 800 years. For those radionuclides that experience sorption and retardation in the SZ, the distribution of radionuclide mass arrival at 20 km is spread over a longer period of time, as indicated by the example shown in Figure 6-2 of this document (ANL-NBS-MD-000002). A retardation factor of two means that the arrival of radionuclide mass at 20 km is spread over about 1600 years and the radionuclide mass flux is one half of that for the non-sorbing species. The expected effective retardation factors for the radionuclides in the analysis are derived from the mid-points of the simulated breakthrough curves for the expected-value case using the SZ site-scale flow and transport model (CRWMS M&O 2000c, (*Input and Results of the Base Case Saturated Zone Flow and Transport Model for TSPA*), Figure 11).

The estimate of dose rate from this simplified analysis is shown in Table 6-1 of this document (ANL-NBS-MD-000002). The representative volume of water for each radionuclide is calculated as the product of the expected annual groundwater usage, the 800 year travel time, and the retardation factor. The dose rate is calculated as the product of the average concentration and the biosphere dose conversion factor (BDCF) for each radionuclide.

The resulting estimated conditional total dose rate is 16.1 mrem/year. It should be noted that over half of this dose rate is contributed by radionuclides with half lives of less than 100 years (i.e., ^{90}Sr, ^{137}Cs, and ^{238}Pu). The transport time through the UZ has been conservatively neglected in this analysis; these three radionuclides are subject to sorption and retardation in the UZ and would probably be considerably attenuated before reaching the water table. The remaining radionuclide among the major contributors to the dose, ^{241}Am, is also relatively short-lived, with a half-life of 432 years. Together, these four relatively short-lived radionuclides account for 93 percent of the total estimated dose from this pathway.

Table 6-1. Screening Estimate of Dose from the SZ for Leaching from Volcanic Ash

Radio-nuclide	Curies/ Package[1]	Total Curies	Expected Effective Rf [2]	Water Volume (L)	Concen-tration (picoCi/L)	BDCF [3] (mrem/yr per pCi/L)	Dose Rate (mrem/yr)
^{14}C	6.05E+00	6.05E+01	1.00E+00	1.91E+12	3.17E-02	5.54E-04	1.76E-05
^{90}Sr	3.59E+05	3.59E+06	1.00E+02	1.91E+14	1.88E+01	1.12E-01	2.10E+00
^{99}Tc	1.51E+02	1.51E+03	2.30E+00	4.40E+12	3.43E-01	1.49E-03	5.11E-04
^{129}I	3.65E-01	3.65E+00	2.40E+00	4.59E+12	7.95E-04	3.56E-01	2.83E-04
^{137}Cs	5.44E+05	5.44E+06	1.00E+02	1.91E+14	2.85E+01	1.84E-01	5.24E+00
^{227}Ac	3.26E-04	3.26E-03	1.00E+02	1.91E+14	1.71E-08	1.80E+01	3.08E-07
^{232}U	2.90E-01	2.90E+00	1.60E+01	3.06E+13	9.48E-05	2.06E+00	1.95E-04
^{233}U	9.01E-04	9.01E-03	1.60E+01	3.06E+13	2.94E-07	3.85E-01	1.13E-07
^{234}U	1.32E+01	1.32E+02	1.60E+01	3.06E+13	4.31E-03	3.77E-01	1.62E-03
^{236}U	2.96E+00	2.96E+01	1.60E+01	3.06E+13	9.67E-04	3.56E-01	3.44E-04
^{238}U	2.84E+00	2.84E+01	1.60E+01	3.06E+13	9.28E-04	3.51E-01	3.26E-04
^{237}Np	4.18E+00	4.18E+01	5.70E+01	1.09E+14	3.83E-04	6.74E+00	2.58E-03
^{238}Pu	3.28E+04	3.28E+05	2.20E+02	4.21E+14	7.79E-01	4.11E+00	3.20E+00
^{239}Pu	3.28E+03	3.28E+04	2.20E+02	4.21E+14	7.79E-02	4.98E+00	3.88E-01
^{240}Pu	5.44E+03	5.44E+04	2.20E+02	4.21E+14	1.29E-01	4.95E+00	6.39E-01
^{241}Am	3.74E+04	3.74E+05	2.20E+02	4.21E+14	8.88E-01	5.01E+00	4.45E+00
^{243}Am	3.23E+02	3.23E+03	2.20E+02	4.21E+14	7.67E-03	5.03E+00	3.86E-02
						Total	**1.61E+01**

[1] Source: CRWMS M&O 2000i, Table I-2.
[2] Source: CRWMS M&O 2000c, Figure 11.
[3] Source: CRWMS M&O 2000j, Table 3-20.

This conditional dose rate should be weighted by the probability of the occurrence of a volcanic eruption to evaluate its potential impact on the overall expected annual dose. Volcanic eruptions at Yucca Mountain are unlikely: CRWMS M&O 2000g (*Characterize Framework for Igneous Activity at Yucca Mountain, Nevada*), Section 7, concludes that the mean annual frequency of igneous intrusion into the potential repository footprint is 1.6E-08. The probability of eruption, rather than intrusion, is less because not all, hypothetical igneous intrusions would result in an eruption at the potential repository. Conservatively adopting the 1.6E-08/yr value, and assuming that future igneous activity at Yucca Mountain is a Poisson process, there is approximately a 1.6E-04 probability of an igneous event at Yucca Mountain in the next 10,000 years. This event is equally likely to occur in any year during the 10,000-year period, and the probability that the event has already occurred (and that groundwater is contaminated) rises from 1.6E-08 in the first year to 1.6E-04 after 10,000 years. A rigorous approach to estimating the probability-weighted dose through time would require evaluating consequences of events at each year and summing the probability-weighted doses, as done in the TSPA-SR for doses incurred by direct exposure to a contaminated ash layer (CRWMS M&O 2000b, (*Total System Performance Assessment for the Site Recommendation*), Section 4.2). However, for the purposes of bounding the probability-weighted consequences of this process, it is sufficient to focus on events that might happen during the first 1000 years, before radioactive decay causes a significant drop in the estimated dose. (Note that essentially none of the ^{90}Sr and ^{137}Cs remain after 1000 years, and very little ^{238}Pu, with a half-life of 88 years, remains. Of the four major contributing radionuclides shown in Table 6-1 of this document (ANL-NBS-MD-000002), only ^{241}Am makes a significant contribution to dose at 1000 years, and its inventory is already less than one quarter of what it was at time zero.) It is conservative, for the fission products, to assume that the dose rate estimated for an igneous event occurring in the first year is representative of events that might occur at any time in the first 1000 years. In fact, the first-year event provides an upper bound on the radionuclide inventory available for later events. The probability of an igneous event occurring during the first 1,000 years is 1.6E-05, which yields a probability-weighted dose rate of approximately 2.6E-04 mrem/year for leaching of radionuclides from contaminated ash. This is significantly less than the probability-weighted doses resulting from other igneous pathways during this period (CRWMS M&O 2000b, (*Total System Performance Assessment for the Site Recommendation*), section 4.2), and the FEP can be excluded on the basis of low consequence to the expected annual dose.

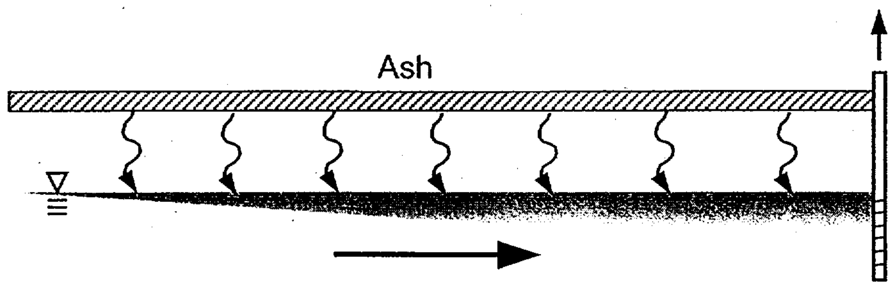

Figure 6-1. Cross-Section Diagram of Simplified One-Dimensional Model for Transport in the SZ of Radionuclides Leached from Volcanic Ash.

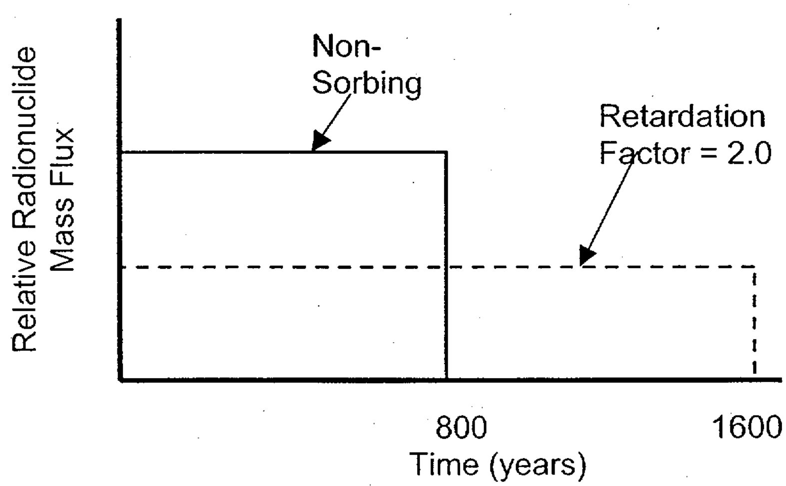

Figure 6-2. Idealized Radionuclide Mass Breakthrough Curves at 20 km Distance Resulting from Volcanic Ash Leaching for Non-Sorbing and Example Sorbing Radionuclide.

6.2.6 Hydrothermal Activity (1.2.06.00.00)

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.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 1.2.10.02.00, 1.2.04.02.00, 2.2.10.02.00, 2.2.10.08.00

IRSR Issues: USFIC5

Screening Argument:

As presented in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport*), because major silicic magmatism, near Yucca Mountain, is not imminent, there is virtually no possibility for hydrothermal activity at or near the mountain during the compliance period. Hydrothermal activity is not expected to occur during the compliance period due to the length of time required to develop hydrothermal activity following the initiation of silicic volcanism. However the probability of hydrothermal activity is not quantified in that analysis. Given the potential effects of hydrothermal activity and the manner in which the K_d parameter is implemented in the SZFT model (i.e., with conservative distributions such that hydrothermal effects would not significantly alter the uncertainty distributions (see *Supplemental Discussion*)), hydrothermal activity will not have a significant impact on the simulated transport as a result, it will not have a significant effect on the expected annual dose. Therefore, this FEP can be excluded based on low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEP, Hydrothermal activity (1.2.06.00.01), is specific to another location, however the general components of that FEP are redundant with the primary FEP. Therefore, the general components of 1.2.06.00.01 that are incorporated in the primary FEP are excluded based on low consequence as described in the *Screening Argument* section.

Supplemental Discussion

Supplemental Text for Screening Argument :

If hydrothermal activity were to occur in the vicinity of the potential 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 potential repository, it would cause greater mixing of waters than predominantly lateral flow. Increased mixing would enhance dilution of the contaminant plume, which would tend to reduce the expected annual dose.

Hydrothermal activity in the past has resulted in alteration of rocks in Yucca Mountain. In the surrounding region, large-scale alteration is associated with silicic volcanism. The effects of hydrothermal activity, potentially impacting contaminant transport, are due 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 higher sorption coefficient values for Cs, Sr, Ra, Pb, Ni, Pu, Np, and U than vitric or devitrified samples (CRWMS M&O 2000k, (*Unsaturated Zone and Saturated Zone Transport Properties*) Table 2b, p.46). There are no significant differences for Se, Pa, or Sn sorption coefficients for the three types of tuff (CRWMS M&O 2000k, (*Unsaturated Zone and Saturated Zone Transport Properties*) Table 2b, p.46). In order not to overestimate sorption, the SZFT model sorption coefficient values are based on the rock type with the lowest sorption capacity (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)). This approach to modeling the K_d values means that the potential effects of hydrothermal alteration will not have a significant effect on the K_d values and therefore won't have a significant effect on the expected annual dose.

D_e is also function of temperature, increasing with higher temperature (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)). Increasing D_e would increase the rate of transport into the matrix and therefore, increase the attenuation of the contaminant plume. However, given the low probability of occurrence of hydrothermal activity during the compliance period, hydrothermal activity will not have a significant effect on the expected annual dose.

6.2.7 Large-scale Dissolution (1.2.09.02.00)

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.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: No closely related FEPs.

IRSR Issues: USFIC5

Screening Argument:

Large-scale dissolution is unlikely because evaporites are not dominant minerals in the formations along the simulated transport pathways and water levels would have to drop more than 700 meters to reach the carbonate rocks (see *Supplemental Discussion*). 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 localized effects of evaporite dissolution and collapse in the valley fill would not alter the model-scale, effective transport parameter characteristics. Since evaporite dissolution will not provide large-scale effects, it will not have a significant effect on contaminant transport and there will be no significant effects on the expected annual dose due to this process, therefore it can be excluded.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEPs, Shallow dissolution (1.2.09.02.01), Lateral dissolution (1.2.09.02.02), Solution chimneys (1.2.09.02.03), Breccia pipes (1.2.09.02.04) and Collapse breccias (1.2.09.02.05), pertain specifically to the stratigraphy at the WIPP site and are not evaluated further in this analysis.

Supplemental Discussion

Supplemental Text for Screening Argument:

Large-scale dissolution can be excluded from 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. The hydrogeologic framework model, which is based on the available geologic information from the Yucca Mountain region (D'Agnese et al. 1997 and USGS 2000), 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 FEP 1.3.07.01.00). This is a reasonable assumption given the depth of the carbonate aquifer below the water table [more than 1000 meters given the approximate elevations of the potentiometric surface and top of the carbonate aquifer (USGS 2000, Figures 6-2 and 6-18)] and the lack of any significant water table decline due to groundwater withdrawal in the Jackass Flats hydrographic basin (La Camera et al. 1999 and Young 1972)..

6.2.8 Hydrologic Response to Seismic Activity (1.2.10.01.00)

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

Screening Decision and Regulatory Basis: Excluded – Low Probability (effects of new faults) and

Excluded – Low consequence (effects of movement along existing faults).

Related Primary FEPs: 1.2.02.01.00, 1.2.02.02.00, 1.2.03.01.00.

IRSR Issues: USFIC5

Screening Argument:

As presented in CRWMS M&O 2000d (*Disruptive Events FEPs,* Sections 6.2.19 – 6.2.20), changes in the hydrologic properties due to faulting along new faults can be excluded based on low probability (applies to secondary FEPs 1.2.10.01.03, 1.2.10.01.09, 1.2.10.01.10 and 1.2.10.01.12). The annual exceedance probability for fault displacement in intact rock is less than 1E-08. Movement along existing faults with an annual exceedance probability greater than 1E-08 is on the order of 0.1 to 1 centimeter. As a result the secondary FEPs (1.2.10.01.04 and

1.2.10.01.08) which require greater than 1 centimeter of movement can also be eliminated based on low probability.

Given the relatively small displacement along faults (hence smaller magnitude of water table rise) and the transient nature of water table rise, the effects of seismic pumping (secondary FEPs 1.2.10.01.01, 1.2.10.01.02, 1.2.10.01.05 and 1.2.10.01.06) and creation of flow barriers (secondary FEP 1.2.10.01.13) will be negligible relative to climate change induced water table rise (see *Supplemental Discussion*). Therefore, seismic induced water table rise will not have a significant effect on the expected annual dose and can be excluded based on low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The following secondary FEPs are special cases of the primary FEP and are subsumed in the primary FEP (as can be seen from the wording of the primary FEP):

1.2.10.01.01	Fault movement pumps fluid from SZ to UZ (seismic pumping)
1.2.10.01.02	Fault creep causes short term fluctuations of the water table
1.2.10.01.03	New faulting breaches flow barrier controlling large hydraulic gradient to the north
1.2.10.01.04	Normal faulting produces a trap for laterally moving moisture in the Tiva Canyon unit
1.2.10.01.05	Head-driven flow up from Carbonates
1.2.10.01.06	Seismically-induced water table changes
1.2.10.01.07	Fault pathway through the altered Topopah Spring basal vitrophyre
1.2.10.01.08	Fault movement connects tuff and carbonate aquifers
1.2.10.01.09	Fault establishes pathway through the UZ
1.2.10.01.10	Fault establishes pathway through the SZ
1.2.10.01.11	Fluid supplied by a fault migrates down the drift
1.2.10.01.12	Fault intersects and drains condensate zone
1.2.10.01.13	Flow barrier south of site blocks flow, causing water table to rise

Two of the secondary FEPs (1.2.10.01.07 and 1.2.10.01.11) apply specifically to the UZ and are not evaluated in this analysis. As presented in the *Screening Argument*, secondary FEPs 1.2.10.01.03, 1.2.10.01.09, 1.2.10.01.10 and 1.2.10.01.12 can be excluded based on low probability due to their dependence on the formation of new faults. Two of the secondary FEPs (1.2.10.01.04 and 1.2.10.01.08) require greater than 1 centimeter of movement and can be eliminated based on low probability (see *Screening Argument*).

The remaining secondary FEPs relate to the effects of seismic pumping (1.2.10.01.01, 1.2.10.01.02, 1.2.10.01.05 and 1.2.10.01.06) and creation of flow barriers (1.2.10.01.13) and can be excluded based on low consequence (see *Screening Argument* and *Supplemental Discussion).*

Supplemental Discussion

Supplemental Text for Screening Argument:

Gauthier et al. (1996) analyzed the potential effects of seismic activity on contaminant transport in the SZ due to changes in water-table elevation (secondary FEP 1.2.10.01.06). 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 tectohydrologic 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 a more hypothetical event of about 4 meters 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 (secondary FEP 1.2.10.01.01). 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.

The results of the modeling of potential effects on the water table due to seismic activity coupled with the expected movement in existing faults of 1 centimeter or less (less than 1/100th of the simulated movement) indicates that the expected water table rise will be a highly transient event when compared to the duration of the compliance period (i.e. a less than 6 month duration event in a 10,000 year time period). The magnitude of the water table rise due to the event will be something less than a meter with the greatest rise occurring over the width of the fracture zone.

Climate change would produce water table rise of greater magnitude over the entire region, rather than isolated along the active fault zone, and would be of significantly longer duration. As discussed in FEP 1.3.07.02.00, water table rise directly beneath the potential repository could alter the timing and magnitude of contaminant flux from the UZ to the SZ due to shortened pathways through the UZ.

Given the short duration and relatively small magnitude of tectonic induced water table rise the effects on SZ flow and transport, due to differences in the flowpath or hydrologic properties along that path, are negligible over the long-term and over the scale of concern (20 km). Therefore this FEP can be excluded due to low consequence.

6.2.9 Hydrologic Response to Igneous Activity (1.2.10.02.00)

FEP Description: Igneous activity may change the groundwater flow directions, water level, water chemistry and temperature. Igneous activity includes magmatic intrusions which may change rock properties and flow pathways, and thermal effects which may heat up groundwater and rock.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 1.2.04.02.00

IRSR Issues: USFIC5

Screening Argument:

As noted in CRWMS M&O 2000d (*Disruptive Events FEPS)*: igneous intrusions are not expected to occur and, even if they do occur, the orientation of intrusive features are likely to parallel existing features and affect a relatively small volume of the SZ. As a result, even if the intrusion differs in permeability from the host rock, it won't significantly affect groundwater flow patterns or have a significant effect on the expected annual dose. Therefore, changes in permeability and flow directions due to igneous activity can be excluded based on low consequence.

Treatment of Secondary FEPs:

The secondary FEPs, Interaction of WT with magma (1.2.10.02.01) and Interaction of UZ pore water with magma (1.2.10.02.02), are special cases of the primary FEP and are subsumed in the primary FEP. The secondary FEPs are analyzed in CRWMS M&O 2000d (*Disruptive Events FEPS)* and can be excluded based on low consequence (see summary of the CRWMS M&O 2000d analysis, above in *Screening Argument)*.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.10 Drought/Water Table Decline (1.3.07.01.00)

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 potential repository.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 1.3.01.00.00

IRSR Issues: USFIC1, USFIC5

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 (secondary FEP 1.3.07.01.00) 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 potential 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 potential repository) in the hydrogeologic framework model (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)).

Given the above rationale, the overall effects of this FEP with in the SZ are beneficial to performance; however, a significant drop in the water level is unlikely. As a result, water table decline will have little to no effect on the expected annual dose.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEP Desert and unsaturation (1.3.07.01.01) is redundant with the primary FEP and can be excluded based on low consequence (see *Screening Argument*). The remaining secondary FEP Dust storms and desertification (1.3.07.01.02) does not apply to the SZ and is not considered further in this analysis.

6.2.11 Water Table Rise (1.3.07.02.00)

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 potential repository. A regionally higher water table and in change flow patterns might move discharge points closer to the potential repository, or flood the potential repository.
Screening Decision and Regulatory Basis:	Included (Preliminary)
Related Primary FEPs:	2.2.03.01.00, 1.3.01.00.00
IRSR Issues:	USFIC2, USFIC5

Screening Argument:

Included in TSPA as described under TSPA Disposition

TSPA Disposition:

The potential effects of water table rise on UZ and SZ flow and transport processes (e.g., increased infiltration and shorter travel path through the UZ (secondary FEP 1.3.07.02.01) and potential flooding of the potential repository) are included as variability in the timing and rate of contaminant transport through the UZ to the SZ. 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 potential repository. These changes could significantly alter the simulated, expected annual dose and should be included in the TSPA-SR models (see *Supplemental Discussion*). It is assumed for this analysis, that the potential effects of water table rise due to climate change will be evaluated using sensitivity analyses of the calibrated SZ flow and transport (TBV-4924).

Treatment of Secondary FEPs:

The secondary FEP, Short Circuit of a Flow Barrier in the Saturated Zone Because of a Water Table Rise (1.3.07.02.01), is a special case of the primary FEP and is subsumed in the primary FEP. It is included as presented in *TSPA Disposition.*

Supplemental Discussion:

Supplemental Text for Screening Argument: 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. 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 based on spring deposit elevations, and the conservative nature of those estimates due to conservative estimates of the depth to the current water table (Quade et al. 1995, p. 213; Paces et al. 1993, p. 1573; and Marshall et al. 1993, p.1948), the expected future water table rise at Yucca Mountain is less than 115 m.

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 potential repository, the rate of transport at the water table would be reduced because it would place the water table below the potential repository, in the Upper Volcanic Confining Unit (Calico Hills hydrogeologic unit) which has significantly lower hydraulic conductivities (CRWMS M&O 2000l (*Calibration of the Site-Scale Saturated Zone Flow Model*)).

As contaminants are transported away from the potential 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-SR (CRWMS M&O 2000c), 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, the simulated flux at the compliance boundary would be reduced and consequently so would the expected annual dose

Supplemental Text for TSPA Disposition: 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 potential 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 TSPA-SR analysis.

6.2.12 Water Management Activities (1.4.07.01.00)

FEP Description: Water management is accomplished through a combination of dams, reservoirs, canals, pipelines, and collection and storage facilities. Water management activities could have a major influence on the behavior and transport of contaminants in the biosphere.

Screening Decision and Regulatory Basis: Included (existing water management activities)

Excluded – By Regulation (changes in water management activities)

Related Primary FEPs: 1.4.07.02.00

IRSR Issues: USFIC5

Screening Argument:

The potential effect, of changes in water management practices (including the secondary FEPs 1.4.07.01.01, 1.4.07.01.03, 1.4.07.01.04, 1.4.07.01.06, 1.4.07.01.07, 1.4.07.01.08, 1.4.07.01.09, 1.4.07.01.10 and 1.4.07.01.012), 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.*

TSPA Disposition:

Water management activities are included explicitly in the biosphere model (CRWMS M&O 2000j) as a volume of water consumed (directly and indirectly) by the hypothetical, proposed, regulatory mandated exposed community (64 FR 8640). Groundwater use is based on current practices in the vicinity of Yucca Mountain (CRWMS M&O 2000m (*Groundwater Usage by the Proposed Farming Community*)). 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 proposed twenty-kilometer boundary are intercepted by the community's wells (CRWMS M&O 2000c (*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 2000m (*Groundwater Usage by the Proposed Farming Community*)).

The effects of existing water management activities (includes secondary FEPs 1.4.07.01.02, 1.4.07.01.05 1.4.07.01.11 and 1.4.07.01.13) on the saturated flow system are not modeled explicitly, but are included implicitly since the flow model is calibrated using existing hydraulic head data (CRWMS M&O 2000l *(Calibration of the Site-Scale Saturated Zone Flow Model)*) which would reflect the effects of existing dams, reservoirs and groundwater pumping on the water table elevation.

Treatment of Secondary FEPs:

The secondary FEPs, Water collection in cisterns over repository (1.4.07.01.01), Water management of nearby ground water basins (1.4.07.01.02), Water table drawdown by down gradient pumping increases hydraulic gradient (1.4.07.01.03), Surface water impoundment is constructed near the site, increasing percolation (1.4.07.01.04), Dams (1.4.07.01.05), Human induced actions on groundwater recharge (1.4.07.01.06), Human-induced changes in surface hydrology (1.4.07.01.07), Dams and reservoirs, built and drained (1.4.07.01.08), River rechannelled (1.4.07.01.09), Damming of streams or rivers (1.4.07.01.10), Reservoirs (1.4.07.01.11), Lake usage (1.4.07.01.12), and Water management schemes (1.4.07.01.13), are special cases of the primary FEP and are subsumed in the primary FEP. As presented in the *Screening Argument* and *TSPA Disposition*, the secondary FEPs and portions of those secondary FEPs that relate to existing water management activities and practices are included in the TSPA-SR models (see *TSPA Disposition*). The secondary FEPs and portions of secondary FEPs that relate to future or changes in existing water management activities and practices are excluded based on regulatory guidance (see *Screening Argument*).

6.2.13 Wells (1.4.07.02.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.4.07.01.00, 2.2.07.16.00.

IRSR Issues: USFIC5

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

The effects of wells on the expected annual dose are included explicitly in the biosphere model (CRWMS M&O 2000j) as a volume of water consumed (directly and indirectly) by the hypothetical, proposed, regulatory mandated exposed community (64 FR 8640). 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 proposed, twenty-kilometer boundary are intercepted by the community's wells (addresses secondary FEPs 1.4.07.02.04 - 1.4.07.02.09) (CRWMS M&O 2000c (*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 2000m (*Groundwater Usage by the Proposed Farming Community*)).

Treatment of Secondary FEPs:

The secondary FEPs, Irrigation wells in Midway Valley increase moisture flux through repository (1.4.07.02.01), Irrigation wells in Midway Valley reduce distance to accessible environment (1.4.07.02.02), Irrigation wells in Crater Flats or Jackass Flats increase hydraulic gradient under repository (1.4.07.02.03), Wells (high demand) (1.4.07.02.04), Groundwater abstraction (1.4.07.02.05), Water resource exploitation (1.4.07.02.06), Deep groundwater abstraction (1.4.07.02.07), Water producing well (1.4.07.02.08) and Groundwater extraction (1.4.07.02.09), are special cases of the primary FEP and are subsumed in the primary FEP. The secondary FEPs and the general portions of those secondary FEPs that are consistent with regulatory guidance on the treatment of human behavior are included in the TSPA-SR models as described in *TSPA Disposition*.

Changes in water management activities including wells at new locations (applies to secondary FEPs 1.4.07.02.01, 1.4.07.02.02 and 1.4.07.02.03) are excluded based on regulatory guidance (see FEP 1.4.07.01.00). The effects of existing wells on the saturated flow system are not modeled explicitly, but are included implicitly since the flow model is calibrated using existing hydraulic head data (CRWMS M&O 2000l) (see FEP 1.4.07.01.00).

6.2.14 Suspension of Particles Larger than Colloids (2.1.09.21.00)

FEP Description: Ground water flow through the waste could remove radionuclide-bearing particles by a rinse mechanism. Particles of radionuclide bearing material larger than colloids could then be transported in water flowing through the waste and EBS by suspension.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 2.2.08.10.00

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Transport of particles larger than colloids will be subject to filtration and settling to a greater degree than the smaller colloids; however the uncertainties in the flow velocities prevent exclusion of this FEP from the SZFT models (see *Supplemental Discussion*) based on a settling velocity argument. Since colloidal size particles are subject to less filtration and tend to remain in solution (i.e., do not settle out of solution) and all particle transport is modeled as colloid transport (see FEP 2.2.08.10.00), this FEP is included in the TSPA-SR models in a conservative fashion.

Treatment of Secondary FEPs:

Two secondary FEPs, Suspended sediment transport (2.1.09.21.01) and Rinse (2.1.09.21.02), are special cases of the primary FEP and are subsumed in the primary FEP. The secondary FEP, Rinse (2.1.09.21.02), applies to the EBS and is not evaluated further in this analysis. Suspended sediment transport (2.1.09.21.01) is included in the SZFT models as presented in *TSPA Disposition.*

Supplemental Discussion

Supplemental Text for Screening Argument:

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 (waste particles (secondary FEP 2.1.09.21.02) or contaminants sorbed on sediment particles (secondary FEP 2.1.09.21.01)) 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) (Krumbein and Sloss 1963, p. 203). 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.

The estimates of settling velocity as a function of particle diameter are used for illustrative purposes. Since the objective is to illustrate the order of magnitude of the settling velocity as a function of particle diameter, the other parameter values are set at constant values while the particle diameter is varied over several orders of magnitude. Even though the other parameter values are not known with certainty, that uncertainty would not cause orders of magnitude changes in the settling velocity. A typical particle density for naturally occurring soil particles of 2650 kg/m^3 (Freeze and Cherry 1979, p. 337), equivalent to the density of quartz, is used in this analysis 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).

If the following are assumed:

- Stokes' Law applies (spherical particles in a fluid with Reynolds number less than 0.5)
- particle diameter (L)of 1 micron (1E-06m)
- particle density (D_p)of 2650 kg/m^3
- water density of (D_w)1000 kg/m^3
- water dynamic viscosity (V)of 1.005E-03 Ns/m^2

then the order of magnitude of the settling velocity (sv) of the particle can be estimated using the following equation (after Krumbein and Sloss 1963, p. 197 (Stokes' Law) and Streeter and Wylie 1979, equation 5.7.1, p. 226 (terminal velocity of a sphere)):

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

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 9E-07 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 sustained transport. 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, based on settling velocity. 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. Therefore, the colloid transport model used in TSPA-SR provides a bounding estimate for the transport of all particles.

6.2.15 Stratigraphy (2.2.03.01.00)

FEP Description: Stratigraphic information is necessary information for the performance assessment. This information should include identification of the relevant rock units, soils and alluvium, and their thickness, lateral extents, and relationships to each other. Major discontinuities should be identified.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.02.01.00, 2.2.03.02.00, 2.2.08.01.00.

IRSR Issues: USFIC5

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Geologic features and stratigraphic units are explicitly included in the SZFT model as cells with hydrologic parameter values in a configuration based on the hydrogeologic framework model created by the USGS (2000). Uncertainty in the location of the contact between alluvium and volcanics at the southern end of the site scale model is modeled probabilistically. The uncertainty in the hydrologic parameter values is a function of the hydrogeologic units defined by the hydrogeologic framework model (CRWMS M&O 2000c (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*); CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)).

Treatment of Secondary FEPs:

The secondary FEPs: M esozoic sedimentary cover (2.2.03.01.01) Permo-Carboniferous Trough (2.2.03.01.02) and Brine Reservoirs (2.2.03.01.03) are special cases of the primary FEP that apply specifically to the stratigraphy at other locations (e.g., WIPP) and are not directly applicable to YM. The relevant, general features of these secondary FEPs are subsumed in the primary FEP. Since the pertinent features of these secondary FEPs are subsumed in the primary FEP, they are included in the SZFT model as described in *TSPA Disposition*.

6.2.16 Rock Properties of Host Rock and Other Units (2.2.03.02.00)

FEP Description: Physical properties such as porosity and permeability of the relevant rock units, soils, and alluvium are necessary for the performance assessment. Possible heterogeneities in these properties should be considered.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.02.01.00, 2.2.03.01.00, 2.2.08.01.00.

IRSR Issues: USFIC5

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Geologic features and heterogeneous 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 (2000). Uncertainty in the location of the contact between alluvium and volcanics at the southern end of the site scale model is modeled probabilistically (CRWMS M&O 2000c (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*); CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)). The uncertainty in the hydrologic parameter values is a function of the hydrogeologic units defined by the hydrogeologic framework model.

Treatment of Secondary FEPs:

A secondary FEP, Rock Heterogeneity (2.2.03.02.01), is subsumed in this primary FEP, as can be seen from the wording of the primary FEP. Since it is subsumed in the primary FEP, it is also included in the SZFT model as described in *TSPA Disposition*.

6.2.17 Changes in Stress Produce Change in Permeability of Faults (2.2.06.02.00)

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

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 1.2.02.01.00, 1.2.02.02.00

IRSR Issues: USFIC5, SDS3

Screening Argument:

As presented in CRWMS M&O 2000d (*Disruptive Events FEPs,* Sections 6.2.19 – 6.2.20), changes in the hydrologic properties due to faulting along new faults can be excluded based on low probability. The annual exceedance probability for fault displacement in intact rock is less than 1E-08. Movement along existing faults, with an annual exceedance probability greater than 1E-08, is on the order of 0.1 to 1 centimeter and changes to hydraulic properties, including permeability, would tend to occur in a relatively narrow zone (on the order of a few meters to tens of meters wide) around the fault. The uncertainty in the effective hydraulic properties incorporated in the SZFT model coupled with the scale of the model (500 meter grid square) overwhelm the changes that would be caused by small (less than 1 meter) movements along existing faults. Therefore, the effects of movements along existing faults would have no effect on the simulated flux at the compliance boundary and therefore no effect on the expected annual dose (see FEPs 1.2.02.01.00 and 1.2.02.02.00). As a result, the expected changes in stress (includes all of the secondary FEPs associated with this primary FEP) and their potential effects can be excluded based on low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The following secondary FEPs are special cases of the primary FEP and are subsumed in the primary FEP:

Aseismic alteration of permeability along and across faults (2.2.06.02.01)
Fracture dilation along faults creates zones of enhanced permeability (2.2.06.02.02)
Relaxation of thermal stresses by fault movement (2.2.06.02.03)
Seismically-stimulated release of thermo-mechanical stress on bounding faults (2.2.06.02.04)
Relaxation of thermal stresses by fault movement (2.2.06.02.05).

Since all the secondary FEPs are subsumed in the primary FEP, they can all be excluded based on low consequence as presented in the *Screening Argument.*

6.2.18 Changes in Stress Alter Perched Water Zones (2.2.06.03.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.03.01.00

IRSR Issues: USFIC5, SDS3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

As noted in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport)*, the potential significant effects of releasing perched water, above or below the potential repository, as a result of seismic activity, are indirectly included using a model for flow focusing in the seepage model abstraction. Therefore, potential significant effects of this FEP are evaluated in the UZFT model and will be included in the source term for the SZFT model (i.e., the contaminant flux through the upper boundary).

Treatment of Secondary FEPs:

The secondary FEP, Perched zones develop as a result of stress changes (2.2.06.03.01), is redundant with the primary FEP and is included as described in *TSPA Disposition*.

6.2.19 Saturated Groundwater Flow (2.2.07.12.00)

FEP Description: Groundwater flow in the saturated zone below the water table may affect long-term performance of the potential repository. The location, magnitude, and direction of flow under present and future conditions and the hydraulic properties of the rock are all relevant.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.02.01.00, 1.2.02.02.00, 1.2.03.01.00, 1.2.06.00.00, 1.2.09.02.00, 1.2.10.01.00, 1.2.10.02.00, 1.3.07.01.00, 1.3.07.02.00, 1.4.07.01.00, 1.4.07.02.00, 2.2.03.01.00, 2.2.06.02.00, 2.2.07.13.00, 2.2.07.14.00, 2.2.10.01.00, 2.2.10.03.00, 2.2.10.07.00, 2.2.10.08.00, 2.2.10.13.00.

IRSR Issues: USFIC5

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Advective transport via saturated flow in fractures (secondary FEP 2.2.07.12.15) is evaluated in the TSPA as the primary mode of contaminant transport from the potential repository to the receptor. The SZFT model simulates flow in a saturated system with the hydrologic properties based on the hydrogeologic framework model developed by the USGS (2000) (includes secondary FEPs 2.2.07.12.01 – 2.2.07.12.06, 2.2.07.12.08 and 2.2.07.12.10 – 2.2.07.12.12). The uncertainty in the flow path due to uncertainties in the distribution and magnitude of hydraulic properties and uncertainties in the water table elevation due to the effects of climate change (TBV 4924) are included using distributions to represent uncertain hydrologic parameter values (see FEP 1.3.07.02.00, includes 2.2.07.12.10 and 2.2.07.12.14). The TSPA-SR models assume steady-state saturated flow that obeys Darcy's Law (i.e., non turbulent flow, which implicitly excludes the secondary FEP 2.2.07.12.13)). This is a reasonable approximation for evaluating the long-term (10,000 year), large-scale (20 kilometer) flow and transport system, particularly since the uncertainty in the average flow and transport velocities is evaluated in TSPA-SR and the effects of turbulence are included implicitly in the dispersion parameter. 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 (secondary FEP 2.2.07.12.07). Parameters influencing groundwater flow include recharge, permeability, temperature, horizontal anisotropy, specific discharge and porosity (CRWMS M&O 2000c (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)). Of these parameters, horizontal anisotropy and groundwater specific discharge, are varied stochastically; while recharge, permeability and temperature are set deterministically.

Treatment of Secondary FEPs:

The following secondary FEPs are redundant with the primary FEP, therefore subsumed in the primary FEP, and are included as described in *TSPA Disposition*:

2.2.07.12.01 Groundwater flow (in geosphere)
2.2.07.12.02 Groundwater flow in LPD
2.2.07.12.03 Groundwater flow path
2.2.07.12.04 Groundwater flow in MWCF
2.2.07.12.05 Groundwater flow path (in geosphere)
2.2.07.12.06 Groundwater flow (in geosphere)
2.2.07.12.08 Groundwater flow path (in geosphere)
2.2.07.12.10 Groundwater flow (in geosphere)

2.2.07.12.11 Groundwater flow (in geosphere)
2.2.07.12.12 Hydrological (processes)

Two of the secondary FEPs, Boundary conditions for flow (2.2.07.12.07) and Enhanced groundwater flow (2.2.07.12.15) represent specific components of the primary FEP and are included as described in *TSPA Disposition.* The secondary FEPs, Hydraulic gradient changes (magnitude, regional direction) (2.2.07.12.09), Turbulence (in groundwater) (2.2.07.12.13) and Changes in groundwater flow (2.2.07.12.14) are special cases of the primary FEP and are subsumed in the primary FEP. These special-case FEPs are included explicitly (2.2.07.12.09 and 2.2.07.12.14) and implicitly (2.2.07.12.13) as described in *TSPA Disposition.*

6.2.20 Water-Conducting Features (2.2.07.13.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.02.01.00, 1.2.02.02.00, 2.2.03.01.00, 2.2.03.02.00, 2.2.12.00.00.

IRSR Issues: USFIC5, SDS3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

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 2000n (*Probability Distribution for Flowing Interval Spacing*)). In the TSPA-SR models, retardation of contaminant transport in the flowing interval occurs by contaminant diffusion out of the flowing intervals into the matrix pores, with sorption on the matrix (CRWMS M&O 2000c (*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, flowing interval porosity, and permeability. Parameters influencing the simulated transport through the flowing intervals 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, flowing interval porosity, dispersivity, colloid concentration, colloid retardation, effective diffusion coefficient, solute sorption and sorption for the colloid facilitated transport model, is evaluated using Monte Carlo simulation (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*) and CRWMS M&O 2000c (*Input and Results of Base Case Saturated Zone Flow and Transport Model for TSPA*)). The 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 1999 (*Recharge and Lateral Groundwater Flow Boundary Conditions for the Saturated Zone Site-Scale Flow and Transport Model*)). 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 (CRWMS M&O 2000l (*Calibration of the Site-Scale Saturated Zone Flow Model*).

Treatment of Secondary FEPs:

The secondary FEP, Water-conducting features (types) (in geosphere) (2.2.07.13.01), is redundant with the primary FEP. Therefore it is included as described in *TSPA Disposition*.

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

FEP Description:	Spatial variation in groundwater density may affect groundwater flow.
Screening Decision and Regulatory Basis:	Excluded – Low consequence
Related Primary FEPs:	2.2.08.02.00, 2.2.10.13.00.
IRSR Issues:	USFIC5

Screening Argument:

The primary FEP is based on the assertion that a contaminant plume reaches the water table with the signature of the potential 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 and that density gradients could drive flow.

The potential effects of density contrasts, due to thermal conditions, on SZ flow are included in the TSPA-SR models (see FEP number 2.2.10.13.00). However, the construction of the TSPA-SR models is such that there are no significant effects of density on the simulated concentration of contaminants in groundwater. The TSPA-SR models calculate 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 (including the secondary FEP (2.2.07.14.02) related to salinity caused 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. It may not be appropriate to exclude this FEP if comparing the performance to a concentration based standard (see *Supplemental Discussion*).

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEP, Salinity effects on flow (2.2.07.14.02), is redundant with the primary FEP, therefore it is excluded based on low consequence as described in the *Screening Argument.* The remaining secondary FEPs , Saline intrusion (in geosphere) (2.2.07.14.01) and Intrusion of saline groundwater (2.2.07.14.03) are specific to other Performance Assessments and are not evaluated further in this analysis. The salinity effects that are potentially important to the Yucca Mountain PA are captured in the primary FEP description.

Supplemental Discussion

Supplemental Text for Screening Argument: The TSPA approach to dose modeling is predicated on the use of a prescribed volume of water. As long as that prescribed volume of water is defensible and consistent with regulations (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.

6.2.22 Advection and Dispersion (2.2.07.15.00)

FEP Description:	Advection and dispersion processes may affect contaminant transport in the saturated zone.
Screening Decision and Regulatory Basis:	Included

Related Primary FEPs: 2.2.07.12.00, 2.2.07.16.00, 2.2.07.17.00, 2.2.08.02.00, 2.2.08.08.00, 2.2.08.10.00.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

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 (includes secondary FEPs 2.2.07.15.01 - 2.2.07.15.05, 2.2.07.15.07 - 2.2.07.15.11). Diffusion out of the fracture system into the porous matrix and equilibrium sorption within the matrix system is also simulated using a particle tracking scheme (CRWMS M&O 2000o (*Saturated Zone Transport Methodology and Transport Component Integration*)). A semi-analytical solution to the diffusion equation is implemented in the FEHM code (CRWMS M&O 2000p (*Type Curve Calculations for 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 due to the uncertainties in hydraulic conductivity and recharge are treated explicitly using 3 separate flux simulations (low, medium and high cases). The values of flux for the three simulations are based on the results of an expert elicitation (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*), CRWMS M&O 1998 (*Saturated Zone Flow and Transport Expert Elicitation Project*)). 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 2000h (*Uncertainty Distribution for Stochastic Parameters*)).

Treatment of Secondary FEPs:

The following secondary FEPs represent one or more components of the primary FEP and are subsumed in the primary FEP:

2.2.07.15.01 Far-field transport: Advection
2.2.07.15.02 Far-field transport: Hydrodynamic dispersion
2.2.07.15.03 Dispersion (water transport)
2.2.07.15.04 Solute transport (water transport)
2.2.07.15.05 Advection (water transport)
2.2.07.15.07 Dispersion (water transport)
2.2.07.15.08 Convection (water transport)

2.2.07.15.09 Dispersion (water transport)
2.2.07.15.10 Dispersion (water transport)
2.2.07.15.11 Dispersion (water transport)

Since these FEPs are subsumed in the primary FEP, they are included as described in *TSPA Disposition.* The remaining secondary FEPs, Convection (water transport) (2.2.07.15.06), Transport and release of nuclides, near-field rock (2.2.07.15.12), Groundwater flow (alluvium of Rhine valley) (2.2.07.15.13) and Exfiltration to a local aquifer (2.2.07.15.14), apply to conditions outside the scope of this analysis (i.e., they pertain to the NFE and other PAs) and are not analyzed further in this analysis.

6.2.23 Dilution of Radionuclides in Groundwater (2.2.07.16.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.4.07.02.00, 2.2.07.12.00, 2.2.07.15.00.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Dilution as a result of pumping is implicitly 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 proposed, hypothetical community are then calculated using a mixing cell model (64 FR 8640, part 63.115; CRWMS M&O 2000m (*Groundwater Usage by the Proposed Farming Community*); and CRWMS M&O 2000j, (*Biosphere Process Model Report*).

Treatment of Secondary FEPs:

The secondary FEPs, Dilution (water transport) (2.2.07.16.01), Dilution of radionuclides in groundwater (water transport) (2.2.07.16.02) and Dilution of radionuclides in HPD (2.2.07.16.03) pertain to dilution as a result of dispersion. These secondary FEPs represent a special case that is subsumed in the primary FEP. Dispersion is included in the SZ transport models (see FEP 2.2.07.15.00).

6.2.24 Diffusion (2.2.07.17.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 2.2.08.08.00

IRSR Issues: USFIC6, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Diffusion is included in the SZ transport model (CRWMS M&O 2000c (*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 (includes secondary FEPs 2.2.07.17.01, 2.2.07.17.04 and 2.2.07.17.05). The diffusion coefficient is also used in the calculation of the dispersivity term (CRWMS M&O 2000c (*Input and Results of the Base Case Saturated Zone Flow and Transport Model for TSPA*))(includes secondary FEP 2.2.07.17.02). 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.

Treatment of Secondary FEPs:

The secondary FEPs, Far-field transport: diffusion (2.2.07.17.01), Diffusion (water transport) (2.2.07.17.04) and Diffusion (water transport) (2.2.07.17.05) are redundant with the primary FEP, therefore they are included as described in *TSPA Disposition*. The secondary FEP, Diffusion (water transport) (2.2.07.17.02), pertains to the diffusive component of dispersion and is also included as described in *TSPA Disposition*. The remaining secondary FEP, Diffusion (water transport) (2.2.07.17.03), is specific to the NFE and is not evaluated in this analysis.

6.2.25 Groundwater Chemistry/Composition in UZ and SZ (2.2.08.01.00)

FEP Description: 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.

Screening Decision and Regulatory Basis:	Included
Related Primary FEPs:	1.2.09.02.00, 2.2.03.02.00, 2.2.08.02.00, 2.2.08.03.00, 2.2.08.06.00, 2.2.08.07.00, 2.2.08.09.00, 2.2.09.01.00, 2.2.10.06.00, 3.2.07.01.00.
IRSR Issues:	USFIC4, USFIC5

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

The spatial variability and uncertainty in the groundwater composition and its effect on contaminant transport are modeled in the K_d value for each element as a function of rock type, effective diffusion coefficient, and the colloid-facilitated transport process model (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters)*) (includes secondary FEPs 2.2.08.01.01, 2.2.08.01.03, 2.2.08.01.05, 2.2.08.01.11, 2.2.08.01.19 2.2.08.01.21, 2.2.08.01.22 and 2.2.08.01.23). Potential changes in the geochemical conditions along the transport pathway, through the saturated zone, that would reduce contaminant solubility or lead to isotopic dilution (e.g., increased salinity, changes in Eh, changes in pH) are included conservatively by not taking credit for precipitation of contaminants out of solution or isotopic dilution (see FEPs 2.2.08.02.00 and 3.1.07.01.00; includes secondary FEPs 2.2.08.01.02, 2.2.08.01.06, 2.2.08.01.08, 2.2.08.01.09, 2.2.08.01.10, 2.2.08.01.12, and 2.2.08.01.14 - 2.2.08.01.18). The uncertainty in K_d values is based on a combination of laboratory experiments and expert judgement on the effects of rock type, mineralogy, water chemistry, pH, reaction kinetics, competitive effects among sorbing constituents and the presence or absence of microbial activity (DTN: LA0003AM831341.001, see FEPs # 2.2.08.06.00, 2.2.08.09.00 and 2.2.09.01.00). The potential effects of lithology on the K_d value are implicitly included in a conservative fashion using a single distribution for each element, based on K_d values for the rock type with the lowest expected value (see FEP 2.2.08.09.00). Reversible colloidal transport, and the potential effects of variable geochemical conditions on that transport, are implicitly included in a similarly conservative fashion by selecting the K_c value based on conditions that tend to maximize the K_c value (see FEP 2.2.08.10.00).

Treatment of Secondary FEPs:

The following secondary FEPs represent specific components and special cases of the primary FEP that are subsumed in the primary FEP and are included in the SZFT models as described in *TSPA Disposition*:

2.2.08.01.01	Groundwater chemistry (in geosphere)
2.2.08.01.02	Deep saline water intrusion
2.2.08.01.03	Interface different waters (in geosphere)
2.2.08.01.05	Groundwater geochemistry (in geosphere)
2.2.08.01.06	Saline intrusion (in geosphere)
2.2.08.01.07	Freshwater intrusion (in geosphere)
2.2.08.01.08	Changes in groundwater Eh
2.2.08.01.09	Changes in groundwater pH
2.2.08.01.10	Oxidizing conditions
2.2.08.01.11	Groundwater composition
2.2.08.01.12	pH-deviations
2.2.08.01.14	Saline (or fresh) groundwater intrusion
2.2.08.01.15	Saline or freshwater intrusion
2.2.08.01.16	Effects at saline-freshwater interface
2.2.08.01.17	Chemical gradients
2.2.08.01.18	Non-radioactive solute plume in geosphere
2.2.08.01.19	Groundwater chemistry (in geosphere)
2.2.08.01.21	Groundwater conditions
2.2.08.01.22	Mineralogy (host rock)
2.2.08.01.23	Mineralogy (host rock)

The remaining secondary FEPs apply to the NFE (Water chemistry in near-field rock (2.2.08.01.04) and Change of groundwater chemistry in nearby rock (2.2.08.01.13)) or other Performance Assessments (Intrusion of saline groundwater (2.2.08.01.20)) and are not evaluated relative to the SZ.

6.2.26 Radionuclide Transport in a Carrier Plume (2.2.08.02.00)

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.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 2.2.08.03.00, 2.2.08.07.00, 3.2.07.01.00.

IRSR Issues: RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Radionuclide solute and colloid transport are modeled as occurring in a carrier plume (includes secondary FEP 2.2.08.02.02). 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, includes secondary FEPs 2.2.08.02.01 and 2.2.08.02.03).

Treatment of Secondary FEPs:

The secondary FEPs, Locally-saturated carrier plume forms (in geosphere) (2.2.08.02.01), Unsaturated carrier plume forms (in geosphere) (2.2.08.02.02) and Precipitation/dissolution (release/migration factors) (2.2.08.02.03), are special cases of the primary FEP and are subsumed in the primary FEP. Therefore they are included as described in *TSPA Disposition*.

6.2.27 Geochemical Interactions in the Geosphere (2.2.08.03.00)

FEP Description: 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.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.09.02.00, 2.2.08.01.00, 2.2.08.02.00, 2.2.08.06.00, 2.2.08.07.00, 2.2.09.01.00, 2.2.10.06.00, 3.2.07.01.00.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

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 2000h (*Uncertainty Distribution for Stochastic Parameters*)). The uncertainty in K_d values is based on a combination of laboratory experiments and expert judgement on the effects of rock type, mineralogy, water chemistry, pH, reaction kinetics, competitive effects among sorbing constituents and the presence or absence of microbial activity (DTN: LA0003AM831341.001, see FEPs # 2.2.08.06.00, 2.2.08.09.00 and 2.2.09.01.00). The potential effects of lithology on the K_d value are implicitly included in a conservative fashion using a single distribution for each element, based on K_d values for the rock type with the lowest expected value (see FEP 2.2.08.09.00) (includes secondary FEPs 2.2.08.03.03, 2.2.08.03.04, 2.2.08.03.06, 2.2.08.03.07, 2.2.08.03.08 and 2.2.08.03.17). Reversible colloidal transport, and the potential effects of variable geochemical conditions on that transport, are implicitly included in a similarly conservative fashion by selecting the K_c value based on conditions that tend to maximize the K_c value (see FEP 2.2.08.10.00).

Potential changes in the geochemical conditions along the transport pathway, through the saturated zone, that would reduce contaminant solubility (e.g., increased salinity, changes in Eh, changes in pH) are included conservatively by not taking credit for precipitation of contaminants out of solution (see FEP 2.2.08.02.00; includes secondary FEPs 2.2.08.03.09 - 2.2.08.03.16). Localized changes in fracture hydraulic properties due to changes in geochemical conditions (secondary FEPs 2.2.08.03.02 and 2.2.08.03.05) can be considered included within the parameter values that represent the effective hydraulic properties of the flowing intervals (see FEP 1.2.02.01.00). (Note: it would be equally valid to exclude these secondary FEPs because the localized effects on fracture hydraulic properties will not have a significant effect on the simulated flow and transport due to the uncertainty incorporated in the SZFT model and the scale over which those parameter values apply (500 m square); however since the bulk of this FEP is included, these secondary FEPs are considered included in this analysis).

Treatment of Secondary FEPs:

The following secondary FEPs represent specific components of the primary FEP and are subsumed in the description of the primary FEP:

2.2.08.03.01	Far-field transport: Changes in groundwater chemistry and flow direction
2.2.08.03.02	Effects of dissolution (in geosphere)
2.2.08.03.03	Rock property changes (in geosphere)
2.2.08.03.04	Hydraulic properties-evolution
2.2.08.03.05	Dissolution of fracture fillings/precipitations (in geosphere)
2.2.08.03.06	Weathering of flow paths (in geosphere)
2.2.08.03.07	Fracture mineralization and weathering (in geosphere)
2.2.08.03.08	Alteration/weathering of flow paths
2.2.08.03.09	Precipitation and dissolution (release/migration factors)
2.2.08.03.10	Chemical precipitation (release/migration factors)

2.2.08.03.11	Dissolution, precipitation and crystallization (release/migration factors)
2.2.08.03.12	Kinetics of precipitation and dissolution (release/migration factors)
2.2.08.03.13	Speciation (contaminant speciation and solubility)
2.2.08.03.14	Speciation (geosphere) (contaminant speciation and solubility)
2.2.08.03.15	Recrystallization (contaminant speciation and solubility)
2.2.08.03.16	Speciation (contaminant speciation and solubility)
2.2.08.03.17	Kinetics of speciation (contaminant speciation and solubility)
2.2.08.03.18	Groundwater chemistry (sorption/desorption processes)

These secondary FEPs are included as described in *TSPA Disposition*.

6.2.28 Complexation in the Geosphere (2.2.08.06.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.09.02.00, 2.2.08.01.00, 2.2.08.02.00, 2.2.08.03.00, 2.2.08.07.00, 2.2.09.01.00, 2.2.10.06.00, 3.2.07.01.00.

IRSR Issues: RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

The effects of complexation agents in the existing groundwater system are included implicitly in the distribution for the K_d value for each element (see FEP 2.2.08.09.00), because the uncertainty in K_d values is based on a combination of laboratory experiments and expert judgement on the effects of rock type, mineralogy, water chemistry, pH, reaction kinetics, competitive effects among sorbing constituents and the presence or absence of microbial activity. (DTN: LA0003AM831341.001, CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)).

Treatment of Secondary FEPs:

There are no secondary FEPs for this primary FEP.

6.2.29 Radionuclide Solubility Limits in the Geosphere (2.2.08.07.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 2.2.08.01.00, 2.2.08.02.00, 2.2.08.03.00, 2.2.08.10.00, 2.1.09.21.00, 3.2.07.01.00.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Solubility in the SZ is treated conservatively by transporting the contaminants in a carrier plume (See FEP 2.2.08.02.00) (CRWMS M&O 2000c (*Input and Results of the Base Case Saturated Zone Flow and Transport Model for TSPA*)).

Increasing element solubility in the saturated zone would not affect the dissolution of the radioactive waste (in the unsaturated zone) and would lead to isotopic dilution (FEP Number 3.2.07.01.00) 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. The transport of particles is conservatively modeled using the colloid transport model. As a result, increased solubility in the SZ, which would retard transport (since colloidal transport provides a faster path than solute transport), is included in a conservative fashion by not taking credit for the potential retardation effects (secondary FEPs 2.2.08.07.03 and 2.2.08.07.04).

Decreasing element solubility in the SZ would lead to precipitation and further retardation of contaminant transport or the formation of colloids. Colloidal transport including uncertainty in the parameters due to natural geochemical conditions is included in the SZFT model (see FEP 2.2.08.10.00), but no credit is taken for retardation as a result of precipitation (see FEP 2.2.08.02.00).

Treatment of Secondary FEPs:

There are two redundant, secondary FEPs with the same description, Solubility limits/colloid formation (2.2.08.07.03 and 2.2.08.07.04) that are subsumed in the primary FEP. These secondary FEPs are included in a conservative fashion as described in *TSPA Disposition*.

The remaining secondary FEPs, Radionuclide transport through LPD (water transport) (2.2.08.07.01) and Radionuclide transport through MWCF (water transport) (2.2.08.07.02), are specific to another PA and are not evaluated further.

6.2.30 Matrix Diffusion (2.2.08.08.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 2.2.07.17.00.

IRSR Issues: USFIC6, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Matrix diffusion is included in the SZ transport model (CRWMS M&O 2000c (*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 (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)). 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 2000p (*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, matrix porosity, groundwater specific discharge and effective diffusion coefficient. Monte Carlo analyses are used to evaluate the uncertainties in the flowing interval spacing, flowing interval porosity, effective diffusion coefficients, groundwater specific discharge and dispersivities (CRWMS M&O 2000n (*Probability Distribution for Flowing Interval Spacing*); CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)).

Treatment of Secondary FEPs:

The following secondary FEPs are redundant with the primary FEP and retained in the list for completeness:

2.2.08.08.01	Matrix diffusion (water transport)
2.2.08.08.02	Matrix diffusion (water transport)
2.2.08.08.03	Matrix diffusion (water transport)
2.2.08.08.04	Matrix diffusion (water transport)
2.2.08.08.05	Matrix diffusion (water transport)
2.2.08.08.06	Matrix diffusion (water transport)
2.2.08.08.07	Matrix diffusion (water transport)
2.2.08.08.08	Matrix diffusion.

Matrix diffusion is included as described in *TSPA Disposition.*

6.2.31 Sorption in the UZ and SZ (2.2.08.09.00)

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.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.04.02.00, 2.2.03.01.00, 2.2.08.02.00, 2.2.08.03.00, 2.2.08.08.00, 2.2.08.10.00, 2.2.10.08.00, 2.3.02.02.00.

IRSR Issues: RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

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 which accounts for the potential effects of variability in rock properties and geochemical conditions (includes secondary FEPs 2.2.08.09.01, 2.2.08.09.02, 2.2.08.09.10 - 2.2.08.09.12, 2.2.08.09.14, 2.2.08.09.16 - 2.2.08.09.19 and 2.2.08.09.21). Sorption is modeled for contaminants that diffuse into the matrix, but no credit is taken for sorption of solutes in the flowing intervals as a retardation factor of 1 is used in the SZFT site-scale model input deck (DTN: SN0004T0501600.005). This conservative treatment of sorption eliminates the need to model the sorption kinetics, track the number of sorption sites available (2.2.08.09.09) or evaluate the potential effects of non-linear sorption on fracture surfaces. The distributions used to represent the uncertainty in the K_d values, account for the geochemical conditions, kinetics (secondary FEP 2.2.08.09.20) and potential non-linearity of the isotherms (secondary FEPs 2.2.08.09.08, 2.2.08.09.013, 2.2.08.09.15 and 2.2.08.09.22) (DTN: LA0003AM831341.001, CRWMS M&O 2000k (*Unsaturated Zone and Saturated Zone Transport Properties (U0100)*)). Changes in sorption properties along the transport path due to heterogeneity in rock properties and geochemical conditions and the uncertainty in those sorption properties (secondary FEPs 2.2.08.09.01 - 2.2.08.09.03) are implicitly included in the SZFT model (see FEPs 2.2.03.01.00, 2.2.03.02.00 and 2.2.08.01.00).

Transport of contaminants that are irreversibly sorbed on colloids is evaluated using a source concentration and colloid retardation coefficient (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)). Transport of contaminants that are reversibly sorbed on colloids (secondary FEP 2.2.08.09.07) is included by assuming equilibrium partitioning between the colloidal and aqueous phases, using a partitioning coefficient and a K_d for the aqueous phase in the matrix (see FEP 2.2.08.10.00).

Treatment of Secondary FEPs:

The following secondary FEPs are special cases of the primary FEP and are subsumed in the primary FEP:

2.2.08.09.01 Far-field transport: Sorption including ion-exchange
2.2.08.09.02 Far-field transport: Changes in sorptive surfaces
2.2.08.09.03 Anion-exclusion General: (in geosphere)
2.2.08.09.07 Sorption (reversible and irreversible)
2.2.08.09.08 Sorption - nonlinear
2.2.08.09.09 Saturation (of sorption sites)
2.2.08.09.10 Sorption (geosphere)
2.2.08.09.11 Sorption
2.2.08.09.12 Sorption
2.2.08.09.13 Nonlinear sorption
2.2.08.09.14 Sorption
2.2.08.09.15 Nonlinear sorption
2.2.08.09.16 Sorption
2.2.08.09.17 Radionuclide sorption
2.2.08.09.18 Sorption
2.2.08.09.19 Actinide sorption
2.2.08.09.20 Kinetics of sorption
2.2.08.09.21 Changes in sorptive surfaces
2.2.08.09.22 Sorption - nonlinear (geosphere)

These secondary FEPs are included as indicated in *TSPA Disposition*.

Three other secondary FEPs, Soil pore water pH (2.2.08.09.04), Soil sorption (2.2.08.09.05) and Ion exchange in soil (2.2.08.09.06) pertain to conditions near the ground surface (UZ and Biosphere) and are not evaluated relative to the SZ.

6.2.32 Colloid Transport in the Geosphere (2.2.08.10.00)

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.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 2.1.09.21.00, 2.2.08.09.00, 2.2.09.01.00.

IRSR Issues: RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Colloid transport is included explicitly in the SZFT model as an abstraction of the colloid process model (CRWMS M&O 2000q (*Saturated Zone Colloid-Facilitated Transport*)). The process model is used to justify the range and probability distribution for the colloid parameter values used in the SZFT model (See the *Supplemental Discussion* for more details on the colloid transport model).

Treatment of Secondary FEPs:

The secondary FEPs, Far-field transport: Transport of radionuclides bound to microbes (2.2.08.10.01), Colloid transport occurs in a carrier plume (in geosphere) (2.2.08.10.02) and Colloids (in geosphere) (2.2.08.10.03), are special cases of the primary FEP and are subsumed in the primary FEP. The three secondary FEPs are included as described in the *Supplemental Discussion*.

Supplemental Discussion

Supplemental Text for TSPA Disposition: 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 (includes secondary FEP 2.2.08.10.03). Retardation is by chemical filtration in the alluvium and volcanic strata. Retardation in the volcanic strata was estimated by field and laboratory tests, and in the alluvium retardation was estimated by filtration theory and evaluation of field test data (CRWMS M&O 2000q (*Saturated Zone Colloid-Facilitated Transport*)). 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 (includes secondary FEP 2.2.08.10.02). 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 simulated 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 (secondary FEP 2.2.08.10.01). Thus, if the source term included microbial colloids, they would be included in the SZFT model (see FEP 2.2.09.01.00).

6.2.33 Distribution and Release Of Nuclides (2.2.08.11.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.4.07.02.00, 2.3.11.04.00.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

The release of nuclides is included in the biosphere model based on regulatory guidance for the proposed rule (64 FR 8640) (CRWMS M&O 2000j (*Biosphere Process Model Report*)). 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.

Treatment of Secondary FEPs:

The secondary FEP, Transport and geochemical (processes) (2.2.08.11.01) is redundant with the primary FEP, therefore it is included as described in *TSPA Dispostion.*

6.2.34 Microbial activity in Geosphere (2.2.09.01.00)

FEP Description:	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.
Screening Decision and Regulatory Basis:	Included
Related Primary FEPs:	1.2.09.02.00, 2.2.08.01.00, 2.2.08.02.00, 2.2.08.03.00, 2.2.08.06.00, 2.2.08.07.00, 2.2.10.06.00, 3.2.07.01.00.
IRSR Issues:	USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

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 parameters (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)). The distributions used to represent the uncertainty in the K_d and colloid parameter values are based on conditions in the natural system including consideration of the effects of the presence and absence of naturally occuring microbial activity (DTN: LA0003AM831341.001 and CRWMS M&O 2000q (*Saturated Zone Colloid-Facilitated Transport*)) (includes secondary FEPs 2.2.09.01.01 - 2.2.09.01.03).

Microbial activity as a result of waste emplacement activities has been excluded based on low consequence (CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport*)).

Treatment of Secondary FEPs:

The secondary FEPs, Microbes (in geosphere) (2.2.09.01.01), Microbes (in geosphere) (2.2.09.01.02) and Microbial activity (in geosphere) (2.2.09.01.03) are redundant with the primary FEP; therefore they are included as described in *TSPA Disposition*:

The remaining secondary FEPs, Far-field transport: Biogeochemical changes (2.2.09.01.04), Bacteria and microbes in soil (2.2.09.01.05) and Chemical transformations (biological processes) (2.2.09.01.06), apply to the UZ and are not evaluated further in this analysis.

6.2.35 Repository Induced Thermal Effects in the Geosphere (2.2.10.01.00)

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

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 2.2.10.13.00

IRSR Issues: USFIC5

Screening Argument:

The effects of thermal loading due to the potential repository and hydrologic response are evaluated in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport, see:* FEP 2.2.07.10.00). That analysis indicates that the significant thermo-chemical effects are limited to the near-field environment (includes all the secondary FEPs) and that they will not have a significant effect on contaminant transport or the expected annual dose. As a result the thermal effects in the SZ, due to the potential repository, can be excluded due to low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The following secondary FEPs are specific, potential effects of the primary FEP and are subsumed in the primary FEP:

2.2.10.01.01	Temperature, far-field
2.2.10.01.02	Temperature, near-field rock
2.2.10.01.03	Thermal effects on groundwater flow
2.2.10.01.04	Groundwater - evolution
2.2.10.01.05	Thermal effects on material properties (in waste and EBS)
2.2.10.01.06	Thermal effects: Rock-mass changes
2.2.10.01.07	Thermal effects: Hydrogeological changes

As described in the *Screening Argument,* none of the secondary FEPs will have a significant effect on the SZ and they can be excluded due to low consequence.

6.2.36 Thermal Convection Cell Develops in SZ (2.2.10.02.00)

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

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 2.2.10.01.00

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

This FEP indicates that a thermal convection cell develops in the saturated zone beneath the potential 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 loading due to the potential repository and hydrologic response are evaluated in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport, see:* FEP 2.2.10.01.00). That analysis indicates that the significant thermo-chemical effects are limited to the near-field environment and that thermal loading will not have a significant effect on contaminant transport or the expected annual dose. As a result the thermal effects in the SZ, due to the potential repository, can be excluded due to low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

There are no secondary FEPs.

6.2.37 Natural Geothermal Effects (2.2.10.03.00)

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

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: No closely related FEPs.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

The geothermal gradient is explicitly included in the 3-D SZFT model (CRWMS M&O 2000l). The geothermal gradient is represented in the model using fixed thermal conditions with a linear, vertical temperature gradient of 25 K/km.

Treatment of Secondary FEPs:

The secondary FEPS, Natural thermal effects (in geosphere) (2.2.10.03.01), Geothermal regime (2.2.10.03.02), Geothermal regime (2.2.10.03.03) and Geothermal gradient effects (2.2.10.03.04), are redundant with the primary FEP; therefore they are included as described in *TSPA Disposition.*

6.2.38 Thermo-chemical Alteration (2.2.10.06.00)

FEP Description: Thermal and chemical processes related to the emplacement of waste in the potential repository may alter the hydrologic properties of the saturated zone. Precipitation of zeolites, silica, or calcite is a relevant process.

Screening Decision

and Regulatory Basis: Excluded – low consequence

Related Primary FEPs: 1.2.09.02.00, 2.2.08.01.00, 2.2.08.02.00, 2.2.08.03.00, 2.2.08.06.00, 2.2.08.07.00, 2.2.09.01.00, 2.2.10.02.000. 3.2.07.01.00.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

The effects of thermal loading due to the potential repository and hydrologic response are evaluated in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport,* see FEP 2.2.07.10.00). That analysis indicates that the significant thermo-chemical effects are limited to the near-field environment and that they will not have a significant effect on contaminant transport or the expected annual dose (includes all of the secondary FEPs). As a result the thermal effects due to the potential repository can be excluded due to low consequence.

However, it should be noted that this FEP could also be classified as included as presented under TSPA Disposition.

TSPA Disposition:

Given the uncertainties evaluated in the SZFT model, this FEP and the related FEPs can also be considered included. The uncertainty in geochemical conditions and the effects on contaminant transport are modeled implicitly through the uncertainty in the K_d value for each element, effective diffusion coefficient, and the colloid-facilitated transport process model parameter values (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)) (includes secondary FEP 2.2.10.06.02). The potential effects of lithology, including zeolitic tuffs, on the K_d value are implicitly included in a conservative fashion using a single distribution for each element, based on values for the rock type with the lowest expected value (see FEP 2.2.08.09.00, includes secondary FEPs 2.2.10.06.03 and 2.2.10.06.05). Reversible colloidal transport, and the potential effects of variable geochemical conditions on that transport, are implicitly included in a similarly conservative fashion by selecting the K_c value based on conditions that tend to maximize the K_c value (see FEP 2.2.08.10.00). The uncertainty in the flowing interval porosity and the specific discharge would more than account for the uncertainties due to clogging of pores and precipitating or dissolving calcite (includes secondary FEPs 2.2.10.06.06 and 2.2.10.06.07.

Treatment of Secondary FEPs:

The following secondary FEPS represent special cases of the primary FEP and are subsumed in the primary FEP:

2.2.10.06.01	Silica phase changes (accompanied by volume change) occur due to elevated temperature
2.2.10.06.02	Thermochemical change

2.2.10.06.03	Alteration of rock properties because of 2-phase flow
2.2.10.06.04	Heat-induced chemical reactions plug small fractures; flow is preferentially redirected to large fractures
2.2.10.06.05	Alteration of minerals to clays (in geosphere)
2.2.10.06.06	Calcite precipitation in hot region produces fluids depleted in calcite which dissolve calcite below the potential repository
2.2.10.06.07	Precipitates from dissolved constituents of tuff and potential repository materials form by evaporation during thermal period

All of these secondary FEPS relate to the NFE or the UZ and are not evaluated further in this analysis. The secondary FEPs were analyzed in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport.* That analysis indicates that the significant thermo-chemical effects are limited to the near-field environment and that those effects will not have a significant effect on flow and transport in the UZ. Therefore all of the secondary FEPs can be excluded based on low consequence. However, some of the secondary FEPs, 2.2.10.06.02, 2.2.10.06.03, 2.2.10.06.05, 2.2.10.06.06 and 2.2.10.06.07, can be considered included as discussed in *TSPA Disposition.*

6.2.39 Thermo-chemical Alteration of the Calico Hills unit (2.2.10.07.00)

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

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 2.2.10.01.00

IRSR Issues: USFIC4, USFIC6, RT1, RT2, RT3

Screening Argument:

The effects of thermal loading due to the potential repository and hydrologic response are evaluated in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport,* see: FEP 2.2.07.10.00). That analysis indicates that the significant thermo-chemical effects are limited to the near-field environment and that they will not have a significant effect on contaminant transport or the expected annual dose. As a result the thermal effects due to the potential repository can be excluded due to low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

There are no secondary FEPs.

6.2.40 Thermo-chemical Alteration of the Saturated Zone (precipitation plugs primary porosity) (2.2.10.08.00)

FEP Description: Thermal and chemical processes related to the emplacement of waste in the potential repository may alter the hydrologic properties of the saturated zone. Precipitation of zeolites, silica, or calcite are relevant processes.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 2.2.10.06.00

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

The effects of thermal loading due to the potential repository and hydrologic response are evaluated in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport,* see: FEP 2.2.07.10.00). That analysis indicates that the significant thermo-chemical effects are limited to the near-field environment and that they will not have a significant effect on contaminant transport or the expected annual dose (includes the secondary FEP). As a result the thermal effects due to the potential repository can be excluded due to low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEP, Precipitation of zeolites in the saturated zone plugs pores (2.2.10.08.01), is a special case of the primary FEP and is subsumed in the primary FEP. It is excluded based on low consequence as described in the *Screening Argument*.

6.2.41 Density-driven Groundwater Flow (thermal) (2.2.10.13.00)

FEP Description: 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.

Screening Decision and Regulatory Basis:

Included (geothermal)

Excluded (repository) – Low consequence

Related Primary FEPs: 2.2.10.01.00

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

The effects of thermal loading (secondary FEP 2.2.10.13.01) due to the potential repository and hydrologic response are evaluated in CRWMS M&O 2000e (*Features, Events, and Processes in UZ Flow and Transport,* see: FEP 2.2.07.10.00). That analysis indicates that the significant thermo-chemical effects are limited to the near-field environment and that they will not have a significant effect on contaminant transport or the expected annual dose. As a result the thermal effects due to the potential repository can be excluded due to low consequence.

The effects of the natural geothermal gradient are included in the SZFT model (see FEP 2.2.10.03.00, includes secondary FEPs 2.2.10.13.01 and 2.2.10.13.02). Changes in the thermal gradients due to hydrothermal activity are excluded based on low consequence due to the localized nature of those effects (see FEPs 1.2.06.00.00 and 1.2.10.02.00, includes secondary FEP 2.2.10.13.03)).

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEPs, Density-driven groundwater flow (thermal) (2.2.10.13.01), Density-driven groundwater flows (temperature/salinity differences) (2.2.10.13.02) and Thermal buoyancy (2.2.10.13.03), represent specific components of the primary FEP and are subsumed in the primary FEP:

The secondary FEPs that apply to the geothermal gradient are included (2.2.10.13.01 and 2.2.10.13.02). The components that apply to repository-induced thermal loading or hydrothermal activity are excluded based on low consequence (2.2.10.13.03).

6.2.42 Naturally Occurring Gases in the Geosphere (2.2.11.01.00)

FEP Description: Naturally occurring gases in the geosphere may intrude into the potential 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.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: No closely related FEPs.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

There is no evidence of large-scale gas buildup in, or flow of gas through, the SZ (includes all the secondary FEPs). There are no known oil or gas fields in the vicinity of Yucca Mountain. While the elements required for a viable petroleum system are present in the Yucca Mountain region, they are unlikely to have accumulated at the potential repository site because the rocks are highly fractured. Quantification of the probability of gas build-up might provide justification for exclusion, however it would not be a trivial task and it is not necessary because the effects can be excluded based on low consequence.

In the unlikely event that gas-generating processes occur in the sedimentary rocks below the tuffs, the influence on the flow and transport pathways would tend to be highly localized. Given the coarse grid used in the flow model, and the uncertainty in the flow and transport pathways incorporated in the model, undetected localized processes or features that divert flow would either be too small in scale to impact the simulations or would be accounted for in the heterogeneity and parameter uncertainties in the SZFT model. As a result, it would not have a significant effect on the effective model parameter values and therefore would not effect the expected annual dose. The potential effects of naturally occurring gases in the geosphere can be excluded from the SZFT model based on low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEPs, Methane intrusion (in geosphere) (2.2.11.01.01) and Methane (2.2.11.01.07), are specific cases of the more general primary FEP and are subsumed in the primary FEP. The remaining secondary FEPs (Natural gas intrusion (2.2.11.01.02), Geogas (2.2.11.01.03), Geogas (2.2.11.01.04), Gas generation and gas sources, far-field (2.2.11.01.05) and Natural gas intrusion (2.2.11.01.06)) are redundant with the primary FEP and can be excluded based on low consequence.

6.2.43 Undetected Features (2.2.12.00.00)

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 potential repository.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: 1.2.02.01.00, 1.2.02.02.00, 2.2.03.01.00, 2.2.03.02.00, 2.2.07.13.00.

IRSR Issues: USFIC5, RT1, RT2, RT3, SDS3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

The purpose of the FEPs process is to identify features that have the potential to negatively impact the site's performance. Undetected features are included in SZFT model in the parameter uncertainties that are evaluated in the Monte Carlo analyses and assumptions regarding parameter values (CRWMS M&O 2000h (*Uncertainty Distribution for Stochastic Parameters*)). In this analysis, and in the other FEP AMRs, potential (i.e., undetected) features are analyzed through a systematic process to define the potential feature and determine if its potential effects are significant. This document provides the basis for inclusion or exclusion of potential FEPs that might influence the SZ flow and transport processes. The issue of faulting is evaluated in FEP 1.2.02.02.00 (includes secondary FEPs 2.2.12.00.02, 2.2.12.00.03 and 2.2.12.00.04), geologic features are evaluated in FEPs 2.2.03.01.00 and 2.2.03.02.00 (includes secondary FEPs 2.2.12.00.01, 2.2.12.00.07 and 2.2.12.00.11), the effects of perched water are included in the UZFT models (see FEP 2.2.06.03.00 (includes secondary FEP 2.2.12.00.05)), fractures are evaluated in FEP 1.2.02.01.00 (included secondary FEP 2.2.12.00.08), and igneous intrusions are evaluated in FEP 1.2.04.02.00 (includes secondary FEP 2.2.12.00.10). The effects of uncertainty in recharge and the hydraulic gradient are included using bounding simulations (see FEP 2.2.07.15.00, includes secondary FEP 2.2.12.00.06).

Treatment of Secondary FEPs:

The secondary FEPS are special cases of the primary FEP and are subsumed in the primary FEP. The secondary FEPs are:

2.2.12.00.01	Undetected dike beneath the potential repository passing thru the Calico Hills provides a highly permeable flow path
2.2.12.00.02	Undetected fault dips below the potential repository providing a highly permeable flow path
2.2.12.00.03	Undetected fault beneath the potential repository acts as a flow barrier altering the flow system
2.2.12.00.04	Undetected fault connects tuff aquifers to carbonate aquifers; providing a fast path
2.2.12.00.05	Perched water escapes detection and waste is put in it
2.2.12.00.06	Undiscovered mine shaft (an old prospect hole) in a wash acts as a source for increased local infiltration
2.2.12.00.07	Rock properties-undetected features
2.2.12.00.08	Undetected fracture zone
2.2.12.00.10	Undetected past intrusions
2.2.12.00.11	Undetected discontinuities (in geosphere)

The secondary FEP, Undetected Features (2.2.12.00.09), is redundant with the primary FEP. All of the secondary FEPs are included in this analysis (see *TSPA Disposition* and relevant primary FEPs). Some of these secondary FEPs (2.2.12.00.01, 2.2.12.00.02, 2.2.12.00.03, 2.2.12.00.04, 2.2.13.00.06 and 2.2.12.00.10) can be excluded based on low consequence, because they would not be of sufficient magnitude relative to the scale of the flow model grid and/or they would not alter the uncertainty that is already incorporated into the SZFT models. Consequently those secondary FEPs would not alter the simulated flow and transport or expected annual dose. Secondary FEPs 2.2.12.00.07, 2.2.12.00.08 and 2.2.13.00.11 are included in the SZFT models through the uncertainty in the hydraulic properties. Secondary FEP 2.2.12.00.05 is included in the UZFT model.

6.2.44 Radionuclide Accumulation in Soils (2.3.02.02.00)

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).

Screening Decision and Regulatory Basis: Included (preliminary)

Related Primary FEPs: 1.2.04.07.00

IRSR Issues: USFIC5, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Since the discharge of contaminated groundwater occurs at the compliance point, the effects of radionuclide accumulation in soils on the expected annual dose are accounted for in the biosphere dose conversion factors implemented in the biosphere model (CRWMS M&O 2000j (*Biosphere Process Model Report*)). Radionuclide accumulation in soils due to sorption and leaching from the soil zone could significantly impact dose and are included in the biosphere model (includes secondary FEPs 2.3.02.02.03 – 2.3.02.02.06 and 2.3.02.02.09). The potential effects of leaching and redistribution of contaminants in the UZ and SZ should also be included in the TSPA analyses (see *Supplemental Discussion*). Sensitivity analyses of the dose conversion factor, that account for the effects of leaching and redistribution of radionuclides on the dose conversion factor, would provide the analyses necessary to determine if leaching to groundwater is a potentially significant process relative to the expected dose (includes secondary FEP 2.3.02.02.10). Therefore, it is assumed for this analysis that the potential effects of leaching of radionuclides and the effects of the redistribution of those radionuclides in the subsurface will be evaluated using sensitivity analyses of the dose conversion factors (TBV-4933).

Treatment of Secondary FEPs:

The secondary FEPs represent specific components of the primary FEP and are subsumed in the primary FEP. The secondary FEPs are:

2.3.02.02.01	Soil moisture and evaporation (water transport)
2.3.02.02.02	Radionuclide accumulation in sediments at Franklin Lake Playa (water transport)
2.3.02.02.03	Accumulation in sediments (sorption/desorption processes)
2.3.02.02.04	Accumulation in soils and organic debris (sorption/desorption processes)
2.3.02.02.05	Soil
2.3.02.02.06	Soil leaching
2.3.02.02.07	Accumulation in peat
2.3.02.02.08	Alkali flats (and other playa deposits)
2.3.02.02.09	Accumulation in soil (exposure factors)
2.3.02.02.10	Soil leaching to groundwater

The secondary FEPs (2.3.02.02.01 – 2.3.02.02.09) relate to processes influencing the accumulation of contaminants within the biosphere and are not evaluated further in this analysis. The secondary FEP 2.3.02.02.10 relates to the potential effects of leaching on contaminant concentrations in groundwater, and therefore may have an effect on the dose due to the groundwater pathway. The potential effects of secondary FEP 2.3.02.02.10 should be included in the sensitivity analyses of the dose conversion factors, as presented in the *Supplemental Discussion*.

Supplemental Discussion

Supplemental Text for TSPA Disposition:

Contaminants transported to the soil zone in irrigation water will be intentionally leached out of the root zone as part of standard agricultural practice. In arid environments, a period of watering in excess of the evapotranspiration demand is typically used to prevent the buildup of salts (due to evaporation and plant uptake of water) in the shallow soil of croplands. Salts are leached from the soil in the root zone of the crop to a region deeper in the vadose zone below the irrigated field (secondary FEP 2.3.02.02.06). If the water table is relatively shallow or the irrigation rate is high enough, this practice could result in transport of these salts (and any leached contaminants, such as radionuclides) into the groundwater of the saturated zone (secondary FEP 2.3.02.02.10). In the exposure scenario for the critical group used in TSPA-SR (CRWMS M&O 2000b), if this process occurs, it could lead to a build-up in radionuclides below the root zone in the unsaturated zone and recycling of radionuclides from the biosphere back to the saturated zone potentially increasing the contaminant concentration in groundwater. It is not clear how this process, particularly transport all the way to the water table, would effect the expected dose over the compliance period. Given existing practices, deep leaching will occur during the irrigation cycle and can not be excluded based on probability.

The hydrologic conditions in the area of the hypothetical farming community, coupled with economic constraints and their impact on current irrigation practices, indicate that transport back to the water table may not have a significant effect on the contaminant concentration in groundwater.

Sustainable agricultural requires maintenance of plant tolerable soil salinity, sufficient water for irrigation and sufficient profit. Current irrigation practices and climatic conditions, in the area of the hypothetical farming community, may limit the depth to which soil leaching would drive dissolved constituents in the vadose zone. The goal of leaching is to remove the evaporative salts from a relatively thin upper layer of the soil that corresponds to the rooting depth of the crop (approximately 15 cm; CRWMS M&O 2000r). Leaching and maintaining soil quality by adding amendments and fertilizers allows continued agricultural production on the same plot of land. Excessive irrigation, to the point of leaching of salts and contaminants to the depth of the water table (approximately 100 m depth in the area of the hypothetical farming community for TSPA-SR; LaPlante and Poor 1997, Figure 2-2), may be precluded by the costs associated with pumping of groundwater, the lack of any benefit to transporting salts to depths significantly below the root zone, sorption in the UZ and high evapotranspiration rates.

Tracer studies in similar arid environments, using irrigation on bare plots (i.e., no plant uptake of moisture or tracer), indicate the potential mean depths of contaminant transport are on the order of 2 meters after 126 days of irrigation and watering (Rice, et al. 1986). In those studies, the depth of the tracer pulse increased over time. The total depth of water (irrigation plus precipitation) applied, periodically, during the 126 days of monitoring was 409 mm. The depths of water applied in each event ranged from 100 mm in the initial irrigation/tracer application event, down to a 7 mm precipitation event 9 days after the tracer was applied. The implication of the tracer studies is that the periodic irrigation and precipitation events following the leaching event could be sufficient to slowly move the contaminants toward the water table. However, these data are for bare plots and do not account for the increased upward gradient that would be created due to plant uptake and transpiration. Therefore, it is not clear how the current irrigation practices will influence the distribution of contaminants in the subsurface and what effect that uncertainty has on the expected dose. A sensitivity analysis of the effect of the dose conversion factors, as a function of leaching, on the expected dose would provide the analysis necessary to bound the potential effects of this secondary FEP. The sensitivity analysis can be used to determine if it can be excluded based on consequence, included conservatively by setting the leaching rate to 0 or included in a more realistic fashion (e.g., account for sorption, dispersion and advection through the UZ to the SZ).

It should be noted that the potential effects due to changes in the existing conditions are excluded based on regulatory guidance, because this secondary FEP is a result of the behavior of the hypothetical farming community (see FEP 1.4.07.01.00).

6.2.45 Groundwater Discharge to Surface (2.3.11.04.00)

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.

Screening Decision and Regulatory Basis: Excluded – Low consequence

Related Primary FEPs: 1.4.07.02.00

IRSR Issues: USFIC5

Screening Argument:

For the present day climate, groundwater discharge from the flow system under Yucca Mountain occurs at Franklin Lake Playa and springs at Ash Meadows (D'Agnese et al. 1997, pp. 40-48), which is beyond the proposed 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-SR models, discharge to the biosphere occurs through hypothetical wells at the compliance point. Spring discharge beyond the compliance location (i.e., more than twenty kilometers from the potential repository location) will not have an effect on the expected annual dose and can be excluded based on low consequence.

TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

Treatment of Secondary FEPs:

The secondary FEPs, Discharge zones (2.3.11.04.01), Groundwater discharge (2.3.11.04.02) and Groundwater discharge (2.3.11.04.03), are redundant with the primary FEP. Therefore, all the secondary FEPs can be excluded based on low consequence as described in the *Screening Argument*.

6.2.46 Radioactive Decay and Ingrowth (3.1.01.01.00)

FEP Description: Radioactive decay of the fuel in the potential 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.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: No closely related FEPs

IRSR Issues: RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Radioactive decay is explicitly included in the convolution integral of the TSPA-SR models (CRWMS M&O 2000b, (*Total System Performance Assessment for the Site Recommendation*). The convolution integral is solved in a subroutine of the GOLDSIM computer code. Ingrowth is accounted for in two different ways in the TSPA-SR models. First, the initial inventory in the waste is adjusted to account for the radionuclide parents 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 2000c (*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.

Treatment of Secondary FEPs:

The secondary FEPs (listed below) are redundant with the primary FEP and are included in the SZ transport models as described in *TSPA Disposition*.

3.1.01.01.01	Radioactive decay
3.1.01.01.02	Radioactive decay
3.1.01.01.03	Radioactive decay
3.1.01.01.04	Radioactive decay and ingrowth
3.1.01.01.05	Radioactive decay
3.1.01.01.06	Radioactive decay
3.1.01.01.07	Radioactive decay of mobile nuclides
3.1.01.01.08	Radionuclide decay and ingrowth
3.1.01.01.09	Radiological events and processes

6.2.47 Isotopic Dilution (3.2.07.01.00)

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.

Screening Decision and Regulatory Basis: Included

Related Primary FEPs: No closely related FEPs.

IRSR Issues: USFIC5, RT1, RT2, RT3

Screening Argument:

Included in TSPA as described under TSPA Disposition.

TSPA Disposition:

Isotopic dilution in the SZ could occur if elements that are in the waste also occur naturally (secondary FEP 3.2.07.01.02). This process would dilute the concentration of radioactive contaminants (secondary FEP 3.2.07.01.01) and reduce the simulated dose. Isotopic dilution is included by conservatively assuming that there is no isotopic dilution in the SZ.

Treatment of Secondary FEPs:

The secondary FEPs, Mass, isotopic and species dilution (3.2.07.01.01) and Natural radionuclides/elements (in host rock disturbed zone) (3.2.07.01.02), represent components of the primary FEP and are, subsumed in the primary FEP. The secondary FEPs are included as described in *TSPA Disposition*.

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 26 FEPs that are included in the performance assessment 4 FEPs that are partially included and partially excluded based on low consequence, low probability or regulatory guidance and 17 FEPs that can be excluded from the TSPA-SR models based on low consequence or low probability (Section 6.2).

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 47 primary FEPs potentially impacting SZFT and the screening results for each of those FEPs are summarized in Table 7-1.

Two of the included FEPs in Table 7-1 (1.3.07.02.00 Water Table Rise and 2,3,02.02.00 Radionuclide Accumulation in Soils) are designated "preliminary" pending confirmation of their inclusion in TSPA (TBV 4923 and TBV 4933). This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the technical product input information quality may be confirmed by review of the DIRS database.

Table 7-1. Screening Results for SZ Primary FEPs

YMP FEP Database ID#	FEP Description	TSPA Screening Decision
1.2.02.01.00	Fractures	Included (existing), Excluded (changes) –low consequence
1.2.02.02.00	Faulting	Included (existing), Excluded (changes in existing) – low consequence, Excluded (new) – low probability
1.2.03.01.00	Seismic Activity	Excluded – low consequence
1.2.04.02.00	Igneous Activity Causes Changes to Rock Properties	Excluded – low consequence
1.2.04.07.00	Ashfall	Excluded – low consequence
1.2.06.00.00	Hydrothermal Activity	Excluded – low consequence
1.2.09.02.00	Large-Scale Dissolution	Excluded – low consequence
1.2.10.01.00	Hydrologic Response to Seismic Activity	Excluded (effects of new faults) - low probability Excluded (effects of existing faults) – low consequence

YMP FEP Database ID#	FEP Description	TSPA Screening Decision
1.2.10.02.00	Hydrologic Response to Igneous Activity	Excluded – low consequence
1.3.07.01.00	Drought/Water Table Decline	Excluded – low consequence
1.3.07.02.00	Water Table Rise	Included (preliminary)
1.4.07.01.00	Water Management Activities	Included (existing), Excluded (changes) – regulatory guidance
1.4.07.02.00	Wells	Included
2.1.09.21.00	Suspension of Particles Larger than Colloids	Included
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	Excluded – low consequence
2.2.06.03.00	Changes in Stress Alter Perched Water Zones	Included
2.2.07.12.00	Saturated Groundwater Flow	Included
2.2.07.13.00	Water-Conducting Features in the Saturated Zone	Included
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	Included
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	Excluded – low consequence
2.2.10.02.00	Thermal Convection Cell Develops in SZ	Excluded – low consequence
2.2.10.03.00	Natural Geothermal Effects	Included

YMP FEP Database ID#	FEP Description	TSPA Screening Decision
2.2.10.06.00	Thermo-Chemical Alteration	Excluded – low consequence
2.2.10.07.00	Thermo-Chemical Alteration of the Calico Hills Unit	Excluded – low consequence
2.2.10.08.00	Thermo-Chemical Alteration of the SZ	Excluded – low consequence
2.2.10.13.00	Density Driven Groundwater Flow (Thermal)	Included (geothermal), Excluded (repository) – low consequence
2.2.11.01.00	Naturally-Occurring Gases in the Geosphere	Excluded – low consequence
2.2.12.00.00	Undetected Features	Included
2.3.02.02.00	Radionuclide Accumulation in Soils	Included (preliminary)
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	Included

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8.3 DATA

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