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REV 00	Initial issue
REV 01	Revised to include consideration of the proposed U.S. Nuclear Regulatory Commission Regulations (Federal Register for February 22, 1999, 64 FR 8640)
REV 02	Revised to remove consideration of the proposed U.S. Nuclear Regulatory Commission Regulations (Federal Register for February 22, 1999, 64 FR 8640) and Dyer (1999) and limit consideration of FEP applicability to
REV 03	Revised to incorporate the current LA FEP List and to describe FEPs treatment in the current biosphere model. This is a complete re-write because changes were extensive

Addendum 1
final U.S. Nuclear Regulatory Commission Regulations (Federal REgister for November 2, 2001, 66 FR 55792) and to incorporate selected NRC/DOE agreement items

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ACRONYMS AND ABBREVIATIONS

A.P.	After Present
BDCF	biosphere dose conversion factor
DOE	U.S. Department of Energy
FEPs	features, events, and processes
KTI	Key Technical Issue
LA	license application
NRC	U.S. Nuclear Regulatory Commission
PRD	Project Requirements Document
RMEI	reasonably maximally exposed individual
SR	Site Recommendation
SME	subject matter expert
TSPA	total system performance assessment
TWP	technical work plan
YMP	Yucca Mountain Project
YMRP	Yucca Mountain Review Plan

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1. PURPOSE

The purpose of this report is to document the evaluation of biosphere features, events, and processes (FEPs) that relate to the license application (LA) process as required by the U.S. Nuclear Regulatory Commission (NRC) regulations at 10 CFR 63.114 (d, e, and f) [DIRS 156605]. The evaluation determines whether specific biosphere-related FEPs should be included or excluded from consideration in the Total System Performance Assessment (TSPA).

This analysis documents the technical basis for screening decisions as required at 10 CFR 63.114 (d, e, and f) [DIRS 156605]. For FEPs that are included in the TSPA, this analysis provides a TSPA disposition, which summarizes how the FEP has been included and addressed in the TSPA model, and cites the analysis reports and model reports that provide the technical basis and description of its disposition. For FEPs that are excluded from the TSPA, this analysis report provides a screening argument, which identifies the basis for the screening decision (i.e., low probability, low consequence, or by regulation) and discusses the technical basis that supports that decision. In cases, where a FEP covers multiple technical areas and is shared with other FEP analysis reports, this analysis may provide only a partial technical basis for the screening of the FEP. The full technical basis for these shared FEPs is addressed collectively by all FEP analysis reports that cover technical disciplines sharing a FEP.

FEPs must be included in the TSPA unless they can be excluded by low probability, low consequence, or regulation. A FEP can be excluded from the TSPA by low probability per 10 CFR 63.114(d) [DIRS 156605], by showing that it has less than one chance in 10,000 of occurring over 10,000 years (or an approximately equivalent annualized probability of 10^{-8}). A FEP can be excluded from the TSPA by low consequence per 10 CFR 63.114 (e or f) [DIRS 156605], by showing that omitting the FEP would not significantly change the magnitude and time of the resulting exposures to the reasonably maximally exposed individual (RMEI) or the radionuclide releases to the accessible environment. FEPs may also be excluded by regulation based on definitions, key concepts, or provisions specifically stated in the applicable NRC regulations.

This analysis report is one of the technical reports containing documentation of the Environmental Radiation Model for Yucca Mountain, Nevada (ERMYN), a biosphere model supporting the TSPA for the Yucca Mountain repository. The included biosphere-related FEPs were used to develop the conceptual model of the biosphere (BSC 2003 [DIRS 164186]) and were also used to develop of the model parameter values. A graphical representation of the biosphere model documentation hierarchy is presented in Figure 1-1. This figure shows the interrelationships among the analysis and model reports supporting biosphere modeling and provides an understanding of how this analysis report contributes to biosphere modeling. The *Biosphere Model Report* (BSC 2003 [DIRS 164186]) describes in detail the biosphere conceptual and mathematical models as well as the model validation. The input parameter reports (BSC 2003 [DIRS 160964]; BSC 2003 [DIRS 160965]; BSC 2003 [DIRS 160976]; BSC 2003 [DIRS 161239]; BSC 2003 [DIRS 161241]) contain detailed description of the model input parameters. The biosphere model calculations and their output, the biosphere dose conversion factors (BDCFs) are documented in the *Nominal Performance Biosphere Dose Conversion Factor*

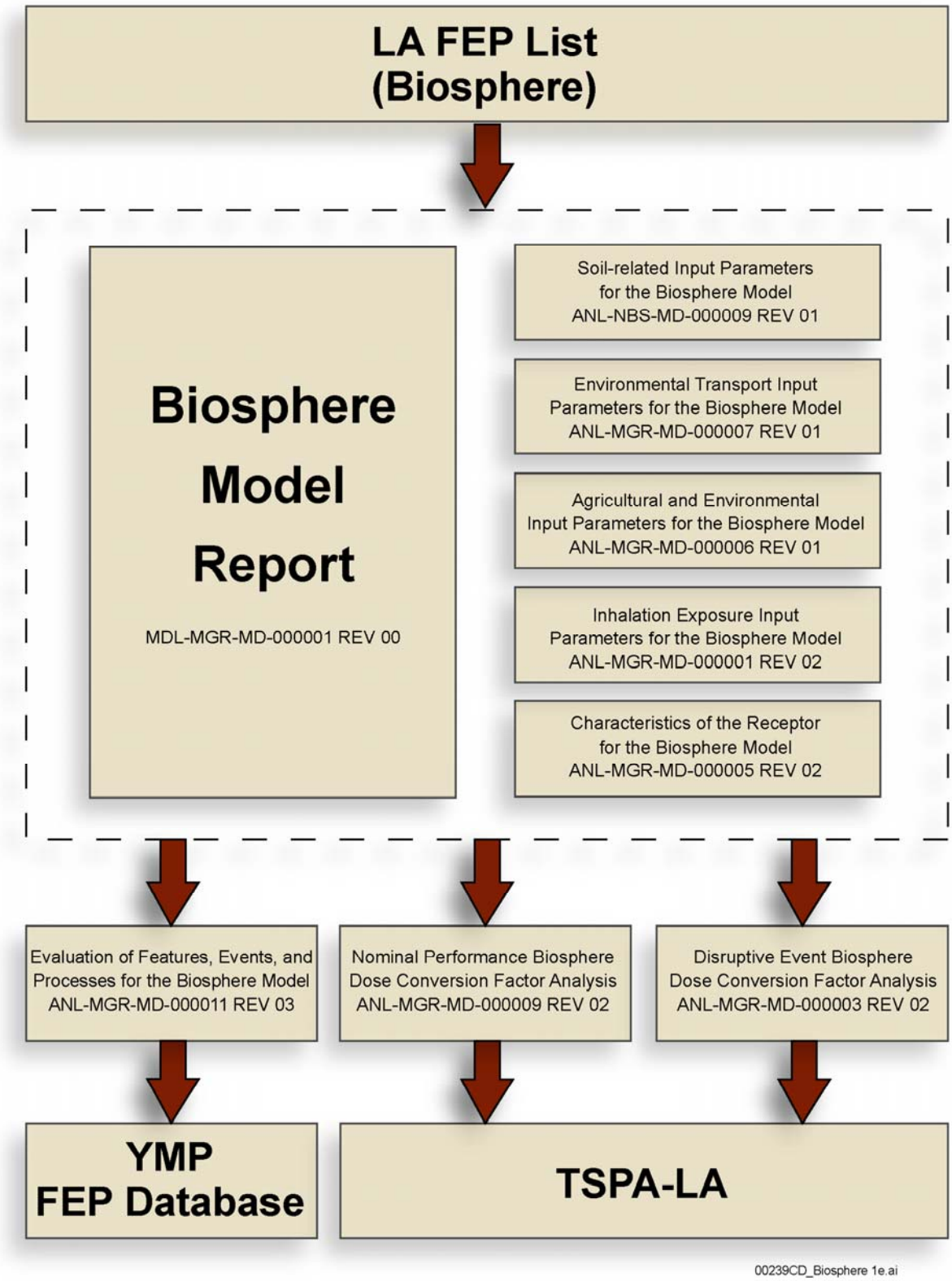

Figure 1-1. Biosphere Model Documentation

Analysis (BSC 2003 [DIRS 164403]) and the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958]) for the groundwater and the volcanic ash exposure scenarios, respectively.

The assessment of annual doses is carried out in the TSPA model using the BDCFs generated in the biosphere model as input parameters (BSC 2003 [DIRS 164186], Section 6.4.10.4). In the biosphere model, two human exposure scenarios are considered: the groundwater exposure scenario and the volcanic ash exposure scenario. These exposure scenarios are considered separately because the initial radionuclide source terms, the radionuclide transport mechanisms in the biosphere, and the human exposure pathways are different. In the TSPA model, three scenario classes are considered: the nominal scenario class and two disruptive event scenario classes (the igneous scenario class and the seismic scenario class) (BSC 2002 [DIRS 160146], pp. 47-48). The igneous scenario class considers two modeling cases: igneous intrusion and volcanic eruption.

The groundwater exposure scenario applies to TSPA scenario classes and modeling cases that consider a groundwater release of radionuclides from the repository at Yucca Mountain. This includes the nominal scenario class, the seismic scenario class, and the igneous intrusion modeling case. Dose assessments for such releases use groundwater exposure BDCFs. The volcanic ash exposure scenario applies to the volcanic eruption modeling case, which considers an airborne release and subsequent deposition of radionuclides. Dose assessments for this type of release use the volcanic ash exposure BDCFs.

This analysis report documents changes to the biosphere FEP list that have occurred since issuance of Revision 02 of this document (BSC 2003 [DIRS 160057]). These changes were due to an update of the FEP list as identified in Section 1.2 and the completion of the biosphere model documentation (Figure 1-1). This revision addresses updates to the technical basis in supporting model and analysis reports and includes corroborative documentation in Sections 4 and 6 of this analysis. Sections 4, 5, and 6 of this report provide additional information pertaining to the relevant FEPs-related acceptance criteria presented in the *Yucca Mountain Review Plan, Final Report* (NRC 2003, Sections 2.2.1.2 [DIRS 163274]).

1.1 PLANNING

Technical Work Plan for: Biosphere Modeling and Expert Support (BSC 2003 [DIRS 163602]) identifies the general overall scope of work and objectives for this document. This analysis uses the most recent interim version of the FEP list (DTN: MO0307SEPFEPS4.000 [DIRS 164527]). Consideration of the *LA FEPs List* (DTN: MO0307SEPFEPS4.000 [DIRS 164527]) constitutes a deviation from the *Technical Work Plan for: Biosphere Modeling and Expert Support* (TWP) (BSC 2003 [DIRS 163602]), which referred to an earlier revision of the FEPs list (DTN: MO0303SEPFEPS2.000 [DIRS 162452]). The changes relative to the FEPs list identified in the TWP include limited modification of FEP names, the FEP descriptions from the previous FEP list, and in the designation of the FEPs as biosphere related.

1.2 SCOPE

The scope of this analysis is to describe, evaluate, and document biosphere FEPs for TSPA. This FEP analysis included a re-evaluation of the biosphere FEPs in accordance with *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966]) and supplemented by the Key Technical Issue (KTI) Letter Report *Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [DIRS 165394]). The re-evaluation included splitting FEPs with mixed include/exclude screening decision; changing the level-of-detail of FEP descriptions; and reviewing FEP screening decisions, screening arguments, and dispositions for TSPA (Section 6.2). Re-evaluation of the Yucca Mountain Project (YMP) FEPs resulted in a list of 48 biosphere FEPs as extracted from the *LA* [License Application] *FEP List* (DTN: MO0307SEPFEPS4.000 [DIRS 164527]). These biosphere FEPs are listed in Table 1-1. Details of the re-evaluation of biosphere FEPs are described in Section 6.1.1 of this report.

1.3 SCIENTIFIC ANALYSIS USE AND LIMITATIONS

The objective of this report was to provide FEP screening information for the biosphere-related subset of FEPs from a project-specific FEP database and to promote traceability and transparency regarding FEP dispositions. For biosphere FEPs that are excluded from TSPA, this analysis provides the technical basis and supporting arguments for exclusion. For biosphere FEPs that are included in TSPA, this analysis summarizes the manner in which the FEP has been included in the TSPA biosphere model component and dispositioned in the TSPA model, gives the associated list of parameters, and discusses any uncertainty considerations. The source documentation for this TSPA disposition information is provided in the cited supporting model and analysis reports.

The following limitations apply to this analysis:

- The limitations of this analysis inherently includes any limitations or constraints described in the supporting reports.

- The scope of this analysis is limited to providing the decision and technical basis from the perspective of the biosphere model. Where a FEP is included in multiple TSPA model components, i.e., it is related to more than one technical discipline, this analysis provides only a partial technical basis for the screening of the FEP. The technical basis for all aspects of such a shared FEP is addressed collectively in FEP analysis reports.

This analysis uses mean magnitude of events, or mean value of consequences as a basis for reaching an include/exclude screening decision. Mean values are determined in part by the range of the uncertainty. The use of mean values implies that there is uncertainty associated with the quantification of probability or consequence that supports the exclusion of FEPs. This uncertainty is considered in arriving at a final screening decision (see Section 6.1.4). For included FEPs, the range of the uncertainty for input parameters is incorporated into the TSPA analyses.

Table 1-1. Biosphere Features, Events, and Processes

FEP NAME	FEP NUMBER
Ashfall	1.2.04.07.0A
Climate change	1.3.01.00.0A
Periglacial effects	1.3.04.00.0A
Glacial and ice sheet effect	1.3.05.00.0A
Human influences on climate	1.4.01.00.0A
Greenhouse gas effects	1.4.01.02.0A
Acid rain	1.4.01.03.0A
Ozone layer failure	1.4.01.04.0A
Water management activities	1.4.07.01.0A
Wells	1.4.07.02.0A
Social and institutional developments	1.4.08.00.0A
Technological developments	1.4.09.00.0A
Species evolution	1.5.02.00.0A
Groundwater discharge to surface within the reference biosphere	2.2.08.11.0A
Soil type	2.3.02.01.0A
Radionuclide accumulation in soils	2.3.02.02.0A
Soil and sediment transport in the biosphere	2.3.02.03.0A
Surface water transport and mixing	2.3.04.01.0A
Marine features	2.3.06.00.0A
Animal burrowing/intrusion	2.3.09.01.0A
Precipitation	2.3.11.01.0A
Groundwater discharge to surface outside the reference biosphere	2.3.11.04.0A
Biosphere characteristics	2.3.13.01.0A
Radionuclide alteration during biosphere transport	2.3.13.02.0A
Radionuclide release outside the reference biosphere	2.3.13.04.0A
Human characteristics (physiology, metabolism)	2.4.01.00.0A
Human lifestyle	2.4.04.01.0A
Dwellings	2.4.07.00.0A
Wild and natural land and water use	2.4.08.00.0A
Implementation of new agricultural practices or land use	2.4.09.01.0A
Agricultural land use and irrigation	2.4.09.01.0B
Animal farms and fisheries	2.4.09.02.0A
Urban and industrial land and water use	2.4.10.00.0A
Radioactive decay and ingrowth	3.1.01.01.0A
Atmospheric transport of contaminants	3.2.10.00.0A
Contaminated drinking water, foodstuffs and drugs	3.3.01.00.0A
Plant uptake	3.3.02.01.0A
Animal uptake	3.3.02.02.0A
Fish uptake	3.3.02.03.0A
Contaminated non-food products and exposure	3.3.03.01.0A
Ingestion	3.3.04.01.0A
Inhalation	3.3.04.02.0A
External exposure	3.3.04.03.0A
Radiation doses	3.3.05.01.0A
Radiological toxicity/effects	3.3.06.00.0A

Table 1-1. Biosphere Features, Events, and Processes (Continued)

FEP NAME	FEP NUMBER
Sensitization to radiation	3.3.06.02.0A
Non-radiological toxicity/effects	3.3.07.00.0A
Radon and radon daughter exposure	3.3.08.00.0A

SOURCE: DTN: MO0307SEPFEPS4.000 [DIRS 164527], Filename=FEPsTableRev0C.doc

2. QUALITY ASSURANCE

Development of this report involves the analysis of technical information to support performance assessment, as described in the TWP (BSC 2003, [DIRS 163602]), and thus is a quality affecting activity in accordance with AP-2.27Q, *Planning for Science Activities*. Approved quality assurance procedures identified in the TWP (BSC 2003 [DIRS 163602], Section 4) were used to conduct and document the activities described in this report. Electronic data used in this analysis were controlled in accordance with the methods specified in the TWP (BSC 2003 [DIRS 163602], Section 8).

This analysis did not require classification of the quality level of natural barriers or other items in accordance with AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*, or other applicable implementing procedures.

3. USE OF SOFTWARE

This document uses no computational software. As a result, these analyses are not subject to software controls. This document was developed using only Microsoft Word software for word processing. This software is exempt from qualification requirements in accordance with AP-SI.1Q, *Software Management*. No additional applications, routines, or macros were developed using this software.

4. INPUTS

4.1 DIRECT INPUTS

4.1.1 Data

No data were used in the preparation of this document.

4.1.2 Parameters and Parameter Uncertainty

The technical evaluations presented herein are based on guidance and regulatory requirements, results documented in other analysis and model reports, or in technical literature. Models developed in the supporting documents are cited for traceability and transparency purposes; however, they were not used directly in development of the screening arguments presented herein. There were no parameters used in this analysis. Analysis and model reports supporting the biosphere model (shown in Figure 1-1) were used in this analysis to support discussion of treatment of included FEPs within the biosphere model, the relevant model parameters and their uncertainty, and the FEP disposition in TSPA.

4.1.3 Other Model/Analyses Inputs and Technical Information

The list of Biosphere FEPs was extracted from the *LA FEP List* documented in DTN: MO0307SEPFEPS4.000 [DIRS 164527], and as such, is considered input for this analysis. This unqualified list of Biosphere FEPs was reviewed and evaluated for appropriateness of use and comprehensiveness, and was determined to be comparable to the list of Biosphere FEPs presented for TSPA for Site Recommendation (SR) (TSPA-SR) (Freeze et al. 2001 [DIRS 154365]) and suitable for use as a list of Biosphere FEPs to be further evaluated for LA.

The provisions of 10 CFR Part 63 [DIRS 156605] are relied upon for exclusion arguments presented in Section 6.2 of this document as described below. The nature of the FEP screening arguments and TSPA dispositions is such that other input and information also are cited in support of FEP screening arguments or TSPA dispositions. This technical information is also listed below.

4.1.3.1 FEPs Screening Criteria

The NRC regulations and guidance specifically allow the exclusion of FEPs from the TSPA if they can be shown to be of low probability or of low consequence. Additionally, FEPs can be excluded based on the constraints provided within the rule. This exclusion is called in this document exclusion by regulation. FEPs screening criteria are described further in the following three subsections.

4.1.3.1.1 Low Probability

The low-probability criterion is stated at 10 CFR 63.114(d) [DIRS 156605]:

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

and supported by 10 CFR 63.342 [DIRS 156605]:

> *DOE's performance assessments should not include consideration of very unlikely features, events, or processes, i.e., those that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal.*

The low-probability criterion (i.e., very unlikely FEPs) is stated as less than one chance in 10,000 of occurring in 10,000 years.

Furthermore, it is stated at 10 CFR 63.342 [DIRS 156605] that:

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

4.1.3.1.2 Low Consequence

The low consequence criteria are stated at 10 CFR 63.114 (e and f) [DIRS 156605]:

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

and supported by 10 CFR 63.342 [DIRS 156605]:

> *DOE's performance assessments need not evaluate, the impacts resulting from any features, events, and processes or sequences of events or processes with a*

> *higher chance of occurrence if the results of the performance assessments would not be changed significantly.*

The terms "significantly changed" and "changed significantly" are undefined terms in the NRC regulations. The absence of "significant change" is inferred for FEP screening purposes to be equivalent to having no or negligible effect. Because the relevant performance measures differ for different FEPs (e.g., effects on performance can be measured in terms of changes in concentrations, flow rates, travel times, or other measures as well as overall expected annual dose), there is no single quantitative test of "significance."

4.1.3.1.3 By Regulation

The provisions and constrains provided within the rule, pertaining to the reference biosphere, receptor, and performance assessment, serve as the basis for exclusion of some FEPs. This process of screening out the FEPs that fall outside the parameters established by the rule is described in the *Yucca Mountain Review Plan, Final Report* (YMRP) (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3 Acceptance Criterion 2) together with the screening criteria of low probability and low consequence:

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

Exclusion of FEPs by regulation involves consideration of those paragraphs of the rule that define requirements and key concepts for performance assessment. In this context, portions of the rule serve as criteria for screening related FEPs. The *Project Requirements Document* (PRD) (Canori and Leitner 2003 [DIRS 161770]) addresses definitions, and pertinent requirements that are listed in Table 4-2 (Section 4.2). For the biosphere FEPs, these include the requirements pertaining to the reference biosphere, the geologic setting, and the RMEI.

Reference Biosphere and Geologic Setting

Per 10 CFR 63.2 [DIRS 156605], the *reference biosphere* is defined as:

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

The requirements pertaining to the characteristics of the reference biosphere are presented at 10 CFR 63.305 [DIRS 156605]. These requirements are:

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

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

c. *DOE must vary factors related to the geology, hydrology, and climate based upon cautious, but reasonable assumptions consistent with present knowledge of factors that could affect the Yucca Mountain disposal system over the next 10,000 years.*

d. *Biosphere pathways must be consistent with arid or semi-arid conditions.*

Reasonably Maximally Exposed Individual (RMEI)

Requirements pertaining to the characteristics of the RMEI are presented at 10 CFR 63.312 [DIRS 156605]. These requirements are:

The RMEI is a hypothetical person who meets the following criteria:

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

b. *Has a diet and living style representative of the people who now reside in the Town of Amargosa Valley, Nevada. DOE must use projections based upon surveys of the people residing in the Town of Amargosa Valley, Nevada, to determine their current diets and living styles and use the mean values of these factors in the assessments conducted for §§ 63.311 and 63.321*

c. *Uses well water with average concentrations of radionuclides based on an annual water demand of 3000 acre-feet*

d. *Drinks 2 liters of water per day from wells drilled into the ground water at the location specified in paragraph (a) of this section*

e. *Is an adult with metabolic and physiological considerations consistent with present knowledge of adults.*

Additional provisions of the rule that are used in FEPs screening include 10 CFR 63.113 [DIRS 156605] that defines postclosure performance objectives for the repository. It includes a statement that radiological exposures to the RMEI are within the limits specified at 63.311 [DIRS 156605]. 66 FR 55732 [DIRS 156671] and 67 FR 62628 [DIRS 162317] provide clarification with respect to consideration of naturally-occurring FEPs that could affect the performance of a geologic repository for the comparisons with the postclosure individual and groundwater protection standards.

4.1.3.2 Other Sources of Technical Information Used in Support of FEP Screening Arguments

Additional sources of technical information that were used in support of the FEP screening arguments included the following technical documents:

USGS (2001 [DIRS 158378], Section 6.6) and Sharpe (2003 [DIRS 161591], Table 6-5) describes the predicted future climate in the region surrounding the Yucca Mountain site;

YMP 1993 [DIRS 100520], p. 55 describes the expected erosion rate in the Yucca Mountain region;

BSC (2001 [DIRS 158204]) was used to define the location of the repository relative to the ground surface.

4.2 CRITERIA

The licensing criteria for postclosure performance assessment are stated in 10 CFR 63.114 [DIRS 156605]. The requirements to be satisfied by TSPA are identified in the PRD (Canori and Leitner 2003 [DIRS 161770]). The acceptance criteria that will be used by the NRC to evaluate the adequacy of technical arguments are identified in the YMRP (NRC 2003 [DIRS 163274]). The pertinent information for this analysis report is summarized in Table 4-1.

Table 4-1 YMRP Criteria Relevant to the Biosphere FEPs

YMRP Section and Acceptance Criterion	Description	How Addressed in this Analysis
Section 2.2.1.2.1.3 **Acceptance Criterion 1**—The Identification of a List of Features, Events, and Processes Is Adequate.	(1) The Safety Analysis Report contains a complete list of features, events, and processes, related to the geologic setting or the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers), that have the potential to influence repository performance. The list is consistent with the site characterization data. Moreover, the comprehensive features, events, and processes list includes, but is not limited to, potentially disruptive events related to igneous activity (extrusive and intrusive); seismic shaking (high-frequency-low magnitude, and rare large-magnitude events); tectonic evolution (slip on existing faults and formation of new faults); climatic change (change to pluvial conditions); and criticality.	The list of Biosphere FEPs is provided in Section 1 and FEP descriptions are provided in Section 6.2. Documentation of the origin of the FEPs list is provided in Section 6.1.1.
Section 2.2.1.2.1.3 **Acceptance Criterion 2**—Screening of the List of Features, Events, and Processes Is Appropriate.	(1) The U.S. Department of Energy has identified all features, events, and processes related to either the geologic setting or to the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers) that have been excluded.	See Table 7-2 for a list of excluded biosphere FEPs.

YMRP Section and Acceptance Criterion	Description	How Addressed in this Analysis
	(2) The U.S. Department of Energy has provided justification for those features, events, and processes that have been excluded. An acceptable justification for excluding features, events, and processes is that either the feature, event, and process is specifically excluded by regulation; probability of the feature, event, and process (generally an event) falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment; and	See the method and approach discussion provided in Section 6.1.2 for an explanation of the use of various types of justification. See the individual FEP discussions in Section 6.2 for the justification for excluding FEPs.
	(3) The U.S. Department of Energy has provided an adequate technical basis for each feature, event, and process, excluded from the performance assessment, to support the conclusion that either the feature, event, or process is specifically excluded by regulation; the probability of the feature, event, and process falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment.	See Section 6.2 for discussion of the individual FEP dispositions and supporting technical bases.

SOURCE: NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3

Acceptance criteria listed in Section 2.2.1.2.2.3 of YMRP (NRC 2003 [DIRS 163274]) pertaining to identification of events with probability greater than 10^{-8} per year are not considered because this analysis does not develop probabilities for such events.

Table 4-2 provides a crosswalk between the NRC regulations (10 CFR Part 63 [DIRS 156605]), and the requirements included in the PRD (Canori and Leitner 2003 [DIRS 161770], Table 2-3).

4.3 CODES AND STANDARDS

This analysis uses provisions in of 10 CFR Part 63, *Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada* [DIRS 156605].

Table 4-2. Relationship Between the NRC Regulations and the PRD Requirements

Description of the Applicable Requirement or Criteria	10 CFR 63 (NRC Regulations)	
	Specific Regulatory Citations	**Associated PRD Requirement**
General Requirements and Scope Pertinent to FEPs Screening		
General requirements pertaining to providing a performance assessment	§63.2 §63.114	PRD-002/P-031 PRD-002/T-015
Include data related to geology, hydrology, and geochemistry (including disruptive processes and events) to the extent necessary	§63.114(a)	PRD-002/T-015
Include information of the design of the engineered barrier system used to define parameters and conceptual models	§63.114(a)	PRD-002/T-015
FEPs Specific Criteria		
Identify and provide understanding of current and future features, events, and processes	§63.2 §63.21(c)(1)	PRD-002/P-031 PRD-002/T-004
Consider alternative conceptual models of features and processes consistent with available data and current scientific understanding	§63.114(c)	PRD-002/T-015
Consider disruptive events (specifically volcanism and seismicity)	§63.114(a)	PRD-002/T-015
Consider features, events, and processes based on regulations	Not Applicable	Not Applicable
Consider features, events, and processes on a probabilistic basis and not to include unlikely FEPs for the human-intrusion and ground water protection standards	§63.114(d) §63.342	PRD-002/T-015 PRD-002/T-034
Provide technical basis for inclusion or exclusion of features, event, and processes. Need not be included if results of the performance assessment would not be significantly changed	§63.114 (e and f) §63.342	PRD-002/T-015 PRD-002/T-034
Terms and Concepts Mentioned in the Relevant Criteria		
Reference Biosphere	§63.2 §63.102(i) §63.305(a) §63.305(b)	PRD-002/P-031 PRD-002/P-029 PRD-002/T-026 PRD-002/T-026
Geologic Setting	§63.2 §63.305(c)	PRD-002/P-031 PRD-002/T-026 PRD-002/T-026
Reasonably Maximally Exposed Individual (RMEI)	§63.2 §63.102 (i) §63.312 (a, b, c, d, and e)	PRD-002/P-031 PRD-002/P-029 PRD-002/T-028

5. ASSUMPTIONS

It is assumed that evolution of the geologic setting and climate will be consistent with present knowledge of natural processes, and that potential naturally occurring events of the type (but perhaps not necessarily the magnitude) have occurred at least once in the past within the geologic record used as the basis for the TSPA.

Justification: This assumption is justified because it is required by the regulation and screening criteria. At 10 CFR 63.305(c) [DIRS 156605], DOE is directed to "…vary factors related to the geology, hydrology, and climate based upon cautious, but reasonable assumptions consistent with present knowledge of factors that could affect the Yucca Mountain disposal system over the next 10,000 years." See also the description of the requirements for *reference biosphere* and *geologic setting* provided in Section 4.1.3.1.3 of this report. Because it is required by regulation, no further confirmation is necessary.

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

Use: This assumption is used throughout Section 6.2.

6. SCIENTIFIC ANALYSIS DISCUSSION

The following subsections document the biosphere FEP analyses. Section 6.1 describes the methods and approach used to identify and screen the biosphere FEPs. Section 6.1 also described how uncertainty, alternative conceptual models, and model and software issues were considered. Section 6.2 presents the technical basis for the FEP screening decisions. The FEPs analyses presented in Section 6.2 are appropriate because, as described below, they are consistent with the TSPA approach to satisfy the performance-assessment requirements. These analyses are also appropriate because they address NRC's acceptance criteria in YMRP (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3), previously discussed in Section 4.2, which are applicable to the FEP discussions provided in Section 6.2.

6.1 METHODS AND APPROACH

The methods and approach for FEP analysis and scenario development in TSPA is provided in generic form in *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966]) and the KTI Letter Report *Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [DIRS 165394]. The first step of the FEP analysis process is the identification of FEPs potentially relevant to the performance of the Yucca Mountain repository. A review of FEP analysis and scenario development in other radioactive waste disposal programs is provided in *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966], Section 2) and includes a discussion of alternate FEP identification and scenario development processes. Regardless of the specific approach chosen to perform the screening, the screening process is a comparison of the FEP against the criteria specified in Section 4.1.3 of this report. Consequently, the outcome of the screening is, to some degree, independent of the particular methodology or assignments selected to perform the screening.

6.1.1 Identification of Biosphere FEPs

The development of a comprehensive list of FEPs potentially relevant to post-closure performance of a Yucca Mountain repository is an iterative process based on site-specific information, design, and regulations. The approach for developing an initial list of FEPs, in support of TSPA–SR, was documented in Freeze et al. (2001 [DIRS 154365]). The initial FEP list contained 328 FEPs, of which 176 were included in TSPA-SR models (CRWMS M&O 2000 [DIRS 153246], Tables B-9 through B-17). Each FEP was assigned a unique YMP FEP database number. The FEP number is the primary method for identifying FEPs, and consists of an eight-digit number having a format ×.×.××.××.××.

Each FEP was determined to be applicable to a specific technical discipline such that the analysis and resolution of the screening decision was performed by subject-matter experts (SME) in the relevant technical disciplines, based on the nature of the FEP. The FEP analyses were then documented in a set of FEP analysis reports corresponding to the technical disciplines. In some cases, the FEPs affect more than one technical discipline. In these cases, rather than create

multiple separate FEPs, the FEP was assigned to more than one technical discipline (i.e., a shared FEP) and the technical basis for screening appears in more than one FEP analysis report.

Biosphere FEP activities for TSPA-LA are described in TWP (BSC 2003 [DIRS 163602], Section 2). The results of these activities are described in this analysis report. The TSPA-LA FEP analysis included a re-evaluation of the YMP FEP list in accordance with *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966]) and supplemented by the KTI Letter Report *Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003 [DIRS 165394]). Specific activities included:

- Reviewing the FEP organizational structure and hierarchical classification system
- Redefining FEPs (changing FEP descriptions), where necessary, to provide an appropriate level of detail for analysis
- Redefining FEPs (splitting), where necessary, to eliminate FEPs with mixed include/exclude screening decisions
- Updating FEP screening decisions, screening arguments and dispositions consistent with the TSPA-LA design, information, and models.

Re-evaluation of the YMP FEPs resulted in a preliminary TSPA-LA FEP list (DTN: MO0301SEPFEPS1.000 [DIRS 161496]). The preliminary list has subsequently undergone minor changes, based on preliminary FEP evaluations by the SMEs. The current TSPA-LA FEP list contains 367 FEPs that are listed in DTN: MO0307SEPFEPS4.000 [DIRS 164527]. Of these, 48 are designated as biosphere FEPs. The list of the biosphere FEPs is shown in Table 1-1. Note that the eight-digit TSPA-LA FEP numbers derive from the TSPA-SR FEP numbers. In general, TSPA-SR FEPs with numbers ending in .00 were converted to TSPA-LA FEPs with numbers ending in .0A. Where new FEPs for TSPA-LA were created by splitting existing TSPA-SR FEPs, the new FEPs end in .0B, .0C, etc., to ensure traceability to their origin in TSPA-SR.

6.1.2 Screening of Biosphere FEPs

As described in Section 6.1.1 of this analysis report, the first step in the FEP analysis process was the identification of FEPs. The second step in the FEP analysis process is the screening of FEPs against the project screening criteria, as illustrated on Figure 6-1.

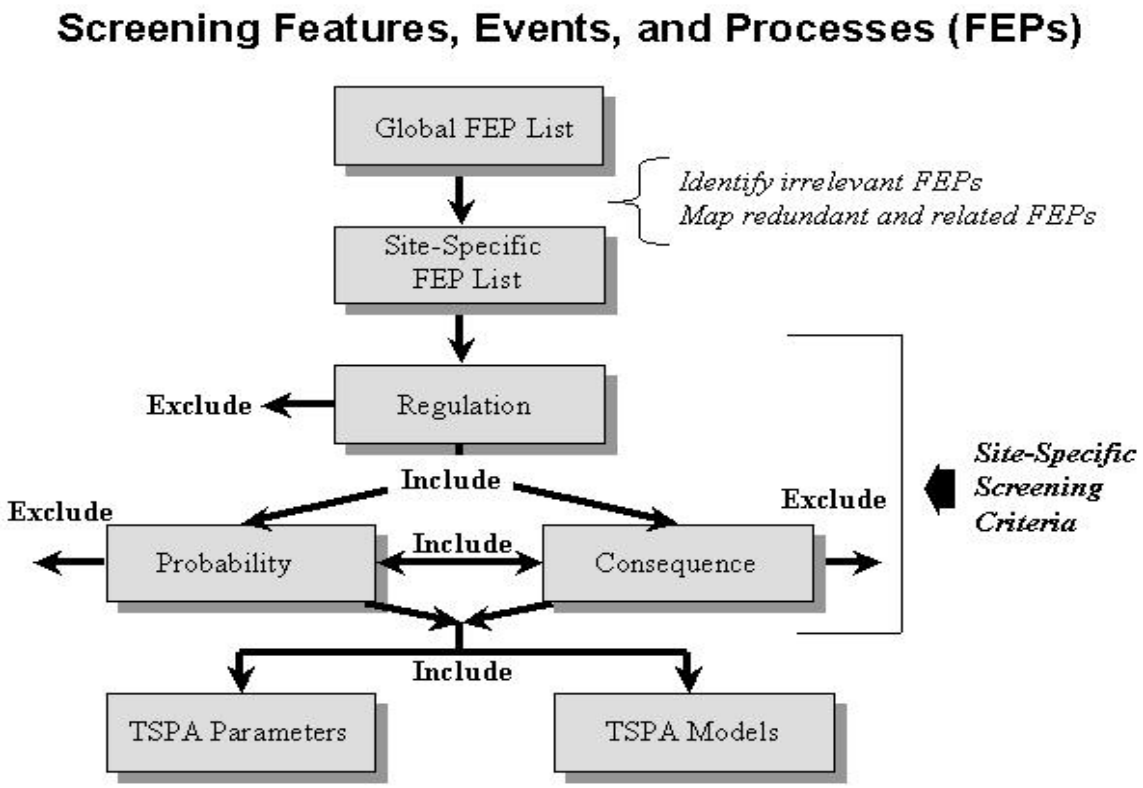

Figure 6-1. Screening Features, Events, and Processes (FEPs).

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

1) The event has at least one chance in 10,000 of occurring over 10,000 years (see 10 CFR 63.114(d) [DIRS 156605]).

2) The magnitude and time of the resulting radiological exposure to the RMEI, or radionuclide release to the accessible environment, would be significantly changed by its omission (see 10 CFR 63.114 (e and f) [DIRS 156605]).

Additionally, the YMRP (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3) directs NRC staff to evaluate the FEPs based on the regulations. These YMRP criteria are used to establish a third FEP screening statement.

3) The FEP is not excluded by regulation.

Evaluation of the FEPs against these screening statements may be done in any order. If there are affirmative conditions for three screening criteria, the FEP is *Included* in the TSPA model. If there is a negating condition in any of the screening statements, the FEP is *Excluded* from the TSPA model.

For *Included* FEPs, the associated TSPA disposition in Section 6.2 of this report describes how the FEP is implemented (through models and/or parameters) in TSPA. For *Excluded* FEPs, the associated screening argument in Section 6.2 of this report describes the technical basis for exclusion through direct comparison with the relevant screening criterion.

6.1.2.1 Considerations for Low-Probability Screening

For the purposes of screening FEPs for TSPA, an event is defined as a natural or human-caused phenomenon that has a potential to affect disposal system performance and that occurs during an interval that is short compared to the period of performance (NRC 2003 [DIRS 163274], Section 3). FEP screening considers two aspects of probability: 1) the probability of the phenomenon occurring (i.e. the *initiating event*), and 2) the potential to affect disposal system performance (i.e., the *associated combinations of repository system component failures*).

The first aspect of the probability screening is the consideration of the probability of a phenomenon occurring, independent of its effect on the repository. This is particularly germane to processes where the phenomena are well defined. This type of screening typically involves a quantitative probability calculation, although in certain obvious cases (e.g., glaciation in the region surrounding the Yucca Mountain Site) the screening may be non-quantitative and termed as “not credible”. If it can be demonstrated that a phenomenon, independent of its effect on the repository, is of sufficiently low probability, then the phenomenon is excluded from the TSPA.

The second aspect of the probability screening can be invoked if an event is defined in terms of its potential to affect the behavior (or response) of the disposal system, rather than solely in terms of the behavior of the independent geologic phenomenon. To evaluate this aspect on a probabilistic basis it is necessary to define a threshold value at which an initiating event has the potential to affect repository performance, and then define the probability of the threshold being violated. This use of the argument is dependent on the design features of the repository, and is justified because: 1) FEPs can be defined temporally, spatially, and in magnitude; 2) the phenomena and effect of the interaction can be quantified (or at least bounded) and, therefore, incorporated into the design in such a way that the potential effect of the FEP is eliminated or minimized; 3) the implementation of the design and changes to the design is subject to a performance-confirmation process; and (4) the "as-built" design can be verified.

Note that this type of probability screening may also be stated as a low consequence screening argument. The logic is as follows: if no damage or impairment of engineered systems occurs, then there is no mechanism for accelerated or increased release of radionuclides. Therefore, there is no significant change in radionuclide exposure or release. Further, because of the dependency on repository design and performance of engineered structures, part of the hazard from a given FEP (such as fault displacement) may be appropriately excluded based on low probability, while a different portion of the hazard may have to be further evaluated considering consequence.

6.1.2.2 Considerations for Low-Consequence Screening

Low consequence screening arguments must be tied to the effect of the FEP on the system performance measures: radionuclide exposure (to the RMEI) and radionuclide release (to the

accessible environment). However, if a FEP can be shown to cause no significant change to an intermediate performance measure (e.g., saturated zone flow and transport, waste package integrity), it is usually an indication that the FEP has no significant effect on radionuclide exposure or release. Ideally, low consequence screening arguments are quantitative, using results of computer simulations of the potential event or process. However, in some cases, the low consequence screening argument may involve qualitative reasoning. An example is changes in the earth's magnetic field. The probability is undetermined (so it cannot be excluded based on low probability), but there is no mechanism identified that can significantly change any intermediate or system performance measure. Various means to demonstrate no significant (negligible) impact include: site-specific data, sensitivity analyses, expertise of the SMEs, natural analogues, modeling studies outside of the TSPA, and reasoned arguments based on literature research or corroborative data.

6.1.2.3 Considerations for By-Regulation Screening

Regulation-based screening arguments should be limited to those provisions, identified in Section 4.1.3.1.3, that address regulatory constraints. These are generally limited to FEPs related to the reference biosphere, characteristics of the RMEI, and human intrusion.

6.1.3 Background, Technical Information Sources, and Literature Searches

The sources of data and technical information used in the screening arguments for the excluded FEPs are cited within each of the individual FEPs discussions. The analysis and model reports describing TSPA disposition of included FEPs are listed in Table 6-2.

Table 6-2. YMP Documents Supporting Biosphere FEPs

AMR Title	Document Identifier	Reference
Biosphere Model Report	MDL-MGR-MD-000001 REV 00	BSC 2003 [DIRS 164186]
Agricultural and Environmental Parameters for the Biosphere Model	ANL-MGR-MD-000006 REV 01	BSC 2003 [DIRS 160976]
Characteristics of the Receptor for the Biosphere Model	ANL-MGR-MD-000005 REV 02	BSC 2003 [DIRS 161241]
Environmental Transport Input Parameters for the Biosphere Model	ANL-MGR-MD-000007 REV 01	BSC 2003 [DIRS 160964]
Inhalation Exposure Input Parameters for the Biosphere Model	ANL-MGR-MD-000001 REV 02	BSC 2003 [DIRS 160965]
Soil-Related Input Parameters for the Biosphere Model	ANL-NBS-MD-000009 REV 01	BSC 2003 [DIRS 161239]
Nominal Performance Biosphere Dose Conversion Factor Analysis	ANL-MGR-MD-000009 REV 02	BSC 2003 [DIRS 164403]
Disruptive Event Biosphere Dose Conversion Factor Analysis	ANL-MGR-MD-000003 REV 02	BSC 2003 [DIRS 163958]

The technical information used in this analysis to support the screening decisions has been obtained from controlled source documents. Sources of such information include, but are not limited to, the model and analysis reports, technical reports, and other documents and databases.

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

The assumption used in the screening of the biosphere FEPs is provided in Section 5, along with the justification and use.

Alternative conceptual models and uncertainty are addressed in the supporting documentation cited as part of the individual FEP evaluations. For included FEPs, alternative conceptual models are incorporated into the TSPA based on their development and evaluation in the biosphere component model.

The quantification of uncertainty may not be applicable to FEPs screening because the FEP evaluations do not directly address parameter quantification, model development, or abstraction. FEP evaluations result in a "binary " (yes or no) decision. The measure of confidence in the decision is related to uncertainty in the data or information used to formulate the decision. How this underlying uncertainty affects the confidence in the screening decision and how it is addressed in the FEP evaluation is discussed below for each of the screening criteria: low probability, low consequence, and by regulation.

The mean probability of an event (which reflects the range in the underlying uncertainty in supporting information) is generally used for the low-probability screening arguments evaluation. Specific consideration of uncertainty is of concern during the FEPs screening process only if the mean probability of the event is roughly equivalent to the screening criteria of 10^{-8} per year, and only if the mean probability is the only basis used to exclude the FEP (i.e., the exclusion is not also coupled to a low consequence argument). If the screening decision is to include a FEP in TSPA, and the resulting consequence is to be probabilistically weighted, then uncertainty becomes an important consideration in parameter or model development.

For low-consequence screening arguments, it is important to identify the mechanisms or sequence of events that could impact the repository performance and any associated intermediate performance measures. Low-consequence screening arguments can be postulated using "worst-case" values for the sequence of events and the associated intermediate performance measures. If it can be demonstrated that such values have negligible impact on repository performance, then the issue of uncertainty is addressed by the use of the bounding conditions. The use of low-consequence arguments is subject to uncertainties stemming from alternative conceptual models. Inherent in the evaluation of such alternative conceptual models are a dependence on data, range in field observations, and on modeling results that have associated uncertainties. For low-consequence screening arguments, consideration of alternative conceptual models and the range in available data and results is more extensively discussed than for low-probability screening arguments. Alternately, modeling that considers uncertainty and alternative conceptual models, and shows a minimal impact on dose or other measures that are representative of radionuclide exposure and release, can be used to support the low-consequence screening argument.

In the case of by-regulation screening arguments, uncertainty (as represented by alternate views of regulatory meaning and intent or appropriate regulatory application) cannot be readily quantified. Rather, this type of uncertainty is resolved through the regulatory review and licensing process. Thus, in the individual FEP discussions, specific citations to the regulations or

regulatory discussions are provided and the application of the regulations is explicitly expressed for each individual FEP.

6.1.5 Alternative Approaches, Mathematical Formulations, and Units of Measure

Alternative approaches/technical methods to the FEP identification and screening process used by YMP are discussed in *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002 [DIRS 158966], Section 2).

In general, FEPs screening involves the comparison of the measure of some FEP to some threshold level of probability, or to a threshold measure that defines the onset of consequence to repository performance. Mathematical and numerical formulations typically are used in the supporting documents to define the measure of the FEP of interest, to define the probability of the event or process, and to define the threshold measure for consequence.

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

6.1.6 Model and Software Issues for Previously Developed and Validated Models

No models were used directly in the FEP evaluations, however, the model results are cited as the technical basis in some instances. This documentation provides a discussion of the formulation of the model, model validation, consideration of uncertainty and consideration of alternate conceptual models. No software beyond that listed in Section 3 was used in the development of this analysis.

6.1.7 Intended Use and Limitations

The intended use of this analysis report is to provide FEPs screening information for a project-specific FEPs database, and to promote traceability and transparency regarding FEP dispositions. For biosphere FEPs that are excluded from TSPA, this analysis report is the source documentation that provides the technical basis and supporting arguments for exclusion. For biosphere FEPs that are included in TSPA, this analysis summarizes the manner in which the FEP has been included, lists the associated parameters, and discusses uncertainty considerations. The source documentation for this TSPA disposition information is provided in the cited supporting model and analysis reports.

6.2 BIOSPHERE FEP EVALUATION AND ANALYSIS

This section provides the technical basis for either inclusion or exclusion of specific biosphere FEPs (DTN: MO0307SEPFEPS4.000 [DIRS 164527]) in the performance assessment, as required by the NRC in 10 CFR Part 63 [DIRS 156605]. The justifications for exclusion of a

FEP from consideration on the basis of low probability, low consequence, or by regulation are based on the requirements provided in Section 4.1.3. For each excluded FEP, the screening argument includes a reference to the section or subsection of 10 CFR Part 63 [DIRS 156605] upon which the exclusion is based and provides a summary of the technical basis for exclusion. For each included FEP, the TSPA disposition summarizes the implementation of the FEP in TSPA.

Included FEPs are dispositioned in TSPA through BDCFs for the groundwater or volcanic ash exposure scenarios that constitute the output of the biosphere model. The assessment of annual doses is carried out in the TSPA model using the BDCFs generated in the biosphere model as input parameters (BSC 2003 [DIRS 164186], Section 6.4.10.4). For the TSPA scenarios classes (nominal and seismic) and modeling case (igneous intrusion) involving groundwater as a source of radionuclides, annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. Such an approach is possible because quantities calculated in the groundwater exposure scenario submodels of the biosphere model, including radionuclide concentrations in the environmental media and the annual dose from various exposure pathways, are proportional to the radionuclide concentration in the groundwater (BSC 2003 [DIRS 164186], Section 6.4.10.2). Thus, for this exposure scenario, the biosphere model contribution to the dose assessment (i.e., BDCFs) can be separated from the source (i.e., radionuclide concentration in the groundwater). The BDCF for a radionuclide is numerically equal to the dose for a unit activity concentration of the radionuclide in the water (BSC 2003 [DIRS 164186], Section 6.4.10.2). To support the assessment of doses in TSPA for the scenario classes and the modeling case involving radionuclide release to the groundwater, three different sets of groundwater exposure scenario BDCFs are generated, corresponding to modern, monsoon, and glacial transition climate states (BSC 2003 [DIRS 164186], Section 6.4.10.2).

For the TSPA volcanic eruption modeling case, annual doses are also calculated as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. Because variation in radionuclide concentrations in deposited volcanic ash is not part of the biosphere model, BDCFs are calculated based on a unit source in volcanic ash deposited on the ground (1 Bq/m^2) (BSC 2003 [DIRS 164186], Section 6.5). The TSPA model calculates radiation dose as a product of the time-dependent source term and the source-independent BDCFs. The time-dependent source term is subject to radioactive decay, volcanic ash redistribution, surface soil erosion, and other removal mechanisms (BSC 2003 [DIRS 164186], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

The preceding two paragraphs may be repeated in full or in part in the TSPA dispositions of included FEPs. This is necessary because TSPA dispositions need to provide stand-alone summaries in the FEP database of the implementation of these FEPs in TSPA.

The FEPs included in the biosphere model are not specifically listed in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403]) and in the *Disruptive*

Event Biosphere Dose Conversion Factor Analysis (BSC 2003 [DIRS 163958]), but rather they are included by reference to the *Biosphere Model Report* (BSC 2003 [DIRS 164186].

6.2.1 Ashfall (FEP 1.2.04.07.0A)

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

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

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Ashfall is incorporated in TSPA as part of the volcanic eruption modeling case of the igneous scenario class. For the volcanic eruption modeling case, the TSPA presumes that a hypothetical eruption occurs through a section of the repository, entraining radionuclide-bearing wastes in the ash plume that disperses downwind and deposits contaminated ash on the ground surface. These ashfall events and processes are directly modeled using ASHPLUME (BSC 2002 [DIRS 160146], Section 2.1). The TSPA model, using ASHPLUME, estimates radionuclide concentrations in contaminated ash falling at the location of the RMEI, based on incorporation of the waste into the volcanic ash, the extent of the ash plume into the atmosphere, the atmospheric transport of the ash and entrained waste, and the thickness of ash deposits in the vicinity of the RMEI. Radionuclides in the contaminated volcanic ash may be incorporated into the food chain, may be inhaled, and may result in external radiation doses. The effects of these radionuclides are incorporated in TSPA through the use of volcanic ash exposure scenario BDCFs.

Ashfall is the initial source of radionuclides in the reference biosphere under the volcanic ash exposure scenario (BSC 2003 [DIRS 164186], Sections 6.1.3, 6.3.2, and 6.5). In the biosphere model, this source is represented by the quantity of radionuclide concentration in volcanic tephra deposited on the ground. In the mathematical model, this FEP is directly addressed in the soil and air submodels (BSC 2003 [DIRS 164186], Table 6.7–1) through the use of the following model input parameters: ash bulk density (BSC 2003 [DIRS 161239], Section 6.7), mass loading for crops (BSC 2003 [DIRS 160965], Section 6.2.5), mass loading for receptor environments (BSC 2003 [DIRS 160965], Sections 6.2.1 to 6.2.4), and mass loading time function (BSC 2003 [DIRS 160965], Sections 6.3).

This FEP is dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios that constitute the output of the biosphere model. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. Because variation in radionuclide concentrations in deposited volcanic ash is not part of the biosphere model, BDCFs are calculated based on a unit source in volcanic ash deposited on the ground (1 Bq/m^2) (BSC 2003 [DIRS 164186], Section 6.5). The

TSPA model calculates radiation dose as a product of the time-dependent source term and the source-independent BDCFs. The time-dependent source term is subject to radioactive decay, volcanic ash redistribution, surface soil erosion, and other removal mechanisms (BSC 2003 [DIRS 164186], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 161239])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

Note: This FEP was not listed as considered in the *Soil-Related Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 161239]) although this report includes the value of the ash bulk density for the biosphere model.

6.2.2 Climate Change (FEP 1.3.01.00.0A)

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

Descriptor Phrases–Climate change

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition– Future climate forecasts (USGS 2001 [DIRS 158378], Section 6.6) indicate that the climate is reasonably expected to evolve to the cooler, wetter conditions of a glacial transition climate within the 10,000-year compliance period. Monsoon and intermediate climate states are predicted to last until 38,000 years A.P. (Sharpe 2003 [DIRS 161591], Table 6-5). Consistent with 10 CFR 63.305(c) [DIRS 156605], that requires that the DOE vary factors related to climate based on cautious, but reasonable assumptions, climate change is included in the TSPA through the use of three discrete climate states: current, monsoon, and glacial transition.

The biosphere model is constructed for a biosphere with an arid or semi-arid climate and little or no surface water discharge or transport. The biosphere model includes climate change using predictions based on the geologic record from the Yucca Mountain region. Although the conceptual model does not change, some parameter values for the modern (interglacial) climate differ from those for a future climate (monsoon and glacial transition climates). Climate change is incorporated into the biosphere model by using different values for input parameters that are influenced by temperature and precipitation (BSC 2003 [DIRS 164186], Table 6.6-2). In addition, different sets of BDCFs for the groundwater exposure scenario are calculated for the current and future climate states (BSC 2003 [DIRS 164403], Section 6.2.2). In the mathematical model, climate change is considered in the following submodels of the biosphere model; soil, plant, fish, ^{14}C, and inhalation, by allowing the value of parameters associated with these submodels to vary with climate. The parameters in the model that address this FEP are: annual average irrigation rate (BSC 2003 [DIRS 160976], Section 6.5), overwatering rate (BSC 2003 [DIRS 160976], Section 6.9), growing time (BSC 2003 [DIRS 160976], Section 6.4), irrigation amount per application (BSC 2003 [DIRS 160976], Section 6.7), daily irrigation rate (BSC 2003 [DIRS 160976], Section 6.8), water concentration modifying factor (BSC 2003 [DIRS 160964], Section 6.4.3), surface area of irrigated land (BSC 2003 [DIRS 160964], Section 6.7.2), and evaporative cooler use factor (BSC 2003 [DIRS 161241], Section 6.3.4.2).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1). Climate change was also evaluated for the volcanic ash exposure scenario but the differences in BDCF values were insignificant and a single climate-independent set of BDCFs for the volcanic ash exposure scenario was developed. This set of BDCFs is a direct input to the TSPA volcanic eruption modeling case model.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.3 Periglacial Effects (FEP 1.3.04.00.0A)

FEP Description–This FEP addresses the physical processes and associated landforms in cold but ice-sheet-free environments. Permafrost and seasonal freeze/thaw cycles are characteristic of periglacial environments. These effects could include erosion and deposition.

Descriptor Phrases– Climate change (glaciation)
Permafrost
Soil erosion (from glaciation)
Soil deposition (from glaciation)

Screening Decision–Excluded based on low probability and low consequence.

Screening Argument–This FEP refers to climate conditions that could produce a cold, but glacier-free environment. In periglacial environments the effects of freezing and thawing may drastically modify the ground surface. Results of such a climate could include permafrost (permanently frozen ground), ground ice, and enhanced erosion. Paleoclimate records indicate that the climate conditions necessary to form permafrost are not credible at Yucca Mountain over the next 10,000 years (USGS 2001 [158378], Section 6.6). This is because the mean annual temperature forecasted for the Yucca Mountain region for the next 10,000 years exceeds 0°C (USGS 2001 [158378], Section 6.6). Therefore, soil erosion and deposition at Yucca Mountain as a result of permafrost is not credible. Freeze/thaw mechanical erosion will likely increase as the climate cools. However, the magnitude of erosion will not likely be significant even during the cooler climate condition. The maximum erosion over a 10,000 year period is expected to be less than 10 cm (YMP 1993 [DIRS 100520], p. 55), which is within the range of existing surface irregularities. This is based on estimates for erosion rates that have occurred at Yucca Mountain over the last 12 million years (YMP 1993 [DIRS 100520], p. 55), and therefore includes the effects of cooler climates. Therefore, this FEP is excluded from TSPA on the basis of low probability and low consequence.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.4 Glacial and Ice Sheet Effect (FEP 1.3.05.00.0A)

FEP Description–This FEP addresses the effects of glaciers and ice sheets occurring within the region of the repository, including direct geomorphologic effects and hydrologic effects. These effects include changes in topography (due to glaciation and melt water), changes in flow fields, and isostatic depression and rebound. These effects could include erosion and deposition.

Descriptor Phrases– Climate change (glaciation)
Permafrost
Soil erosion (from glaciation)
Soil deposition (from glaciation)
Glaciation (transport in biosphere)

Screening Decision–Excluded based on low probability.

Screening Argument–This FEP refers to the local effects of glaciers and ice sheets. Paleoclimate records indicate that the climate conditions necessary to form glaciers and ice sheets are not credible at Yucca Mountain over the next 10,000 years (USGS 2001 [158378], Section 6.6). The closest alpine glaciers to Yucca Mountain during the Pleistocene were in the Sierra Nevada of California (CRWMS M&O 2000 [151945], Section 6.3.4.1.2.6), too far from Yucca Mountain to have any effect on site geomorphology or hydrology. Given the relatively low elevation of Yucca Mountain, there is no credible mechanism by which a glacier could form at the site over the next 10,000 years. The geomorphologic and hydrologic effects associated with glaciers such as changes in topography due to erosion, deposition, and glacial transport, changes in flow fields, and isostatic depression and rebound, are not credible process at Yucca Mountain. Therefore, this FEP is excluded from TSPA on the basis of low probability.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.5 Human Influences on Climate (FEP 1.4.01.00.0A)

FEP Description–This FEP addresses future human actions that could influence global, regional, or local climate. Human actions may be intentional or accidental.

Note: This FEP aggregates all human influences on climate into a single category. Technical discussions are presented separately for greenhouse gas effects (1.4.01.02.0A), acid rain (1.4.01.03.0A), and ozone layer failure (1.4.01.04.0A).

Descriptor Phrases– Climate change (anthropogenic)

Screening Decision–Excluded by regulation.

Screening Argument–Human influences on climate are excluded on the basis of requirements of 10 CFR 63.305(c) [DIRS 156605]. The licensing rule and the preamble (66 FR 55732 [DIRS 156671]) indicate that only natural evolution of the reference biosphere is to be included in the performance assessment and that the changes caused by the future human behaviors are not to be included. In response to comments on climate change (66 FR 55732 [DIRS 156671], p. 55757), the NRC emphasized the importance of including "climate change in both the geosphere and the biosphere performance assessment calculations to ensure that the conceptual model of the environment is consistent with our scientific understanding of reasonably anticipated natural events." Similarly, in the background discussion of the 2002 amendment to the rule the NRC stated "DOE's performance assessments are required to consider the naturally occurring features, events and processes that could affect the performance of a geologic repository…" (67 FR 62628 [DIRS 162317], p. 62629). As the part of the response to the comments the NRC also stated that considering future economic growth trends and human behaviors would add inappropriate speculation into the requirements and would lead to problems deciding which alternative futures are credible and which are unrealistic (66 FR 55732 [DIRS 156671], p. 55757). The NRC stated

further that the natural systems of the biosphere should be allowed to vary consistent with the geologic records, which provide basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). Because human behavior cannot be similarly predicted, such an approach cannot be used for the RMEI (66 FR 55732 [DIRS 156671], p. 55757) and, extending this reasoning, for the human-induced changes to the environment. Prediction of the human-induced climate changes, would not only involve speculations about the local population but also introduce inherently large uncertainties in prediction of the global population behaviors and their consequences. In their discussion of consideration of future economic growth trends the NRC concluded that inclusion of such future predictions would not only add inappropriate speculation but also would not enhance public safety and be likely inconsistent with the EPA standards. Based on these statements, the FEPs associated with the characteristics of the reference biosphere and their change are limited to naturally occurring FEPs and exclude FEPs related to human activities. Likewise, the geological, hydrological and climatological factors that the DOE must vary under 10 CFR 63.305(c), are also limited to naturally occurring FEPs.

Because this FEP focuses on the consequences of future human activities on climate, it is excluded on the basis of inconsistency with the requirements of 10 CFR 63.305(c) [DIRS 156605].

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.6 Greenhouse Gas Effects (FEP 1.4.01.02.0A)

FEP Description–The greenhouse effect refers to the presence in the atmosphere of carbon dioxide and other gases that tend to allow solar radiation through to the earth's surface and reflect heat back to it. Thus, these gases act much as the glass of a greenhouse, with the earth as the greenhouse. Human activities such as burning of fossil fuels, forest clearance, and industrial processes produce these greenhouse gases. The greenhouse effect could increase concentrations of carbon dioxide and other gases in the atmosphere, and lead to changes in climate such as global warming.

Descriptor Phrases– Climate change (greenhouse gasses)

Screening Decision–Excluded by regulation.

Screening Argument– Human influences on climate are excluded on the basis of requirements of 10 CFR 63.305(c) [DIRS 156605]. The licensing rule and the preamble (66 FR 55732 [DIRS 156671]) indicate that only natural evolution of the reference biosphere is to be included in the performance assessment and that the changes caused by the future human behaviors are not to be included. In response to comments on climate change (66 FR 55732 [DIRS 156671], p. 55757), the NRC emphasized the importance of including "climate change in both the geosphere and the biosphere performance assessment calculations to ensure that the conceptual model of the environment is consistent with our scientific understanding of reasonably anticipated natural events." Similarly, in the background discussion of the 2002 amendment to the rule the NRC

stated "DOE's performance assessments are required to consider the naturally occurring features, events and processes that could affect the performance of a geologic repository…" (67 FR 62628 [DIRS 162317], p. 62629). As the part of the response to the comments the NRC also stated that considering future economic growth trends and human behaviors would add inappropriate speculation into the requirements and would lead to problems deciding which alternative futures are credible and which are unrealistic (66 FR 55732 [DIRS 156671], p. 55757). The NRC stated further that the natural systems of the biosphere should be allowed to vary consistent with the geologic records, which provide basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). Because human behavior cannot be similarly predicted, such an approach cannot be used for the RMEI (66 FR 55732 [DIRS 156671], p. 55757) and, extending this reasoning, for the human-induced changes to the environment. Prediction of the human-induced climate change would not only involve speculations about the local population but also introduce inherently large uncertainties in prediction of the global population behaviors and their consequences. In their discussion of consideration of future economic growth trends the NRC concluded that inclusion of such future predictions would not only add inappropriate speculation but also would not enhance public safety and be likely inconsistent with the EPA standards. Based on these statements, the FEPs associated with the characteristics of the reference biosphere and their change are limited to naturally occurring FEPs and exclude FEPs related to human activities. Likewise, the geological, hydrological and climatological factors that the DOE must vary under 10 CFR 63.305(c), are also limited to naturally occurring FEPs.

Because this FEP focuses on the consequences of human activities on climate, it is excluded on the basis of inconsistency with the requirements of 10 CFR 63.305(c) [DIRS 156605].

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.7 Acid Rain (FEP 1.4.01.03.0A)

FEP Description–Human actions may result in acid rain on a local to regional scale. Acid rain can detrimentally affect aquatic and terrestrial life by interfering with the growth, reproduction and survival of organisms. It can influence the behavior and transport of contaminants in the biosphere, particularly by affecting surface water and soil chemistry.

Descriptor Phrases– Climate change (acid rain)
Surface water (chemistry)

Screening Decision–Excluded by regulation.

Screening Argument– Human influences on climate are excluded on the basis of requirements of 10 CFR 63.305(c) [DIRS 156605]. The licensing rule and the preamble (66 FR 55732 [DIRS 156671]) indicate that only natural evolution of the reference biosphere is to be included in the performance assessment and that the changes caused by the future human behaviors are not to be included. In response to comments on climate change (66 FR 55732 [DIRS 156671], p. 55757), the NRC emphasized the importance of including "climate change in both the geosphere and the

biosphere performance assessment calculations to ensure that the conceptual model of the environment is consistent with our scientific understanding of reasonably anticipated natural events." Similarly, in the background discussion of the 2002 amendment to the rule the NRC stated "DOE's performance assessments are required to consider the naturally occurring features, events and processes that could affect the performance of a geologic repository…" (67 FR 62628 [DIRS 162317], p. 62629). As the part of the response to the comments the NRC also stated that considering future economic growth trends and human behaviors would add inappropriate speculation into the requirements and would lead to problems deciding which alternative futures are credible and which are unrealistic (66 FR 55732 [DIRS 156671], p. 55757). The NRC stated further that the natural systems of the biosphere should be allowed to vary consistent with the geologic records, which provide basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). Because human behavior cannot be similarly predicted, such an approach cannot be used for the RMEI (66 FR 55732 [DIRS 156671], p. 55757) and, extending this reasoning, for the human-induced changes to the environment. Prediction of the human-induced climate change would not only involve speculations about the local population but also introduce inherently large uncertainties in prediction of the global population behaviors and their consequences. In the discussion of consideration of future economic growth trends the NRC concluded that inclusion of such future predictions would not only add inappropriate speculation but also would not enhance public safety and be likely inconsistent with the EPA standards. Based on these statements, the FEPs associated with the characteristics of the reference biosphere and their change are limited to naturally occurring FEPs and exclude FEPs related to human activities. Likewise, the geological, hydrological and climatological factors that the DOE must vary under 10 CFR 63.305(c), are also limited to naturally occurring FEPs.

Because this FEP focuses on the consequences of human activities on climate, it is excluded on the basis of inconsistency with the requirements of 10 CFR 63.305(c) [DIRS 156605].

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.8 Ozone Layer Failure (FEP 1.4.01.04.0A)

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

Descriptor Phrases– Climate change (ozone failure)

Screening Decision–Excluded by regulation.

Screening Argument– Human influences on climate are excluded on the basis of requirements of 10 CFR 63.305(c) [DIRS 156605]. The licensing rule and the preamble (66 FR 55732 [DIRS 156671]) indicate that only natural evolution of the reference biosphere is to be included in the performance assessment and that the changes caused by the future human behaviors are not to be included. In response to comments on climate change (66 FR 55732 [DIRS 156671], p. 55757),

the NRC emphasized the importance of including "climate change in both the geosphere and the biosphere performance assessment calculations to ensure that the conceptual model of the environment is consistent with our scientific understanding of reasonably anticipated natural events." Similarly, in the background discussion of the 2002 amendment to the rule the NRC stated "DOE's performance assessments are required to consider the naturally occurring features, events and processes that could affect the performance of a geologic repository…" (67 FR 62628 [DIRS 162317], p. 62629). As the part of the response to the comments the NRC also stated that considering future economic growth trends and human behaviors would add inappropriate speculation into the requirements and would lead to problems deciding which alternative futures are credible and which are unrealistic (66 FR 55732 [DIRS 156671], p. 55757). The NRC stated further that the natural systems of the biosphere should be allowed to vary consistent with the geologic records, which provide basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). Because human behavior cannot be similarly predicted, such an approach cannot be used for the RMEI (66 FR 55732 [DIRS 156671], p. 55757) and, extending this reasoning, for the human-induced changes to the environment. Prediction of the human-induced climate change would not only involve speculations about the local population but also introduce inherently large uncertainties in prediction of the global population behaviors and their consequences. In their discussion of consideration of future economic growth trends the NRC concluded that inclusion of such future predictions would not only add inappropriate speculation but also would not enhance public safety and be likely inconsistent with the EPA standards. Based on these statements, the FEPs associated with the characteristics of the reference biosphere and their change are limited to naturally occurring FEPs and exclude FEPs related to human activities. Likewise, the geological, hydrological and climatological factors that the DOE must vary under 10 CFR 63.305(c), are also limited to naturally occurring FEPs.

Because this FEP focuses on the consequences of human activities on climate, it is excluded on the basis of inconsistency with the requirements of 10 CFR 63.305(c) [DIRS 156605].

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.9 Water Management Activities (FEP 1.4.07.01.0A)

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

Descriptor Phrases– Land use
Water use
Surface activities (water management)
Radionuclide release to the biosphere (irrigation water)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The living style (called the lifestyle hereafter) and behaviors of the current residents of the Town of Amargosa Valley (called Amargosa Valley hereafter) explicitly includes certain aspects of water management activities, such as irrigation and fish farming and implicitly includes other aspects (water management structures in the Amargosa Valley such as pipelines, storage and collection facilities, and ponds) through the presence of groundwater withdrawal wells.

Consistent with 10 CFR 63.305(a) [DIRS 156605], that requires that the reference biosphere shall be consistent with present knowledge of the conditions in the region, and with 10 CFR 63.305(b) [DIRS 156605], that requires that the DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology, future projection of water management activities in Amargosa Valley are assumed to be the same as the current activities.

This FEP is included in the biosphere model through the aspects of the water use, such as irrigation and fish farming that are incorporated into the exposure pathway conceptual models. The direct expression of this FEP in the mathematical model (plant and fish submodels) of the groundwater exposure scenario is through parameters that deal with the fraction of overhead irrigation (BSC 2003 [DIRS 160976], Section 6.3), the irrigation intensity (BSC 2003 [DIRS 160976], Section 6.6), and the water concentration modifying factor (BSC 2003 [DIRS 160964], Section 6.4.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

Other aspects of this FEP (water management structures in the Amargosa Valley such as pipelines, storage and collection facilities, and ponds) associated with the use of groundwater are considered under FEP 1.4.07.02.0A, Wells.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])

6.2.10 Wells (FEP 1.4.07.02.0A)

FEP Description–One or more wells drilled for human use (e.g., drinking water, bathing) or agricultural use (e.g., irrigation, animal watering) may intersect the contaminant plume. The plume may include radionuclides that have leached out of the soil and back into the groundwater.

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

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The use of well water for domestic and agricultural purposes is consistent with current human behavior and characteristics as per 10 CFR 63.312(c) [DIRS 156605]. Regulation 10 CFR 63.312(c) [DIRS 156605] specifies that the RMEI uses well water with average concentration of radionuclides based on annual water demand of 3,000 acre-feet. Therefore, use of wells for domestic and agricultural purposes is included. Groundwater wells are the initial source of radionuclides entering the reference biosphere for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Table 6.2-1, Section 6.3.1, Table 6.7-1). Radionuclide concentration in groundwater is the corresponding parameter in the mathematical model that is used in the soil, air, plant, animal, fish, ^{14}C, and ingestion submodels of the biosphere model (BSC 2003 [DIRS 164186], Sections 6.4.1 to 6.4.6 and 6.4.9).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs. The assessment of annual doses is carried out in the TSPA model using the BDCFs generated in the biosphere model as input parameters (BSC 2003 [DIRS 164186], Section 6.4.10.4). For the TSPA scenarios classes (nominal and seismic) and modeling case (igneous intrusion) involving groundwater as a source of radionuclides, annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. Such an approach is possible because quantities calculated in the groundwater exposure scenario submodels of the biosphere model, including radionuclide concentrations in the environmental media and the annual dose from various exposure pathways, are proportional to the radionuclide concentration in the groundwater (BSC 2003 [DIRS 164186], Section 6.4.10.2). Thus, for this exposure scenario, the biosphere model contribution to the dose assessment (i.e., BDCFs) can be separated from the source (i.e., radionuclide concentration in the groundwater). The BDCF for a radionuclide is numerically equal to the dose for a unit activity concentration of the radionuclide in the water (BSC 2003 [DIRS 164186], Section 6.4.10.2). To support the assessment of doses in TSPA for the scenario classes and the modeling case involving radionuclide release to the groundwater, three different sets of groundwater exposure scenario BDCFs are generated, corresponding to modern, monsoon, and glacial transition climate states (BSC 2003 [DIRS 164186], Section 6.4.10.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])

- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])

6.2.11 Social and Institutional Developments (FEP 1.4.08.00.0A)

FEP Description–This FEP addresses social and institutional developments that could affect the long-term performance of the repository. The most likely is social and institutional development resulting in new activities, communities or cities in the vicinity of Yucca Mountain.

Descriptor Phrases– Lifestyle
Land use
Water use

Screening Decision–Excluded by regulation.

Screening Argument–Social and institutional developments are excluded on the basis of the regulatory requirements of 10 CFR 63.305(b) [DIRS 156605]. Regulation 10 CFR 63.305(b) [DIRS 156605] states that "DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology. In all analyses done to demonstrate compliance with this part, the DOE must assume that all of those factors remain constant as they are at the time of submission of the license application." Therefore, changes in the social and institutional attributes of society, lifestyle, land use, and water use are excluded on the basis of the regulatory requirements (10 CFR 63.305(b) [DIRS 156605]).

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.12 Technological Developments (FEP 1.4.09.00.0A)

FEP Description–Technological developments may affect the long-term performance of the repository. These include changes in the ability of man to intrude the site, and changes that might affect contaminant exposure and its health implications.

Descriptor Phrases– Lifestyle
Human intrusion

Screening Decision–Excluded by regulation.

Screening Argument–Technological developments were excluded on the basis of regulatory requirements of 10 CFR 63.305(b) [DIRS 156605]. Regulation 10 CFR 63.305(b) [DIRS 156605] specifically states that "DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology. In all analyses done to demonstrate compliance with this part, the DOE must assume that all of those factors remain constant as they are at the time of submission of the license application."

Therefore, technological development is excluded on the basis of the regulatory requirements at 10 CFR 63.305(b) [DIRS 156605].

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.13 Species Evolution (FEP 1.5.02.00.0A)

FEP Description–Species living at or near the repository, including humans, may evolve in the future and new behavior and characteristics of living organisms may affect their contaminant exposure and its health implications.

Descriptor Phrases– Lifestyle
Physiology

Screening Decision–Excluded by regulation.

Screening Argument–Species evolution is excluded on the basis of the regulatory requirements of 10 CFR 63.305(b) [DIRS 156605]. Regulation 10 CFR 63.305(b) [DIRS 156605] states that the "DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology. In all analyses done to demonstrate compliance with this part, the DOE must assume that all of those factors remain constant as they are at the time of submission of the license application." Therefore, species evolution, including changes in lifestyle and physiology, is excluded on the basis of the regulatory requirements (10 CFR 63.305(b) [DIRS 156605]).

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

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

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

Descriptor Phrases– Radionuclide release to biosphere (surface discharge at receptor)
Water table elevation
Capillary effects (wicking) in the UZ

Screening Decision–Included.

Screening Argument– N/A

TSPA Disposition–Surface water expressions become more likely for the predicted future climate. Modeling of the effects of climatic change on the groundwater flow system around Yucca Mountain indicates that a change to wetter climate will result in an increase in the groundwater elevation (D'Agnese et al. 1999 [DIRS 120425], p. 21). The forecasted future climate for the Yucca Mountain region that is the longest in duration is a glacial-transition climate that is wetter, but not substantially wetter than the modern climate (USGS 2001 [DIRS 158378], Section 6.6, Table 2, and Section 7). Estimates of the effect of climate change (DOE 2002 [DIRS 155970], p. 3-59) indicate that the regional groundwater table could rise between 50 and 130 meters. Given the depth to groundwater shown in *Information and Analyses to Support Selection of Critical Groups and Reference Biospheres for Yucca Mountain Exposure Scenarios* (LaPlante and Poor 1997 [DIRS 101079], Figure 2-2) and the possible paleo-discharge locations identified in *Simulated Effects of Climate Change on the Death Valley Regional Ground-Water Flow System, Nevada and California* (D'Agnese et al. 1999 [DIRS 120425], p. 6), groundwater discharge into lakes, wetlands, and springs under future climate conditions is included consistent with 10 CFR 63.305(c) [DIRS 156605], that requires that the DOE vary factors related to hydrology and climate based on cautious, but reasonable assumptions consistent with present knowledge. In addition, the use of such water needs to be included consistent with 10 CFR 63.312(c) [DIRS 156605], which specifies the constraints for the radionuclide concentration in the groundwater used by the RMEI.

The biosphere model for the groundwater exposure scenario implicitly includes this FEP because the model calculates BDCFs for a unit activity concentration in the water, regardless of the origin, if the reference biosphere remains unchanged. Characteristics of the RMEI will be adjusted in the model based on periodic updated information of diet and lifestyle, as appropriate to maintain information that accurately reflects diet and lifestyle of people in Amargosa Valley. This FEP is considered in the conceptual and mathematical models for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Table 6.7-1). Groundwater flowing into the biosphere through a spring or other discharge point would be treated in a manner similar to groundwater from a well. Therefore, this FEP is considered in the model, analogous to the FEP 1.4.07.02.0A, *Wells*, in the soil, air, plant, animal, fish, ^{14}C, and ingestion submodels (BSC 2003 [DIRS 164186], Sections 6.4.1 to 6.4.6 and 6.4.9).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])

6.2.15 Soil Type (FEP 2.3.02.01.0A)

FEP Description–Soil type is determined by many different factors (e.g., formative process, geology, climate, vegetation, land-use). The physical and chemical attributes of the surficial soils (such as organic matter content, pH) may influence the mobility of contaminants.

Descriptor Phrases– Land use
Radionuclide accumulation (soil type)
Soil chemistry

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Soil is a feature that constitutes part of the reference biosphere and is therefore included consistent with the requirement of 10 CFR 63.305(a) [DIRS 156605] that FEPs describing the reference biosphere be consistent with present knowledge of the conditions in the Yucca Mountain region.

Soil is the biosphere medium that contains the majority of the radionuclide inventory in the reference biosphere. The soil type FEP is included in the biosphere model through the selection of the soil type-dependent values of model input parameters that may influence radionuclide transport to and from the surface soil. Specifically, this feature is considered in the soil, plant, and ^{14}C submodels of the biosphere model. Characteristics of this feature are based, in part, on consideration of the characteristics of the soil types in northern Amargosa Valley (BSC 2003 [DIRS 164186], Table 6.2-1). Parameters relevant to this FEP are surface soil (tillage) depth (BSC 2003 [DIRS 160976], Section 6.10), soil bulk density (BSC 2003 [DIRS 161239], Section 6.2), surface soil erosion rate (BSC 2003 [DIRS 161239], Section 6.4), volumetric water content (BSC 2003 [DIRS 161239], Section 6.6), irrigation intensity (BSC 2003 [DIRS 160976], Section 6.6), and ^{14}C emission rate from soil (BSC 2003 [DIRS 160964], Section 6.7.1).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 161239])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.16 Radionuclide Accumulation in Soils (FEP 2.3.02.02.0A)

FEP Description–Radionuclide accumulation in soils may occur as a result of upwelling of contaminated groundwater (leaching, evaporation at discharge location), deposition of contaminated water or particulates (irrigation water, runoff), and/or atmospheric deposition.

Descriptor Phrases– Radionuclide accumulation (soil)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Radionuclide accumulation in soil, as a result of long-term irrigation, is an integral process in the modeling of the reference biosphere and is included consistent with the requirements of 10 CFR 63.305(a) and 10 CFR 63.305(c) [DIRS 156605] that FEPs describing the reference biosphere be consistent with present knowledge of the conditions in the Yucca Mountain region and the factors that could affect these conditions.

Radionuclide accumulation in soil as a result of long-term irrigation is accounted for in the soil submodel by assuming that radionuclides exist at equilibrium (saturation) concentrations in the soil (BSC 2003 [DIRS 164186], Sections 6.4.1 and 5.5). The equilibrium concentrations of radionuclides in the soil are calculated as a function of groundwater concentrations (which are considered constant at 1 Bq/m^3); the annual irrigation rate for crops; and loss by radionuclide decay, leaching, and erosion (BSC 2003 [DIRS 164186], Section 6.4.1). This calculation is based on the conservation of the mass of radionuclides in the topsoil. The solution to the resulting equation is time dependent, so the biosphere model uses the time-independent asymptotic solution to the rate equations. This is a conservative approach and avoids speculation about changes in agricultural practices and land use over the 10,000-year compliance period. At saturation, the rate of increase of radionuclides in topsoil is equal to the rate of addition from irrigation water less the rate of loss from radioactive decay, leaching, and erosion. Leaching is included in the soil submodel to account for the residence time of radionuclides in the surface soil and their removal to deeper soil. The leaching rate is a function of the amount of water that percolates below the surface soil (i.e., the overwatering rate that depends on the overall water

balance in the topsoil and considers storage capacity of the soil, precipitation, and evapotranspiration), element-specific solid-liquid partition coefficients, and other soil properties (e.g., bulk density, soil porosity, and soil moisture content at field capacity). In the current arid conditions at Yucca Mountain, leaching occurs primarily when irrigation water is added to flush accumulated salts from the surface soil to maintain plant productivity. In wetter climates, such as those predicted to occur in the future at Yucca Mountain, leaching also occurs when excess precipitation flows through the surface soil, primarily during winter. The values of parameters used to calculate quantities related to accumulation of radionuclides in the soil are such that the radionuclide losses through mechanisms other than those described above (e.g., through runoff), are minimized.

Relevant parameters are the annual average irrigation rate (BSC 2003 [DIRS 160976], Section 6.5), overwatering rate (BSC 2003 [DIRS 160976], Section 6.9), surface soil depth (tillage depth) (BSC 2003 [DIRS 160976], Section 6.10), soil solid-liquid partition coefficient (BSC 2003 [DIRS 161239], Section 6.3), soil bulk density (BSC 2003 [DIRS 161239], Section 6.2), volumetric water content (BSC 2003 [DIRS 161239], Section 6.6), surface soil erosion rate (BSC 2003 [DIRS 161239], Section 6.4), and critical thickness for the resuspension (BSC 2003 [DIRS 160964], Section 6.8).

The degree of elemental solubility may have an effect on the rate of removal of radionuclides from soils, thereby affecting the magnitude and duration of radionuclide accumulation in soil. For the groundwater exposure scenario, where radionuclides are introduced into the biosphere from groundwater use, it is assumed that the solubility limits are not achieved for radionuclides introduced as solutes, i.e., the rate of radionuclide removal from soil by leaching is proportional to the radionuclide concentration in the soil (BSC 2003 [DIRS 164186], Sections 6.4.1.1 to 6.4.1.3). Those radionuclides that reach the biosphere as colloids and, therefore, will not take part in the sorption (partition coefficient) exchange with soil (the radionuclides are already irreversibly attached to colloidal particles) will be transported through the soil system without any sorption build-up in soil. Because these radionuclides are not in solution, they are not available for plant uptake (via soil to plant transfer). In the biosphere model, radionuclide transfer from the soil to crops via root uptake is proportional to the radionuclide concentration in the surface soil (BSC 2003 [DIRS 164186], Section 6.4.3.1), i.e., all radionuclides (solutes and colloids) in groundwater (BSC 2003 [DIRS 164186], Section 6.4.3.1) are in solution and available for plant uptake. This is a conservative approach for cases where colloids are present.

For the volcanic ash exposure scenario, the radionuclides are deposited on the ground as particles of waste attached to tephra (Jarzemba 1997 [DIRS 100987], Section 2.1). As the climate considered is arid to semi-arid, the biosphere model does not take credit for any removal mechanism, including losses due to liquid phase leaching. Thus, solubility limits are not needed to inhibit the rate of removal of radionuclides. In the case of agricultural lands, the model implicitly and conservatively assumes that all radionuclides in soil on agricultural lands are available for transport to crop via root uptake (BSC 2003 [DIRS 164186], Section 6.5.3.1), thus implying that they are in solution.

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated

as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 161239])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.17 Soil and Sediment Transport in the Biosphere (FEP 2.3.02.03.0A)

FEP Description–Contaminated sediments can be transported to and through the biosphere by surface runoff and fluvial processes, and, to a lesser extent, by aeolian processes and bioturbation. Sediment transport and redistribution may cause concentration or dilution of radionuclides in the biosphere.

Descriptor Phrases– Runoff (transport in the biosphere)
Soil erosion (transport in the biosphere)
Soil deposition (transport in the biosphere)
Soil transport (fluvial)
Soil transport (aeolian)
Soil bioturbation (transport in the biosphere)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition– Soil and sediment transport are processes currently occurring in the Yucca Mountain region and are included consistent with the requirement of 10 CFR 63.305(a) [DIRS 156605] that FEPs describing the reference biosphere be consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain site.

Although the region around Yucca Mountain lacks permanent surface water bodies, sediment transport may occur by fluvial processes such as during flash floods. There are several environmental transport processes resulting in the soil and sediment transport that are included in the biosphere model. One of these processes is removal of radionuclides from the top layer of soil by erosion, which is addressed in the model for the groundwater exposure scenario. Soil erosion in agricultural fields is incorporated into the soil submodel for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Section 6.4.1.4). Soil erosion may result from various individual transport processes that are included in this FEP and the influence of these processes is included in the model for the groundwater exposure scenario in calculation of the surface soil removal constant (BSC 2003 [DIRS 161239], Section 6.4). Bioturbation is the process of sediment or soil mixing by biological activity. In the case of the shallow waste burial, bioturbation may bring the waste to the surface soil layer. In the case of deep geologic repository this is not plausible (see FEP 2.3.09.01.0A). The process of bioturbation is also not important in the context of biosphere modeling because of the distribution of radionuclides in the surface soil (in both exposure scenarios the soil receives radionuclides from the top and radionuclides would preferentially travel down through the soil profile).

The model for the volcanic ash exposure scenario implicitly includes this FEP because it applies to any areal radionuclide concentration in the soil, regardless of the soil and sediment transport processes that may affect it. In addition, the biosphere model for the volcanic ash exposure scenario indirectly considers soil transport processes that affect the radionuclide concentration in the air. Soil and sediment transport is accounted for in the soil and air submodels as represented by the following parameters: surface soil erosion rate (BSC 2003 [DIRS 161239], Section 6.4), soil bulk density (BSC 2003 [DIRS 161239], Section 6.2), dry deposition velocity (BSC 2003 [DIRS 160964], Section 6.2.2.1), critical thickness for resuspension (BSC 2003 [DIRS 160964], Section 6.8), and mass loading decrease constant (BSC 2003 [DIRS 160965], Section 6.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash

thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 161239])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.18 Surface Water Transport and Mixing (FEP 2.3.04.01.0A)

FEP Description–Contaminants released from an underground repository might enter the biosphere through discharge of deep groundwater into a lake or river. Transport and mixing within the surface water bodies affects the subsequent behavior and transport of contaminants in the biosphere. Transport and mixing includes dilution, sedimentation, aeration, streamflow, and river meander.

Descriptor Phrases– Surface water (transport in the biosphere)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Surface water transport is included consistent with the requirements of 10 CFR 63.305(c) [DIRS 156605] that requires that the DOE vary factors related to hydrology and climate based on cautious, but reasonable assumptions consistent with present knowledge of factors that could affect the Yucca Mountain disposal system. Although the region around Yucca Mountain currently lacks permanent surface water bodies, future climate forecasts, based on the analysis of paleoclimatic conditions in the Yucca Mountain region (USGS 2001 [DIRS 158378], Section 6.6), indicate that the climate will evolve to a cooler, wetter climate over the next 10,000 years. Monsoon and glacial transition climate states are forecasted to last until 38,000 years A.P. (2003 [DIRS 161591], Table 6-6). Estimates of the effect of climate change (DOE 2002 [DIRS 155970], p. 3-59) indicate that the regional groundwater table could rise between 50 and 130 meters. Therefore, permanent surface water bodies and associated surface water transport may occur in the future.

The biosphere model for the groundwater exposure scenario implicitly includes this FEP because the model applies to the use of any contaminated water, regardless of the origin, if the reference biosphere, water use practices, and the characteristics of the RMEI remain essentially unchanged. Because the BDCFs calculated by the biosphere model are developed for unit radionuclide concentration in the water, the results of biosphere modeling are insensitive to the actual radionuclide concentration in the water. The biosphere model conservatively assumes that only contaminated water is used in agriculture, animal husbandry and for human consumption. These assumption bounds the possible effects of surface water transport and mixing because such processes would likely lead to dilution of radionuclide concentration in the soil and water.

This FEP is considered in the conceptual and mathematical models for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Table 6.7-1). Any water supply in the biosphere would be modeled in a manner similar to groundwater from a well. Therefore, this FEP is considered in the model, analogous to the FEP 1.4.07.02.0A, *Wells*, in the soil, air, plant, animal, fish, ^{14}C, and ingestion submodels (BSC 2003 [DIRS 164186], Sections 6.4.1 to 6.4.6 and 6.4.9).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])

6.2.19 Marine Features (FEP 2.3.06.00.0A)

FEP Description–This FEP addresses marine and coastal features and processes. Processes include erosion, sedimentation, deposition, sea-level change, and storms.

Descriptor Phrases– Marine features

Screening Decision–Excluded based on low probability.

Screening Argument–The *Yucca Mountain Site Description* (CRWMS M&O 2000 [DIRS 151945], Figure 1.1–1) shows Yucca Mountain relative to the continental boundaries of the United States. Given the location of Yucca Mountain, the potential for impact of coastal or marine features and processes on the area around Yucca Mountain is not considered credible.

Future climate forecasts based on the analysis of paleoclimatic conditions that have occurred in the Yucca Mountain region (USGS 2001 [DIRS 158378], Section 6.6) indicate that the climate will evolve to a cooler, wetter climate over the next 10,000 years. Monsoon and glacial transition climate states are forecasted to last until 38,000 years A.P. (Sharpe 2003 [DIRS

161591], Table 6-5). Although this climate is cooler and slightly wetter than the current interglacial climate, the change is expected to have no effect on current coastlines relative to Yucca Mountain.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.20 Animal Burrowing/Intrusion (FEP 2.3.09.01.0A)

FEP Description–Burrowing animals may intrude into the repository, promoting release and spread of contamination. Burrowing animals may also contact or ingest contaminated soil.

Descriptor Phrases– Animal intrusion (burrowing)

Screening Decision–Excluded based on low consequence.

Screening Argument–The overburden thickness used in thermohydrologic modeling of the repository was between about 235 and 419 m (BSC 2001 [DIRS 158204], Table 6-2), which indicates that the subsurface emplacement level of the repository will be at a depth of not less than 200 meters below the directly overlying ground surface. Wildlife, including species known to occur at Yucca Mountain (DOE 2002 [DIRS 155970], Section 3.1.5.1.2) do not burrow to these depths. Therefore, intrusion by a burrowing animal that promotes the release of contamination and results in contact with or ingestion of contaminated soil by the receptor is not credible. In the unlikely event of animals intruding into the repository, spreading contamination to the location of the receptor (about 18 km away from the repository) to the extent that the activity concentration in the environmental media the receptor comes in contact with (such as soil or air) would be affected is not credible. Therefore this FEP is excluded based on low consequence.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.21 Precipitation (FEP 2.3.11.01.0A)

FEP Description–Precipitation is an important control on the amount of recharge. It transports solutes with it as it flows downward through the subsurface or escapes as runoff. Precipitation influences agricultural practices of the receptor. The amount of precipitation depends on climate.

Descriptor Phrases– Precipitation (effects on infiltration)
Precipitation (effects on biosphere)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Precipitation is included consistent with requirements of 10 CFR 63.305(a) and 10 CFR 63.305(c) [DIRS 156605] that the FEPs that describe the reference biosphere be consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain site and the factors that could affect these conditions. Precipitation levels are currently low, ranging between 4 to 10 inches per year (DOE 2002 [DIRS 155970], Section 3.1.2.2). Future climate forecasts (USGS 2001 [DIRS 158378], Section 6.6) indicate that the climate is reasonably expected to evolve to the cooler, wetter conditions within the 10,000-year compliance period. Monsoon and glacial transition climate states are forecasted to last until 38,000 years A.P. (Sharpe 2003 [DIRS 161591], Table 6-5).

Although precipitation is not directly used as input to the mathematical biosphere model, it is used to derive the values of parameters, such as leaching rate and irrigation rates, that depend on the overall water balance (BSC 2003 [DIRS 164186], Table 6.2-1). Specifically, precipitation rate, along with irrigation rates and evapotranspiration rates, are used to calculate the overwatering rate (BSC 2003 [DIRS 160976], Section 6.9), a parameter that controls infiltration of water and thus radionuclide transport below the root zone. Within the biosphere model, precipitation is addressed in the soil, plant, and ^{14}C submodels. The relevant parameters are annual average irrigation rate (BSC 2003 [DIRS 160976], Section 6.5), overwatering rate (BSC 2003 [DIRS 160976], Section 6.9), irrigation amount per application (BSC 2003 [DIRS 160976], Section 6.7), and daily irrigation rate (BSC 2003 [DIRS 160976], Section 6.8).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])

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

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

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

Screening Decision–Excluded by regulation.

Screening Argument–Reference biosphere is defined as the description of the environment inhabited by the RMEI (10 CFR 63.2 [DIRS 156605]). FEPs that describe the reference biosphere are those that affect the RMEI. FEPs that occur outside the reference biosphere do not influence the radionuclide transport and exposure pathways for the RMEI and are not included. Postclosure performance objectives for the repository include the requirement that doses to the RMEI are within the specified limits 10 CFR 63.113(b) [DIRS 156605]. The rule also specifies criteria that pertain to the characteristics of a reference biosphere that are required to show compliance with the postclosure standards for disposal (66 FR 55733 [DIRS 156671]). Similarly, the preamble to the rule states that Section 63.305, *Required Characteristics of the Reference Biosphere*, specifies characteristics of the reference biosphere to be used by DOE in its performance assessment to demonstrate compliance with the requirements specified at 10 CFR 63.113(b) and (d) (66 FR 55732 [DIRS 156671], p. 55784). Since the demonstration of compliance specifies conditions of the reference biosphere, the FEPs related to any processes occurring outside the reference biosphere are implicitly excluded. Therefore, groundwater discharge to surface outside the reference biosphere is excluded on the basis of inconsistency with the requirements of 10 CFR 63.113(b) [DIRS 156605].

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.23 Biosphere Characteristics (FEP 2.3.13.01.0A)

FEP Description–The principal components, conditions, or characteristics of the biosphere system can influence contaminant transport and affect the long-term performance of the disposal system. These include the characteristics of the natural environment of the reference biosphere such as climate, soils and microbes, flora and fauna, and their influences on human activities.

Descriptor Phrases– Climate change
Lifestyle
Land use
Water use

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition– Consideration of FEPs that describe the reference biosphere, and which are consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain, is required under 10 CFR 63.305(a) [DIRS 156605]. Biosphere characteristics that are based on cautious but reasonable assumptions consistent with present knowledge of potential changes in geology, hydrology, and climate are included in accordance with 10 CFR 63.305(c)

[DIRS 156605]. Therefore, this FEP is included consistent with the requirement of those sections.

Biosphere characteristics encompass the principal components, conditions, and characteristics of the reference biosphere that influence contaminant transport from the point of release into the biosphere through the environment to the receptor. This FEP includes the natural environment (e.g., climate, soils, flora, and fauna) and human activities, such as land and water use. The relationships among these components form the foundation of the biosphere model (BSC 2003 [DIRS 164186], Table 6.2-1).

Distributions of parameter values were developed based in part on variation and uncertainty in site-specific characteristics of the reference biosphere, such as temperature, wind speed, and evaporation rate (BSC 2003 [DIRS 160976], Sections 6.4, 6.5, 6.6, 6.7, 6.8, and 6.9); BSC 2003 [DIRS 161241], Sections 6.3.4.2; BSC 2003 [DIRS 160964], Sections 6.2.2.1, 6.4.3, 6.5.2, and 6.7.2). This FEP is addressed in the soil, air, plant, animal, fish, and ^{14}C submodels through many parameters such as the annual average irrigation rate (BSC 2003 [DIRS 160976], Section 6.5), overwatering rate (BSC 2003 [DIRS 160976], Section 6.9), water evaporation rate (use rate) for evaporative coolers (BSC 2003 [DIRS 160964], Section 6.5.2), dry deposition velocity (BSC 2003 [DIRS 160964], Section 6.2.2.1), daily irrigation rate (BSC 2003 [DIRS 160976], Section 6.8), irrigation application (BSC 2003 [DIRS 160976], Section 6.7), irrigation intensity (BSC 2003 [DIRS 160976], Section 6.6), growing time (BSC 2003 [DIRS 160976], Section 6.4), water concentration modifying factor (BSC 2003 [DIRS 160964], Section 6.4.3), annual average wind speed (BSC 2003 [DIRS 160964], Section 6.7.2), and evaporative cooler use factor (BSC 2003 [DIRS 161241], Section 6.3.4.2). Additional biosphere characteristics are covered by other FEPs, such as climate change (FEP 1.3.01.00.0A), soil type (FEP 2.3.02.01.0A), and precipitation (FEP 2.3.11.01.0A).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs. For the TSPA scenarios classes (nominal and seismic) and modeling case (igneous intrusion) involving groundwater as a source of radionuclides, annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs generated in the biosphere model. Such an approach is possible because quantities calculated in the groundwater exposure scenario submodels of the biosphere model, including radionuclide concentrations in the environmental media and the annual dose from various exposure pathways, are proportional to the radionuclide concentration in the groundwater (BSC 2003 [DIRS 164186], Section 6.4.10.2). Thus, for this exposure scenario, the biosphere model contribution to the dose assessment (i.e., BDCFs) can be separated from the source (i.e., radionuclide concentration in the groundwater). The BDCF for a radionuclide is numerically equal to the dose for a unit activity concentration of the radionuclide in the water (BSC 2003 [DIRS 164186], Section 6.4.10.2). To support the assessment of doses in TSPA for the scenario classes and the modeling case involving radionuclide release to the groundwater, three different sets of groundwater exposure scenario BDCFs are generated, corresponding to modern, monsoon, and glacial transition climate states (BSC 2003 [DIRS 164186], Section 6.4.10.2).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. Because

variation in radionuclide concentrations in deposited volcanic ash is not part of the biosphere model, BDCFs are calculated based on a unit source in volcanic ash deposited on the ground (1 Bq/m^2) (BSC 2003 [DIRS 164186], Section 6.5). The TSPA model calculates radiation dose as a product of the time-dependent source term and the source-independent BDCFs. The time-dependent source term is subject to radioactive decay, volcanic ash redistribution, surface soil erosion, and other removal mechanisms (BSC 2003 [DIRS 164186], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.24 Radionuclide Alteration During Biosphere Transport (FEP 2.3.13.02.0A)

FEP Description–Once in the biosphere, radionuclides may be transported and transferred through and between different compartments of the biosphere. Temporally- and spatially-dependent physical and chemical environments in the biosphere may lead to alteration of both the physical and chemical properties of the radionuclides as they move through or between the different compartments of the biosphere. These alterations could consequently control exposure to the human population.

Descriptor Phrases– Radionuclide alteration (transport in the biosphere)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The biosphere model is constructed around the radionuclide transfer interaction matrix (BSC 2003 [DIRS 164186], Sections 6.3.1.3 and 6.3.2.3, for the groundwater and volcanic ash exposure scenarios, respectively), which is constructed to identify the important processes leading to radionuclide transfer between biosphere components. Most of these transfer processes involve the change of physical and chemical form of a radionuclide (alteration). The

example of the processes involving the change of the physical form include the release of ^{14}C, initially present in groundwater, from the soil to the air as $^{14}CO_2$ (BSC 2003 [DIRS 164186], Section 6.4.6.2) and from the surface water (fish ponds) to the air (BSC 2003 [DIRS 160964], Section 6.4.4), the plant uptake of carbon dioxide from the air (BSC 2003 [DIRS 164186], Section 6.4.6.3), and release of gaseous species during operation of evaporative coolers (BSC 2003 [DIRS 164186], Section 6.4.2.2). This FEP is also implicitly addressed through the use of steady-state radionuclide-specific and crop-type-specific soil-to-plant transfer factors (BSC 2003 [DIRS 160964], Section 6.2.1.2), and steady-state radionuclide-specific and animal-product-specific transfer factors (BSC 2003 [DIRS 160964], Section 6.3.3) in the plant and animal submodels, respectively as identified in the *Biosphere Model Report* (BSC 2003 [DIRS 164186], Sections 6.4 and 6.5).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

Note: This FEP was not listed as included in the analysis and model reports supporting biosphere modeling. This is because these reports used an earlier version of the FEP List (DTN: MO0303SEPFEPS2.000 [DIRS 162452]) that did not include FEP 2.3.13.02.0A. This FEP was restored with a modified scope in the subsequent iteration of the FEP List (DTN: MO0307SEPFEPS4.000 [DIRS 164527]) and, as such, is considered in the biosphere model as described above.

6.2.25 Radionuclide Release Outside the Reference Biosphere (FEP 2.3.13.04.0A)

FEP Description–Releases outside the reference biosphere can occur. This could include areas surrounding distant springs and surface water bodies (such as at Ash Meadows), remote natural outfalls, or discharge areas such as playas (e.g. Franklin Playa), or forests, grasslands, or wetlands that occur is isolated areas in the region. This might also include withdrawal from wells in remote areas. Radionuclide accumulation could occur in these areas. Sediment transport and redistribution may cause concentration or dilution of radionuclides. Flora and fauna in these areas may be exposed and radionuclides be bioaccumulated and enter the food chain. Intermittent use of these areas by humans may also lead to exposure.

Descriptor Phrases– Land use
Water use
Radionuclide release to biosphere (wells away from receptor)
Radionuclide accumulation (soil away from receptor)
Surface water transport
Radionuclide accumulation (plants away from receptor)
Radionuclide accumulation (animals away from receptor)

Screening Decision–Excluded by regulation.

Screening Argument– Reference biosphere is defined as the description of the environment inhabited by the RMEI (10 CFR 63.2 [DIRS 156605]). FEPs that describe the reference biosphere are those that affect the RMEI. FEPs that occur outside the reference biosphere do not influence the radionuclide transport and exposure pathways for the RMEI and are not included. Postclosure performance objectives for the repository include the requirement that doses to the RMEI are within the specified limits 10 CFR 63.113(b) [DIRS 156605]. The rule also specifies criteria that pertain to the characteristics of a reference biosphere that are required to show compliance with the postclosure standards for disposal (66 FR 55732 [DIRS 156671], p. 55733). Similarly, the preamble to the rule states that Section 63.305, *Required Characteristics of the Reference Biosphere*, specifies characteristics of the reference biosphere to be used by DOE in its performance assessment to demonstrate compliance with the requirements specified at 10 CFR 63.113(b) and (d) (66 FR 55732 [DIRS 156671], p. 55784). Since the demonstration of compliance specifies conditions of the reference biosphere, the FEPs related to any processes occurring outside the reference biosphere are implicitly excluded. Therefore, radionuclide release outside the reference biosphere is excluded on the basis of inconsistency with the requirements of 10 CFR 63.113(b) [DIRS 156605].

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.26 Human Characteristics (Physiology, Metabolism) (FEP 2.4.01.00.0A)

FEP Description–This FEP addresses human characteristics. These include physiology, metabolism, and variability among individual humans.

Descriptor Phrases– Physiology

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Characteristics of the human receptor, the RMEI, are representative of the physiology and metabolic characteristics of adults, consistent with 10 CFR 63.312(e) [DIRS 156605], which specifies that the RMEI is an adult. As a result, consideration is limited to the physiology and metabolic characteristics of adults. Elements of human physiology and metabolism are inherent in the dose conversion factors (conversion factors from radionuclide intake to dose) used in the biosphere model and in the breathing rates. These parameters are used, and thus this FEP is addressed, in the external exposure, inhalation, and ingestion submodels through the use of dose coefficients (BSC 2003 [DIRS 161241], Section 6.5.3.1), dose conversion factors (BSC 2003 [DIRS 161241], Section 6.5.3.2), and breathing rates (BSC 2003 [DIRS 161241], Section 6.3.3) that are based on adult human physiologic and metabolic characteristics. Variability among individual humans adds to the uncertainty in the values of parameters that depend on human characteristics, such as dose conversion factors and dose coefficients. Uncertainty in these parameters is discussed in BSC (2003 [161241], Section 6.5.5.2).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.27 Human Lifestyle (FEP 2.4.04.01.0A)

FEP Description–Human lifestyle, including everyday household activities and leisure activities, will influence the critical exposure pathways to man.

Descriptor Phrases– Lifestyle
Radionuclide exposure

Screening Decision–Included

Screening Argument–N/A

TSPA Disposition–Aspects of human lifestyle including work and leisure activities that are included in TSPA are representative of the residents of Amargosa Valley. This is consistent with 10 CFR 63.312(b) [DIRS 156605], which states that the lifestyle of the RMEI must be based on the people who reside in the Amargosa Valley. Human lifestyle information is used to select values for exposure parameters, which, in addition to food and water consumption rates (FEP 3.3.04.01.0A, *Ingestion*), include the amount of time spent indoors and outdoors for work and recreation. The current lifestyle also includes certain uses of wild and natural resources (e.g., hunting and consumption of game products) (see FEP 2.4.08.00.0A) but it is inconsistent with the hunter/gatherer lifestyle. This FEP is considered in the air, external exposure, inhalation, and ingestion submodels of the biosphere model.

Distributions of the parameters related to human lifestyle are based, in part, on variation and uncertainty of the lifestyles and characteristics of people living in Amargosa Valley (BSC 2003 [DIRS 160965], Sections 6.1 and 6.2; BSC 2003 [DIRS 161241], Sections 6.3 and 6.4). Influence of human lifestyle on external exposure is considered in BSC (2003 [DIRS 164186], Eq. 6.4.7-1 for the groundwater exposure scenario; Eq. 6.5.5-1 for the volcanic ash exposure scenario). Influences on inhalation pathway considered in BSC (2003 [DIRS 164186], Eqs. 6.4.8-2 to 6.4.8-7 for the groundwater exposure scenario; Eqs. 6.5.6-2 and 6.5.6-3 for the volcanic ash exposure scenario). Influences on the ingestion pathway are considered in BSC (2003 [DIRS 164186], Eqs. 6.4.9-2 to 6.4.9-6 for the groundwater exposure scenario; Eqs. 6.5.7-2 to 6.5.7-4 for the volcanic ash exposure scenario). The following parameters address this FEP: mass loading for receptor environments (BSC 2003 [DIRS 160965], Sections 6.1.1 to 6.1.4 and 6.2.1 to 6.2.4), population proportion (BSC 2003 [DIRS 161241], Sections 5.1 and 6.3.1), exposure time (BSC 2003 [DIRS 161241], Section 6.3.2), evaporative cooler usage factor (BSC 2003 [DIRS 161241], Section 6.3.4.2), fraction of house with evaporative cooler (BSC 2003 [DIRS 161241], Section 6.3.4.1), and consumption rates for water locally produced foodstuffs (crops, animal products and fish) and soil (BSC 2003 [DIRS 161241], Sections 6.4.2 and 6.4.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.28 Dwellings (FEP 2.4.07.00.0A)

FEP Description–This FEP addresses human dwellings, and the ways in which dwellings might affect human exposures. Exposure pathways might be influenced by building materials and location.

Descriptor Phrases– Lifestyle
Radionuclide exposure (dwellings)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The choice of dwellings is one of the attributes of a lifestyle (FEP 2.4.04.01.0A). Characteristics of dwellings that are included in TSPA are representative of the residents of Amargosa Valley, consistent with 10 CFR 63.312(b) [DIRS 156605], which states that the lifestyle of the RMEI must be based on the people who reside in the Amargosa Valley. The location of dwellings that are included in the TSPA-LA model is consistent with the location of the RMEI, above the highest concentration of radionuclides in the plume of contamination, consistent with 10 CFR 63.312(a) [DIRS 156605].

This FEP is incorporated into the biosphere model through consideration of the characteristics of the dwellings in Amargosa Valley and their effects on the inhalation and external exposure pathways. Data from *The 1997 "Biosphere" Food Consumption Survey Summary Findings and Technical Documentation* (DOE 1997 [DIRS 100332], Table 2.4.2) indicate that the predominant

housing type is a trailer or mobile home and that most residences have evaporative coolers. This information was used in selecting values for several pertinent parameters. This FEP is addressed in the air, inhalation, and external exposure submodels by including characteristics of the dwellings in the Amargosa Valley and their effects on the inhalation and external exposure pathways (BSC 2003 [DIRS 164186], Table 6.2-1).

The parameter distributions used in the biosphere model are based in part on uncertainty and variation in the characteristics of types of dwellings in Amargosa Valley. Specifically, this FEP is addressed through the following parameters: evaporative cooler water evaporation rate (BSC 2003 [DIRS 160964], Section 6.5.2), evaporative cooler air flow rate (BSC 2003 [DIRS 160964], Section 6.5.2), interior wall height (BSC 2003 [DIRS 160964], Section 6.5.2 and 6.6.2), house ventilation rate (BSC 2003 [DIRS 160964], Section 6.6.2), building shielding factor (BSC 2003 [DIRS 161241], Section 6.6) (shielding provided by building materials), fraction of houses with evaporative coolers (BSC 2003 [DIRS 161241], Section 6.3.4.1), and evaporative cooler use factor (BSC 2003 [DIRS 161241], Section 6.3.4.2).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.29 Wild and Natural Land and Water Use (FEP 2.4.08.00.0A)

FEP Description–This FEP addresses human uses of wild and natural lands (forests, bush, coastlines) and water (lakes, rivers, oceans) that may affect the long-term performance of the repository. Wild and natural land use will be primarily controlled by natural factors (topography, climate, etc.).

Descriptor Phrases– Lifestyle
Land use
Water use

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The lifestyle and behaviors of the current residents of Amargosa Valley implicitly include certain uses of wild and natural lands and water. Consistent with 10 CFR 63.312(b) [DIRS 156605], which states that the RMEI has a diet and lifestyle representative of the current residents of Amargosa Valley, and with 10 CFR 63.305(a) [DIRS 156605], that requires that the reference biosphere shall be consistent with present knowledge of the conditions in the region, future uses of wild and natural lands and water are assumed to be the same as the current uses.

This FEP is incorporated in the biosphere model by combining the consumption of game with the consumption rate for all meats and by considering the time the RMEI spends in the indoor versus outdoor environment (BSC 2003 [DIRS 164186], Table 6.2-1). This FEP is addressed in the air, external exposure and ingestion submodels of the biosphere model. The parameters that address this FEP are mass loading for receptor environments (BSC 2003 [DIRS 160965], Sections 6.1.1 to 6.1.4 and 6.2.1 to 6.2.4), exposure time (BSC 2003 [DIRS 161241], Section 6.3.2), and annual consumption rate of locally produced animal products (BSC 2003 [DIRS 161241], Section 6.4.2).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])

6.2.30 Implementation of New Agricultural Practices or Land Use (FEP 2.4.09.01.0A)

FEP Description–Agricultural land use depends on many interrelated factors including climate, geology, topography, human lifestyle, and economics. Land use may include practices such as traditional crop farming, greenhouses, and hydroponics. Agricultural practices have the potential for radionuclide transfer through the food chain and may influence alternate pathways. Changes in current agricultural practices could change the significance of various exposure pathways.

Descriptor Phrases– Lifestyle
Land use
Water use

Screening Decision–Excluded by regulation.

Screening Argument–Implementation of new agricultural practices and land use is excluded on the basis of inconsistency with regulatory requirements of 10 CFR 63.305(b) [DIRS 156605]. Regulation 10 CFR 63.305(b) [DIRS 156605] states "DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology. In all analyses done to demonstrate compliance with this part, the DOE must assume that all of those factors remain constant as they are at the time of submission of the license application." Implementation of new agricultural practices and land use is also inconsistent with 10 CFR 63.312(b) [DIRS 156605], which states that the RMEI "has a diet and lifestyle representative of the people who now reside in the Town of Amargosa Valley". Therefore, implementation of new agricultural practices (e.g., greenhouses, hydroponics) or land use (e.g., change to a hunter-gatherer use) is excluded by regulation.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.31 Agricultural Land Use and Irrigation (FEP 2.4.09.01.0B)

FEP Description–Agricultural areas exist near Yucca Mountain, particularly in the direction of groundwater flow. Current practices include irrigation, plowing, fertilization, crop storage, and soil modification and amendment. Existing practices may play a significant role in determining exposure pathways and dose.

Descriptor Phrases– Lifestyle
Land use
Water use
Radionuclide accumulation (plants)
Radionuclide release to the biosphere (irrigation water)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The lifestyle and behaviors of the current residents of Amargosa Valley includes agricultural land use and irrigation (BSC 2003 [160976], Appendix A). Consistent with 10 CFR 63.312(b) [DIRS 156605], which states that the RMEI has a diet and lifestyle representative of the current residents of Amargosa Valley, and with 10 CFR 63.305(a) [DIRS 156605], that requires that the reference biosphere shall be consistent with present knowledge of the conditions in the region, future agricultural practices are assumed to be the same as the current practices.

This FEP is considered in the soil, air, plant, animal, ^{14}C, and fish submodels of the biosphere model (BSC 2003 [DIRS 164186], Table 6.7-1). Agricultural land use and irrigation are represented in the model through irrigation techniques including the fraction of overhead irrigation (BSC 2003 [DIRS 160976], Section 6.3), annual average irrigation rate (BSC 2003 [DIRS 160976], Sections 6.5), overwatering rate (BSC 2003 [DIRS 160976], Section 6.9), mass loading for receptor environments (BSC 2003 [DIRS 160965], Sections 6.1.1 to 6.1.4 and 6.2.1 to 6.2.4), mass loading for crops (BSC 2003 [DIRS 160965], Section 6.2.5), crop growing time (BSC 2003 [DIRS 160976], Section 6.4), tillage depth (BSC 2003 [DIRS 160976], Section 6.10), irrigation intensity (BSC 2003 [DIRS 160976], Section 6.6), irrigation amount per application (BSC 2003 [DIRS 160976], Section 6.7), daily irrigation rate (BSC 2003 [DIRS 160976], Section 6.8), animal consumption rate of water (BSC 2003 [DIRS 160964], Section 6.3.2), surface area of irrigated land (BSC 2003 [DIRS 160964], Section 6.7.2), and water concentration modifying factor (BSC 2003 [DIRS 160964], Section 6.4.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. This FEP is also dispositioned in TSPA through the use of volcanic ash exposure scenario BDCFs that are used as input parameters for the volcanic eruption modeling case.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.32 Animal Farms and Fisheries (FEP 2.4.09.02.0A)

FEP Description–Domestic livestock or fish could become contaminated through the intake of contaminated feed, water, or soil. Such contamination would then enter the food chain.

Descriptor Phrases– Lifestyle
Land use
Water use
Radionuclide accumulation (livestock)
Radionuclide accumulation (fish)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The lifestyle and behaviors of the current residents of Amargosa Valley includes animal farms and fisheries. Socioeconomic and dietary survey data (DOE 1997 [DIRS 100332], Section 2.3) indicate that residents raise and consume locally produced domestic livestock and fish. Consistent with 10 CFR 63.312(b) [DIRS 156605], which states that the RMEI has a diet and lifestyle representative of the current residents of Amargosa Valley, and with 10 CFR 63.305(a) [DIRS 156605], that requires that the reference biosphere shall be consistent with present knowledge of the conditions in the region, future use of animal farms and fisheries is assumed to be the same as the current use.

This FEP is addressed in the animal and fish submodels of the biosphere model (BSC 2003 [DIRS 164186], Table 6.7-1) and is represented in the model by animal consumption rates of locally produced feed, contaminated water, and contaminated soil (BSC 2003 [DIRS 160964], Section 6.3.2) and water concentration modifying factor (BSC 2003 [DIRS 160964], Section 6.4.3). Relevant parameters are developed based in part on variation and uncertainty in animal and fish farming practices in Amargosa Valley.

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. This FEP is also dispositioned in TSPA through the use of volcanic ash exposure scenario BDCFs that are used as input parameters for the volcanic eruption modeling case.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.33 Urban and Industrial Land and Water Use (FEP 2.4.10.00.0A)

FEP Description–This FEP addresses urban and industrial uses of land and water (industry, urban development, earthworks, energy production, etc.) that may affect the long-term performance of the repository. Urban and industrial land use will be controlled by both natural factors (topography, climate, etc.) and human factors (economics, population density, etc.).

Descriptor Phrases– Lifestyle
Land use
Water use
Surface activities (industrial)
Surface activities (urban)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–The lifestyle and behaviors of the current residents of Amargosa Valley implicitly include certain uses of urban and industrial land and water. Consistent with 10 CFR 63.312(b) [DIRS 156605], which states that the RMEI has a diet and lifestyle representative of the current residents of Amargosa Valley, and with 10 CFR 63.305(a) [DIRS 156605], that requires that the reference biosphere shall be consistent with present knowledge of the conditions in the region, future uses of urban and industrial land and water are assumed to be the same as the current uses.

This FEP is addressed in the model by considering land and water use practices in residential and industrial settings in Amargosa Valley (BSC 2003 [DIRS 160965], Section 6.1 and 6.2; BSC 2003 [DIRS 161241], Section 6.3.2; BSC 2003 [DIRS 160964], Section 6.5). The use of contaminated water in residential and urban environments is included in the soil submodel (BSC 2003 [DIRS 164186], Eq. 6.4.1-2) and air submodel (BSC 2003 [DIRS 164186], Eq. 6.4.2-3) of the groundwater exposure scenario. The biosphere model also implicitly includes urban industrial land and water use through the proportion of time that the RMEI spends away from the agricultural environment. Parameters that address urban and industrial land and water use are annual average irrigation rate (BSC 2003 [DIRS 160976], Sections 6.5), mass loading for the receptor environments (BSC 2003 [DIRS 160965], Sections 6.1.1. to 6.1.4 and 6.2.1 to 6.2.4), evaporative cooler water evaporation rate (BSC 2003 [DIRS 160964], Section 6.5.2) and exposure time (BSC 2003 [DIRS 161241], Section 6.3.2).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. This FEP is also dispositioned in TSPA through the use of volcanic ash exposure scenario BDCFs that are used as input parameters for the volcanic eruption modeling case.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])

- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.34 Radioactive Decay and Ingrowth (FEP 3.1.01.01.0A)

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

Descriptor Phrases– Radioactive decay and ingrowth

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Radionuclide decay and ingrowth in surface soils is included in the soil (BSC 2003 [DIRS 164186], Eq. 6.4.1-9), external exposure (BSC 2003 [DIRS 164186], Eq. 6.4.7-1), inhalation (BSC 2003 [DIRS 164186], Eqs. 6.4.8-2 to 6.4.8-7), and ingestion (BSC 2003 [DIRS 164186], Eq. 6.4.9-3 to 6.4.9-6) submodels of the groundwater exposure scenario. It is also included in the external exposure (BSC 2003 [DIRS 164186], Eq. 6.5.5-1), inhalation (BSC 2003 [DIRS 164186], Eq. 6.5.6-2 to 6.5.6-4), and ingestion (BSC 2003 [DIRS 164186], Eq. 6.5.7-2 to 6.5.7-4) submodels of the volcanic ash exposure scenario. This FEP is also included in associated dose conversion factors and dose coefficients (BSC 2003 [DIRS 161241], Section 6.5). Specifically, this FEP is included in the calculation of effective dose coefficients (for external dose) and effective dose conversion factors (for inhalation and ingestion dose). These factors include dose contributions from short-lived decay products of the primary radionuclides. Radionuclide decay and ingrowth is also included in calculations of radionuclide build up in the soil. The associated input parameters include dose coefficients (BSC 2003 [DIRS 161241], Section 6.5.3.1), and dose conversion factors (BSC 2003 [DIRS 161241], Sections 6.5.3.2 and 6.5.4).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. This FEP is also dispositioned in TSPA through the use of volcanic ash exposure scenario BDCFs that are used as input parameters for the volcanic eruption modeling case.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.35 Atmospheric Transport of Contaminants (FEP 3.2.10.00.0A)

FEP Description–Atmospheric transport includes radiotoxic and chemotoxic species in the air as gas, vapor, particulates or aerosol. Transport processes include wind, plowing and irrigation, degassing, saltation, and precipitation.

Descriptor Phrases– Atmospheric transport in the biosphere

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Atmospheric transport of radionuclides is included in the biosphere model through the effects of resuspension of contaminated soil, gaseous emission of radionuclides from soil to air followed by atmospheric dispersion, deposition of airborne particulate mater, as well as generation of atmospheric aerosols (evaporative cooler), and gases (radon and ^{14}C). The biosphere model does not include processes related to long-range atmospheric transport and dispersion of airborne radionuclides. Chemotoxic species are outside the scope of performance assessment because the performance standards for the repository do not concern chemical toxicity.

The process of atmospheric transport is included in the air submodel for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Eqs. 6.4.2-1 to 6.4.2-8), the air submodel for the volcanic ash exposure scenario (BSC 2003 [DIRS 164186], Eqs. 6.5.2-1 to 6.5.2-8), and the ^{14}C special submodel for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Eq. 6.4.6-2 and 6.4.6-3). The associated parameters include mass loading for crops (BSC 2003 [DIRS 160965], Sections 6.1.5 and 6.2.5), mass loading for the receptor environments (BSC 2003 [DIRS 160965], Sections 6.1.1 to 6.1.4 and 6.2.1 to 6.2.4), soil bulk density (BSC 2003 [DIRS 161239], Section 6.2), resuspension enhancement factor (BSC 2003 [DIRS 161239], Section 6.5), fraction of radionuclides transferred from water to air (BSC 2003 [DIRS 160964], Section 6.5.2), water evaporation rate for evaporative coolers (BSC 2003 [DIRS 160964], Section 6.5.2),

evaporative cooler air flow rate (BSC 2003 [DIRS 160964], Section 6.5.2), radon release factor (BSC 2003 [DIRS 160964], Section 6.6.1), interior wall height (BSC 2003 [DIRS 160964], Section 6.6.2), house ventilation rate (BSC 2003 [DIRS 160964], Section 6.6.2), fraction of ^{222}Rn from soil entering the house (BSC 2003 [DIRS 160964], Section 6.6.2), ratio of ^{222}Rn concentration in air to flux density from soil (BSC 2003 [DIRS 160964], Section 6.6.1), ^{14}C release rate (BSC 2003 [DIRS 160964], Section 6.7.2), surface area of irrigated land (BSC 2003 [DIRS 160964], Section 6.7.2), annual average wind speed (BSC 2003 [DIRS 160964], Section 6.7.2), ^{14}C mixing height (BSC 2003 [DIRS 160964], Section 6.7.2), and concentration of stable carbon in air (BSC 2003 [DIRS 160964], Section 6.7.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 161239])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.36 Contaminated Drinking Water, Foodstuffs and Drugs (FEP 3.3.01.00.0A)

FEP Description–This FEP addresses human diet and fluid intake. Consumption of food, water, soil, drugs, etc., will affect human exposure to radionuclides. Other influences include filtration of water, dilution of diet with uncontaminated food, and food preparation techniques.

Descriptor Phrases– Lifestyle
Radionuclide exposure (food)
Radionuclide exposure (drinking water)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Dietary survey data (DOE 1997 [DIRS 100332], Section 2.3) indicate that residents consume locally grown foods and groundwater. The consumption of contaminated locally grown crops, animal products, fish, as well as water and soil, is addressed in the ingestion submodel of the biosphere model through the consumption rates of these media (BSC 2003 [DIRS 161241], Sections 6.4.2 and 6.4.3). The biosphere model conservatively does not consider radioactivity loss due to filtration of water or food preparation. Consumption rates used in the model only concern locally produced crops and animal products and are based on the survey of the Amargosa Valley population. Uncontaminated food is not included in the model because it does not contribute to the dose to the receptor. There is no evidence of the production of drugs in Amargosa Valley using local materials.

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])

- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.37 Plant Uptake (FEP 3.3.02.01.0A)

FEP Description–Uptake and accumulation of contaminants by plants could affect potential exposure pathways. Plant uptake from contaminated soils and irrigation water is possible. Particulate deposition onto plant surfaces is also possible. These plants may be used as feed for livestock and/or consumed directly by humans.

Descriptor Phrases– Lifestyle
Radionuclide accumulation (plants)
Radionuclide release to biosphere (irrigation water)
Radionuclide accumulation (bioconcentration, biomagnification)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–A dietary survey (DOE 1997 [DIRS 100332], Section 2.3) indicates that Amargosa Valley residents consume locally grown crops from home gardens with water for these gardens obtained from a local ground source. The human ingestion pathway represented by this consumption includes plant uptake of radionuclides, deposition of radionuclides on plant surfaces, and subsequent transfer to humans via ingestion. Two plant uptake routes are included in the biosphere model: root uptake and direct deposition on crops due to the interception of irrigation water and resuspended particulates. Crops considered in the model include leafy vegetables, other vegetables, fruit, grain, and animal feed (BSC 2003 [DIRS 164186], Table 6.2-1). The process of plant uptake of radionuclides (also referred to as radionuclide accumulation, bioconcentration, or biomagnification) is included in the plant submodel for the groundwater (BSC 2003 [DIRS 164186], Eqs. 6.4.3-1 to 6.4.3-8) and volcanic ash exposure scenarios (BSC 2003 [DIRS 164186], Eqs. 6.5.3-1 to 6.5.3-5), and in the ^{14}C special submodel for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Eqs. 6.4.6-4 and 6.4.6-6).

There are a number of model parameters related to plant uptake associated with these submodels including soil-to-plant transfer factor (BSC 2003 [DIRS 160964], Section 6.2.1.2), dry-to-wet ratio (BSC 2003 [DIRS 160976], Section 6.2), fraction of overhead irrigation (BSC 2003 [DIRS 160976], Section 6.3), translocation factor (BSC 2003 [DIRS 160964], Section 6.2.2.2), weathering half-life (BSC 2003 [DIRS 160964], Section 6.2.2.3), crop growing time (BSC 2003 [DIRS 160976], Section 6.4), crop wet yield (BSC 2003 [DIRS 160976], Section 6.11), daily irrigation rate (BSC 2003 [DIRS 160976], Section 6.8), crop dry biomass (BSC 2003 [DIRS 160976], Section 6.1), irrigation amount per application (BSC 2003 [DIRS 160976], Section 6.7), irrigation intensity (BSC 2003 [DIRS 160976], Section 6.6), dry deposition velocity (BSC 2003 [DIRS 160964], Section 6.2.2.1), soil bulk density (BSC 2003 [DIRS 161239], Section 6.2), fraction of air-derived carbon in plants (BSC 2003 [DIRS 160964], Section 6.7.3), fraction

of soil-derived carbon in plants (BSC 2003 [DIRS 160964], Section 6.7.3), fraction of stable carbon in plants (BSC 2003 [DIRS 160964], Section 6.7.3), fraction of stable carbon in soil (BSC 2003 [DIRS 160964], Section 6.7.3), and concentration of stable carbon in air and soil (BSC 2003 [DIRS 160964], Section 6.7.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 161239])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.38 Animal Uptake (FEP 3.3.02.02.0A)

FEP Description–Livestock may accumulate radionuclides as a result of ingestion of water, feed and soil/sediment and inhalation of aerosols and particulates. Depending on the livestock, they may be used for human consumption directly, or their produce (milk, eggs, etc.) may be consumed.

Descriptor Phrases– Lifestyle
Radionuclide accumulation (livestock)
Radionuclide accumulation (bioconcentration, biomagnification)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–A dietary survey (DOE 1997 [DIRS 100332], Section 2.3) indicates that Amargosa Valley residents consume locally produced animal products. The human ingestion pathway represented by this consumption includes radionuclide accumulation in animals and their products, and subsequent transfer to humans via ingestion. Three mechanisms of animal uptake are included in the model: consumption of contaminated water, feed, and soil. Radionuclide concentrations are calculated using steady-state transfer factors. Animal products include meat, milk, poultry, and eggs (BSC 2003 [DIRS 164186], Table 6.2-1). This FEP is addressed in the animal and ^{14}C submodels of the biosphere model (BSC 2003 [DIRS 164186], Table 6.7-1). For the groundwater exposure scenario, the animal uptake submodel includes ingestion of contaminated water, animal feed, and soil to assess the resulting radionuclide concentrations in animal products (BSC 2003 [DIRS 164186], Eqs. 6.4.4-1 to 6.4.4-4 for the groundwater exposure scenario and Eqs. 6.5.4-1 to 6.5.4-3 for the volcanic ash exposure scenario), and in the ^{14}C special submodel for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Eq. 6.4.6-7). The contribution of inhaled contaminated soil to the activity concentration in an animal product was evaluated and found to be inconsequential (BSC 2003 [DIRS 164186], Section 7.4.5). As a result, this subpathway was not considered.

The following input parameter support modeling of animal uptake: animal transfer coefficients (BSC 2003 [DIRS 160964], Section 6.3.3), animal consumption rate of feed, water and soil (BSC 2003 [DIRS 160964], Section 6.3.2), fraction of stable carbon in animal products (BSC 2003 [DIRS 160964], Section 6.7.4), fraction of stable carbon in crops (BSC 2003 [DIRS 160964], Section 6.7.3), and concentration of stable carbon in farm animal water (BSC 2003 [DIRS 160964], Section 6.7.4).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.39 Fish uptake (FEP 3.3.02.03.0A)

FEP Description–Uptake and bioaccumulation of contaminants in aquatic organisms could affect potential exposure pathways.

Descriptor Phrases– Lifestyle
Radionuclide accumulation (fish)
Radionuclide accumulation (bioaccumulation)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Uptake of radionuclides by aquatic organisms is a process that is expected to occur during commercial fish farming. A dietary survey (DOE 1997 [DIRS 100332], Section 2.3) indicates that Amargosa Valley residents consumed locally grown fish; therefore the accumulation of radionuclides in aquatic organisms is included.

This FEP applies to the uptake of radionuclides by fish due to the use of contaminated groundwater in fish farming. The fish uptake FEP is addressed in the fish submodel (BSC 2003 [DIRS 164186], Section 6.4.5) that includes the bioaccumulation of radionuclides in fish (BSC 2003 [DIRS 164186], Eqs. 6.4.5-1 and 6.4.5-2). The transfer process, as represented by the bioaccumulation factor, is based on an equilibrium between radionuclide concentrations in the water, the aquatic environment, and concentrations in the edible part of fish (BSC 2003 [DIRS 160964], Section 6.4.1). Because the fish are fed uncontaminated, commercially-produced feed (Roe 2002 [DIRS 160674], p. 2), bioaccumulation factors provide an upper bound of activity concentration in the fish. The parameters involved in modeling of this process include the bioaccumulation factor (BSC 2003 [DIRS 160964], Section 6.4.3) and fishpond water concentration modifying factor (BSC 2003 [DIRS 160964], Section 6.4.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])

6.2.40 Contaminated Non-Food Products and Exposure (FEP 3.3.03.01.0A)

FEP Description–Contaminants may be concentrated in various products: clothing (e.g., hides, leather, linen, wool); furniture (e.g., wood, metal); building materials (e.g., stone, clay for bricks, wood, dung); fuel (e.g., peat), tobacco, pets.

Descriptor Phrases– Lifestyle
Radionuclide exposure (non-food products)
Radionuclide exposure (dwellings)
Radionuclide exposure (external)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition– The use of contaminated non-food products by the RMEI is consistent with requirements of 10 CFR 63.312(b) and 10 CFR 63.312(c) [DIRS 156605]. Regulation 10 CFR 63.312(b) [DIRS 156605] states that the RMEI has a lifestyle representative of people residing in the Amargosa Valley. Regulation 10 CFR 63.312(c) [DIRS 156605] specifies that the RMEI uses water from a well with average concentrations of radionuclides based on a specified annual water demand.

Contamination of non-food products mainly causes external exposure. This FEP is implicitly considered in the model because the exposure to non-food products, in general, is lower than that to contaminated soil, which is the medium that contains the majority of the radionuclide inventory in the biosphere. This FEP is implicitly considered in the external exposure submodels of the groundwater (BSC 2003 [DIRS 164186], Section 6.4.7) and volcanic ash (BSC 2003 [DIRS 164186], Section 6.5.5) exposure scenarios. Parameters that address this FEP are the same as those for FEP 3.3.04.03.0A. Other possible pathways resulting from exposure to contaminated non-food products include the use of locally grown tobacco products. However, the socioeconomic surveys conducted in Amargosa Valley (CRWMS M&O 1997 [DIRS 101090], Section 3.4; YMP 1999 [DIRS 158212], Section 3.4) and other biosphere studies (Horak and Carns 1997 [DIRS 124149]) did not provide evidence of this crop in Amargosa Valley.

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. This FEP is also dispositioned in TSPA through the use of volcanic ash exposure scenario BDCFs that are used as input parameters for the volcanic eruption modeling case.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.41 Ingestion (FEP 3.3.04.01.0A)

FEP Description–Ingestion is human exposure to repository-derived radionuclides through eating contaminated foodstuffs or drinking contaminated water.

Descriptor Phrases– Lifestyle
Physiology
Radionuclide exposure (ingestion - food)
Radionuclide exposure (ingestion - drinking water)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Dietary survey data (DOE 1997 [DIRS 100332], Section 2.3) indicate that consumption of groundwater and locally grown livestock and fish does occur. This FEP is addressed through the ingestion rates of contaminated locally-produced food and groundwater in the ingestion submodel (BSC 2003 [DIRS 164186], Table 6.7-1). For the groundwater exposure scenario, the ingestion exposure pathways include consumption of water from a groundwater well; locally produced plant foodstuffs, animal products, and fish; as well as inadvertent soil ingestion (BSC 2003 [DIRS 164186], Section 6.3.1.5). For the volcanic activity scenario, only the ingestion of locally produced plant foodstuffs, animal products, and inadvertent soil ingestion are considered (BSC 2003 [DIRS 164186], Section 6.3.2.5).

Within the mathematical representation of this submodel for the groundwater exposure pathway (BSC 2003 [DIRS 164186], Section 6.4.9, Eqs. 6.4.9-1 to 6.4.9-6), the annual water consumption rater is defined at 2 liters per day, as specified at 10 CFR 63.312(d) ([DIRS 156605]). Exposure to contaminated plant foodstuff is addressed through annual consumption rate of each of four locally grown crop food types (BSC 2003 [DIRS 161241], Section 6.4.2) and their associated radionuclide-specific activity concentration (BSC 2003 [DIRS 164186], Section 6.4.3). Selection of crop types used in the biosphere model is addressed in BSC (2003 [DIRS 164186], Section 6.4.3). Similarly, exposure to contaminated animal products is the product of the consumption rate of each of four types of locally produced animal products (BSC 2003 [DIRS 161241], Section 6.4.2) and their associated radionuclide-specific activity concentration (BSC 2003 [DIRS 164186], Section 6.4.4). Selection of animal product types used in the biosphere model is discussed in BSC (2003 [DIRS 164186], Section 6.4.4). Ingestion of fish is addressed within this submodel as the annual consumption rate of locally produced fish (BSC 2003 [DIRS 161241], Section 6.4.2) times the radionuclide-specific activity concentration in fish (BSC 2003

[DIRS 164186], Section 6.4.5). The inadvertent intake of soil, contaminated as a result of long-term irrigation of crops, is addressed in this submodel as the product of the mass activity concentration of each of the primary radionuclides in soil (BSC 2003 [DIRS 164186], Section 6.4.1) times the annual consumption rate of soil (BSC 2003 [DIRS 161241], Section 6.4.3). The mathematical representation of this submodel for the volcanic activity scenario is similar to that for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Section 6.5.7, Eqs. 6.5.7-1 to 6.5.7-4). The consumption of contaminated water, and crop and animal products, contaminated as a result of irrigation, are not considered because the groundwater is assumed to be uncontaminated for this exposure scenario.

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.42 Inhalation (FEP 3.3.04.02.0A)

FEP Description–Two inhalation pathways are likely. The first is inhalation of gases and vapors emanating directly from the ground after transport through the far-field. The second is inhalation of suspended, contaminated particulate matter (e.g., daughter products of radon, dust, smoke, pollen, and soil particles).

Descriptor Phrases– Lifestyle
Physiology
Radionuclide exposure (inhalation)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Inhalation of gases, vapors, and suspended particulate matter are processes by which the RMEI may be exposed to radionuclides in the reference biosphere. This FEP is addressed in the inhalation submodels for the groundwater (BSC 2003 [DIRS 164186], Section 6.4.8) and the volcanic ash (BSC 2003 [DIRS 164186], Section 6.5.6) exposure scenarios through the inhalation of resuspended particles, aerosols from evaporative coolers, and gases (e.g., radon, and ^{14}C). The inhalation submodel for the groundwater exposure scenario includes inhalation of contaminated resuspended particles, aerosols from evaporative coolers, ^{14}C, and radon decay products (BSC 2003 [DIRS 164186], Eqs. 6.4.8-1 to 6.4.8-7). For the volcanic ash exposure scenario (BSC 2003 [DIRS 164186], Eqs. 6.5.6-1 to 6.5.6-4), inhalation of ^{14}C is not included because ^{14}C is not a primary radionuclide for this scenario. Also, inhalation of atmospheric aerosols produced by evaporative coolers is not considered in this scenario because the groundwater is uncontaminated (BSC 2003 [DIRS 164186], Section 6.3.2).

Within the mathematical representations of this FEP human lifestyles, behavior, and physiology are accounted for through the use of the following parameters: environment-specific breathing rates (BSC 2003 [DIRS 161241], Section 6.3.3), population proportions (BSC 2003 [DIRS 161241], Section 6.3.1), and environment- and population group-specific exposure times (BSC 2003 [DIRS 161241], Section 6.3.2). The exposure source terms for the submodels are quantified, as applicable, by the following parameters: activity concentration in air for radionuclides attached to resuspended particle (BSC 2003 [DIRS 164186], Section 6.4.2.1 and 6.5.2.1), activity concentration in air for radionuclides resulting from the use of an evaporative cooler (BSC 2003 [DIRS 164186], Section 6.4.2.2), activity concentration of ^{14}C in air (BSC 2003 [DIRS 164186], Section 6.4.6.2), and activity concentration of ^{222}Rn in air (BSC 2003 [DIRS 164186], Section 6.4.2.3 and 6.5.2.2). The other parameters of the inhalation submodel include dose conversion factors for inhalation (BSC 2003 [DIRS 161241], Section 6.5.3.1 and 6.5.4), mass loading for the receptor environments (BSC 2003 [DIRS 160965], 6.1.1 to 6.1.4 and 6.2.1 to 6.2.4), and equilibrium factor for ^{222}Rn decay products (BSC 2003 [DIRS 160964], Section 6.6.3).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash

thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160965])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.43 External Exposure (FEP 3.3.04.03.0A)

FEP Description–External exposure is human exposure to repository-derived radionuclides by contact, use, or exposure to contaminated materials.

Descriptor Phrases– Lifestyle
Physiology
Radionuclide exposure (external)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–External exposure to radionuclides through the use of, contact with, or exposure to contaminated materials are processes that may lead to the RMEI being exposed depending upon lifestyle. The lifestyle of the Amargosa Valley residents include people coming in contact with the environmental media that may potentially become contaminated.

The biosphere model includes exposure to contaminated soil. Indoor exposures are mitigated by building materials providing shielding from contaminated soil. The model does not include other external exposure pathways (e.g., air submersion and water immersion). External exposure as a result of submersion of radionuclides in air and water is not considered in this submodel for either exposure scenario. Comparisons of the potential relative-dose from air or water submersion pathways with that from exposure to contaminated soils indicate that the dose from air or water submersion is inconsequential (BSC 2003 [DIRS 164186], Section 7.4.8).

This FEP is addressed in the external exposure submodel for the groundwater (BSC 2003 [DIRS 164186], Section 6.4.7) and the volcanic ash (BSC 2003 [DIRS 164186], Section 6.5.5) exposure scenarios. For the groundwater exposure scenario, soil is considered contaminated to an infinite depth in order to account for the emissions from radionuclides that have been leached from the

surface soil but still contribute to the external radiation field (BSC 2003 [DIRS 164186], Section 6.4.7.1). For the volcanic ash exposure scenario, it is assumed that all of the radionuclides in the ash are on the top of the soil regardless of thickness of the ash (BSC 2003 [DIRS 164186], Section 6.5.5.1). Within the mathematical representation of this FEP (BSC 2003 [DIRS 164186], Equations 6.4.7-1 and 6.5.5-1), parameters such as building shielding factor (BSC 2003 [DIRS 161241], Section 6.6), external exposure time (BSC 2003 [DIRS 161241], Section 6.3.2), and population proportion (BSC 2003 [DIRS 161241], Section 6.3.1) are used to account for receptor behavior and lifestyle. The exposure-dose relationship is represented through the dose coefficients for exposure to contaminated soil (BSC 2003 [DIRS 161241], Section 6.5.3.2).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the modern, monsoon, and glacial transition climates (BSC 2003 [DIRS 164403], Section 7.1).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Agricultural and Environmental Parameters for the Biosphere Model* (BSC 2003 [DIRS 160976])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.44 Radiation Doses (FEP 3.3.05.01.0A)

FEP Description–The radiation dose is calculated from exposure rates (external, inhalation, and ingestion) and dose conversion factors. The latter are based upon radiation type, human metabolism, metabolism of the element of concern in the human body, duration of exposure.

Descriptor Phrases– Lifestyle

Physiology
Radionuclide exposure (dosimetry)
Radionuclide accumulation (humans)

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Regulation 10 CFR 63.113(b) [DIRS 156605] establishes the postclosure performance objective for the repository in terms of the limit on radiological exposure to the RMEI. The limit is specified at 10 CFR 63.311 [DIRS 156605] and is expressed as an annual dose to the RMEI.

Within the biosphere model, the external exposure, ingestion, and inhalation submodels (BSC 2003 [DIRS 164186] Table 6.7-1) address this FEP. The exposure rates depend on radionuclide concentrations in environmental media and on the dietary and lifestyle characteristics of the receptor. The doses arising from these exposures depend on radiation type, physiology, metabolism and the biometrics of the receptor. In the model, the annual radiation dose from each of the primary radionuclides is the sum of the annual effective dose equivalent from the external exposure to each radionuclide and the annual committed effective dose equivalent from the ingestion and inhalation of each radionuclide (BSC 2003 [DIRS 164186], Section 6.4.10, Eqs. 6.4.10-1 and 6.4.10-2 for the groundwater exposure scenario and Section 6.5.8, Eqs. 6.5.8.1 and 6.5.8-2 for the volcanic ash exposure scenario). For the dose from the ingestion or inhalation of each of the radionuclides of interest, the dose is the product of the individual radionuclide activity intakes into the body times the appropriate radionuclide-specific effective dose conversion factor (BSC 2003 [DIRS 164186], Sections 6.4.8, 6.4.9, 6.5.6 and 6.5.7). External exposure is calculated using the radionuclide concentration in contaminated soil, various exposure times to the contaminated soil, and radionuclide-specific effective dose coefficients (BSC 2003 [DIRS 164186], Sections 6.4.7 and 6.5.5).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs. For the TSPA scenarios classes (nominal and seismic) and modeling case (igneous intrusion) involving groundwater as a source of radionuclides, annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs generated in the biosphere model. Such an approach is possible because quantities calculated in the groundwater exposure scenario submodels of the biosphere model, including radionuclide concentrations in the environmental media and the annual dose from various exposure pathways, are proportional to the radionuclide concentration in the groundwater (BSC 2003 [DIRS 164186], Section 6.4.10.2). Thus, for this exposure scenario, the biosphere model contribution to the dose assessment (i.e., BDCFs) can be separated from the source (i.e., radionuclide concentration in the groundwater). The BDCF for a radionuclide is numerically equal to the dose for a unit activity concentration of the radionuclide in the water (BSC 2003 [DIRS 164186], Section 6.4.10.2). To support the assessment of doses in TSPA for the scenario classes and the modeling case involving radionuclide release to the groundwater, three different sets of groundwater exposure scenario BDCFs are generated, corresponding to modern, monsoon, and glacial transition climate states (BSC 2003 [DIRS 164186], Section 6.4.10.2).

This FEP is also dispositioned in TSPA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios. Annual doses are calculated in TSPA as the product of radionuclide concentration at the source (in volcanic ash) and the BDCF components. Because variation in radionuclide concentrations in deposited volcanic ash is not part of the biosphere model, BDCFs are calculated based on a unit source in volcanic ash deposited on the ground (1 Bq/m^2) (BSC 2003 [DIRS 164186], Section 6.5). The TSPA model calculates radiation dose as a product of the time-dependent source term and the source-independent BDCFs. The time-dependent source term is subject to radioactive decay, volcanic ash redistribution, surface soil erosion, and other removal mechanisms (BSC 2003 [DIRS 164186], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA model. The first one is for the time-independent component, which includes external exposure, radon inhalation, and ingestion. The second one is for the ash thickness dependent component, which includes inhalation of resuspension particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under post-volcanic conditions (BSC 2003 [DIRS 164186], Section 6.5.8.2).

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

6.2.45 Radiological Toxicity/Effects (FEP 3.3.06.00.0A)

FEP Description–This FEP addresses the estimation of human health effects resulting from radiation doses.

Descriptor Phrases– Lifestyle
Physiology
Radionuclide exposure (health effects)

Screening Decision–Excluded by regulation.

Screening Argument–Regulation 10 CFR 63.311 [DIRS 156605] requires calculating radiation dose to the RMEI, but it does not require calculating health effects. Therefore, this FEP is excluded on the basis of inconsistency with the regulation.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.46 Sensitization to Radiation (FEP 3.3.06.02.0A)

FEP Description–Human and other organisms may become sensitized to radiation exposure so that its effects are more severe.

Descriptor Phrases– Lifestyle
Physiology
Radionuclide exposure (sensitization)

Screening Decision–Excluded by regulation.

Screening Argument–Regulation 10 CFR 63.305(b) [DIRS 156605] states that the DOE should not project changes in human biology. Therefore, the increase in biological effects of radiation exposure due to sensitivity is excluded on the basis of inconsistency with the regulation.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.47 Non-Radiological Toxicity/Effects (FEP 3.3.07.00.0A)

FEP Description–This FEP addresses the estimation of human health effects resulting from the non-radiological toxicity of the waste.

Descriptor Phrases– Non-radionuclide exposure (health effects)

Screening Decision–Excluded by regulation.

Screening Argument–Regulation 10 CFR 63.311 [DIRS 156605] requires calculating a radiation dose to the RMEI, but it does not require the estimating health effects resulting from non-radiological toxicity of the waste; therefore this FEP is excluded.

TSPA Disposition–N/A

Supporting Analysis and Model Reports–N/A

6.2.48 Radon and Radon Daughter Exposure (FEP 3.3.08.00.0A)

FEP Description–This FEP addresses human exposure to radon and radon decay products. ^{226}Ra occurs in nuclear fuel waste and it gives rise to ^{222}Rn gas, the radioactive daughters of which can be harmful to humans and animals upon inhalation.

Descriptor Phrases– Radon and radon daughter exposure

Screening Decision–Included.

Screening Argument–N/A

TSPA Disposition–Radon (^{222}Rn) is a decay product of one of the primary radionuclides considered in TSPA (BSC 2003 [DIRS 164186], Table 6.3-7). Human exposure to radon and radon decay products occurs through inhalation.

Exposure to radon (^{222}Rn) and radon decay products is included in the air and inhalation submodels of the groundwater (BSC 2003 [DIRS 164186], Sections 6.4.2.3 and 6.4.8.4) and volcanic ash (BSC 2003 [DIRS 164186], Sections 6.5.2.2 and 6.5.6.2) exposure scenarios. Concentrations of radon and radon decay products are calculated in the air submodels for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Eq. 6.4.2-4 through 6.4.2-8) and volcanic ash exposure scenario (BSC 2003 [DIRS 164186], Eq. 6.5.2-2 through 6.5.2-8). The consequences of inhalation of radon and the decay products are included in the inhalation submodels for the groundwater exposure scenario (BSC 2003 [DIRS 164186], Eq. 6.4.8-5 through 6.4.8-7) and the volcanic ash exposure scenario (BSC 2003 [DIRS 164186], Eq. 6.5.6-3 and 6.5.6-4) (BSC 2003 [DIRS 164186], Table 6.7-1). The parameters supporting this FEP include radon release factor (BSC 2003 [DIRS 160964], Section 6.6.1), interior wall height (BSC 2003 [DIRS 160964], Section 6.6.2), house ventilation rate (BSC 2003 [DIRS 160964], Section 6.6.2), fraction of ^{222}Rn from soil entering the house (BSC 2003 [DIRS 160964], Section 6.6.2), ratio of ^{222}Rn concentration in air to flux density from soil (BSC 2003 [DIRS 160964], Section 6.6.1), equilibrium factor for ^{222}Rn decay products (BSC 2003 [DIRS 160964], Section 6.6.3), fraction of radionuclide transfer from water to air for evaporative coolers (BSC 2003 [DIRS 160964], Section 6.5.2), and dose conversion factor for radon decay products (BSC 2003 [DIRS 161241], Section 6.5.4).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models. This FEP is also dispositioned in TSPA through the use of volcanic ash exposure scenario BDCFs that are used as input parameters for the volcanic eruption modeling case.

Supporting Analysis and Model Reports–

- *Biosphere Model Report* (BSC 2003 [DIRS 164186])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2003 [DIRS 161241])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2003 [DIRS 160964])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 164403])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2003 [DIRS 163958])

7. CONCLUSIONS

Of the 48 FEPs identified in Table 1-1, 31 are screened as included and are implemented in the biosphere and TSPA models (Table 7-1) . The status of, or changes to, any referenced document may affect the conclusions in this document. Any changes to this document that may occur as a result of changes to the referenced documents will be reflected in subsequent revisions.

As a result of this analysis (Section 6), 17 biosphere-related FEPs were excluded. For each of these FEPs, justification for excluding the FEP is provided (e.g., the FEP is excluded by regulation, the probability of the FEP is below the regulatory criterion, or omission of the FEP does not significantly change the magnitude and time of the resulting radiological exposures to the RMEI or radionuclide releases to the accessible environment). In support of the justification, a technical basis for excluding the FEP is provided.

A list of excluded FEPs, including a summary of the reason(s) for excluding the FEP, is presented in Table 7-2. Because of the specificity of the regulations concerning the characteristics of the reference biosphere (10 CFR 63.305 [DIRS 156605]) and the RMEI (10 CFR 63.312 [DIRS 156605]), the most commonly used justification for excluding FEPs is exclusion by regulation.

Uncertainty in FEPs screening is discussed in Section 6.1.4; parameter uncertainty is addressed in Section 4.1.2. Intended use and limitations of this analysis are described in Section 6.1.7.

Table 7-1. Biosphere-related Features, Events, and Processes Included in TSPA

FEP Name	LA FEP Number
Ashfall	1.2.04.07.0A
Climate change	1.3.01.00.0A
Water Management Activities	1.4.07.01.0A
Wells	1.4.07.02.0A
Groundwater discharge to surface within the reference biosphere	2.2.08.11.0A
Soil type	2.3.02.01.0A
Radionuclide accumulation in soils	2.3.02.02.0A
Soil and sediment transport in the biosphere	2.3.02.03.0A
Surface water transport and mixing	2.3.04.01.0A
Precipitation	2.3.11.01.0A
Biosphere characteristics	2.3.13.01.0A
Radionuclide alteration during biosphere transport	2.3.13.02.0A
Human characteristics (physiology, metabolism)	2.4.01.00.0A
Human lifestyle	2.4.04.01.0A
Dwellings	2.4.07.00.0A
Wild and Natural Land and Water Use	2.4.08.00.0A
Agricultural land use and irrigation	2.4.09.01.0B
Animal farms and fisheries	2.4.09.02.0A
Urban and Industrial Land and Water Use	2.4.10.00.0A
Radioactive decay and ingrowth	3.1.01.01.0A
Atmospheric transport of contaminants	3.2.10.00.0A
Contaminated drinking water, foodstuffs and drugs	3.3.01.00.0A
Plant uptake	3.3.02.01.0A
Animal uptake	3.3.02.02.0A
Fish uptake	3.3.02.03.0A
Contaminated Non-Food Products and Exposure	3.3.03.01.0A
Ingestion	3.3.04.01.0A
Inhalation	3.3.04.02.0A
External exposure	3.3.04.03.0A
Radiation doses	3.3.05.01.0A
Radon and Radon Daughter Exposure	3.3.08.00.0A

Table 7-2. Biosphere-related Features, Events and Processes Excluded from TSPA

FEP Name	LA FEP Number	Justification
Periglacial effects	1.3.04.00.0A	Excluded – low probability and low consequence
Glacial and ice sheet effect	1.3.05.00.0A	Excluded – low probability
Human influences on climate	1.4.01.00.0A	Excluded – by regulation
Greenhouse gas effects	1.4.01.02.0A	Excluded – by regulation
Acid rain	1.4.01.03.0A	Excluded – by regulation
Ozone layer failure	1.4.01.04.0A	Excluded – by regulation
Social and institutional developments	1.4.08.00.0A	Excluded – by regulation
Technological developments	1.4.09.00.0A	Excluded – by regulation
Species evolution	1.5.02.00.0A	Excluded – by regulation
Marine features	2.3.06.00.0A	Excluded – low probability
Animal burrowing/intrusion	2.3.09.01.0A	Excluded – low consequence
Groundwater discharge to surface outside the reference biosphere	2.3.11.04.0A	Excluded – by regulation
Radionuclide release outside the reference biosphere	2.3.13.04.0A	Excluded – by regulation
Implementation of new agricultural practices or land use	2.4.09.01.0A	Excluded – by regulation
Radiological toxicity/effects	3.3.06.00.0A	Excluded – by regulation
Sensitization to radiation	3.3.06.02.0A	Excluded – by regulation
Non-radiological toxicity/effects	3.3.07.00.0A	Excluded – by regulation

8. INPUTS AND REFERENCES

8.1 REFERENCES AND INPUTS CITED

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