BECHTEL SAIC COMPANY LLC

QA: QA

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October 2004

# Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model

Prepared for:
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Change History

| 12. Revision No. | 13. Description of Change |
|---|---|
| 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 final U.S. Nuclear Regulatory Commission Regulations (Federal Register for November 2, 2001, 66 FR 55792) and to incorporate selected NRC/DOE agreement items. |
| 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. |
| REV 04 | This revision is caused by the recent updates in the LA FEP List and in the documentation supporting the implementation of the included FEPs in the biosphere model. The analysis was 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. |
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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| A.P. | after present |
| BDCF | biosphere dose conversion factor |
| DOE | U.S. Department of Energy |
| DTN | data tracking number |
| FEP | feature, event, or process |
| KTI | Key Technical Issue |
| LA | license application |
| NRC | U.S. Nuclear Regulatory Commission |
| PRD | Project Requirements Document |
| RMEI | reasonably maximally exposed individual |
| SZ | saturated zone |
| 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 analysis report is to evaluate and document the inclusion or exclusion of biosphere features, events, and processes (FEPs) with respect to modeling used to support the total system performance assessment (TSPA) for the license application (LA). A screening decision, either *Included* or *Excluded*, is given for each FEP along with the corresponding technical basis for the excluded FEPs and the descriptions of how the included FEPs were incorporated in the biosphere model. This information is required by the U.S. Nuclear Regulatory Commission (NRC) regulations at 10 CFR 63.114 (d, e, and f) [DIRS 156605].

The FEPs addressed in this report concern characteristics of the reference biosphere, the receptor, and the environmental transport and receptor exposure pathways for the groundwater and volcanic ash exposure scenarios considered in biosphere modeling. This revision provides the summary of the implementation of included FEPs in TSPA-LA, (i.e., how the FEP is included); for excluded FEPs, this analysis provides the technical basis for exclusion from TSPA-LA (i.e., why the FEP is excluded).

This report is one of the 10 documents constituting the biosphere model documentation suite. A graphical representation of the documentation hierarchy for the biosphere model is presented in Figure 1-1. This figure shows the interrelationships among the products (i.e., analysis and model reports) developed for biosphere modeling. The *Biosphere Model Report* describes in detail the biosphere conceptual model and mathematical model. The input parameter reports shown to the right of the *Biosphere Model Report* contain detailed descriptions of the model input parameters and their development. Outputs from these six reports are used in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* and *Disruptive Event Biosphere Dose Conversion Factor Analysis* to generate the biosphere dose conversion factors (BDCFs), which are input parameters for the TSPA-LA model. The *Biosphere Dose Conversion Factor Importance and Sensitivity Analysis* analyzes the output of these two BDCF reports.

## 1.1 PLANNING AND DOCUMENTATION

Development of this report follows the technical work scope, content, and management in *Technical Work Plan for: Regulatory Integration Team Revision of Features, Events, and Processes (FEPs) Analysis Reports Integration* (BSC 2004 [DIRS 170408]). Because this report is a source of information used to populate a FEPs database, it contains self-identifying references (i.e., "in this analysis report" or a FEP Number) within the text of Section 6 and subsections. This analysis uses the most recent version of the FEP list (DTN: MO0407SEPFEPLA.000 [DIRS 170760]). This is a deviation from the technical work plan (TWP). The scope of work includes an update to the list of FEPs, text modifications to achieve better consistency between FEPs reports, greater transparency and improved readability of the FEPs exclusion arguments and descriptions of how the included FEPs were addressed; developing additional information to more clearly establish the association between this analysis report and other reports, revisions to the list of parameters for which values are generated in the various analysis reports, and an update to the list of applicable procedures. This analysis is concerned with this scope of work as it pertains to the biosphere modeling. The changes from the planned work scope are further described in Section 6.1.1.

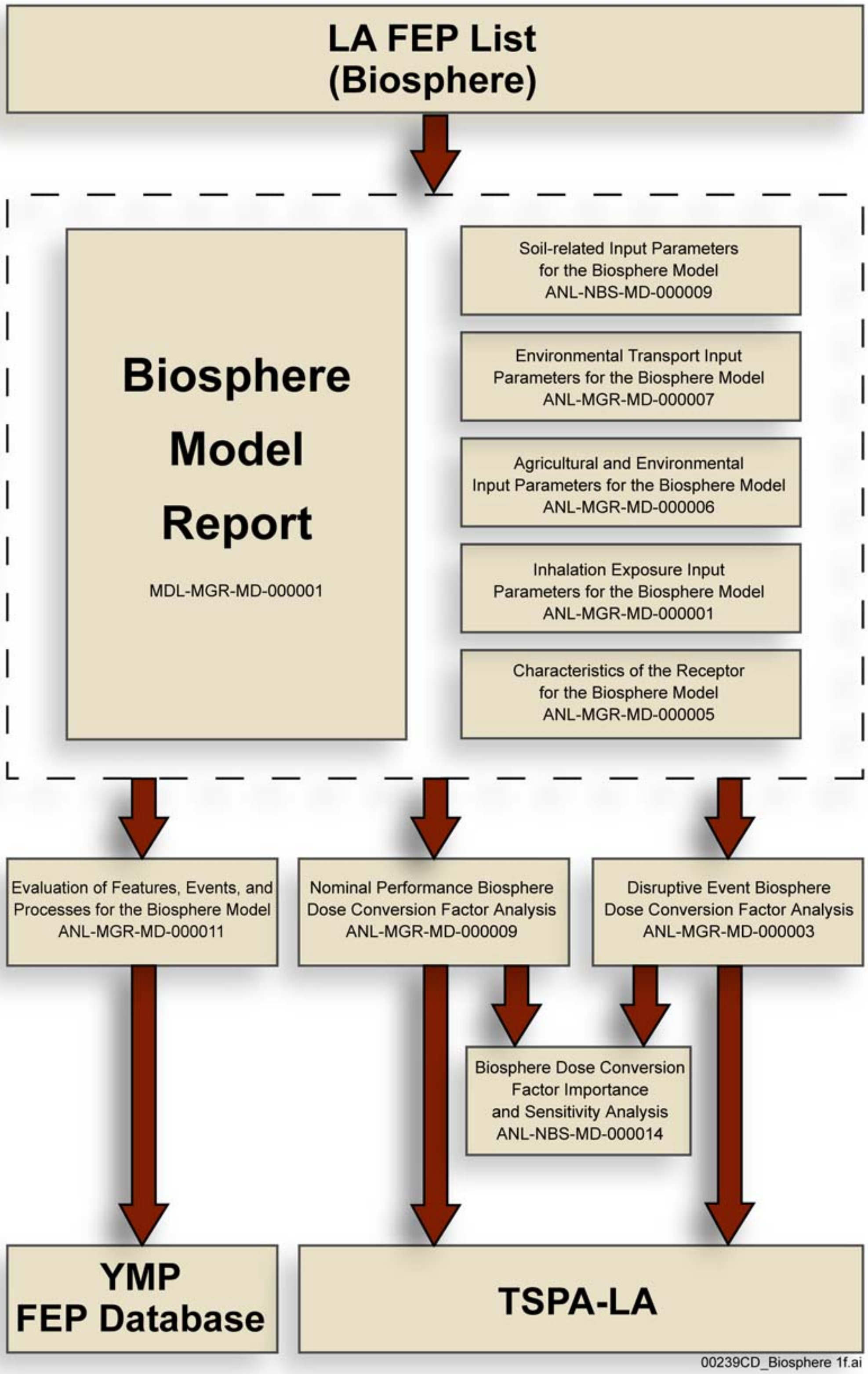


Figure 1-1. Biosphere Model Documentation

Development of this report is also included in the *Technical Work Plan for Biosphere Modeling and Expert Support* (BSC 2004 [DIRS 169573]). However, both TWPs are consistent and the Regulatory Integration Team TWP (BSC 2004 [DIRS 170408]) provides an additional level of detail to ensure consistency between the FEP analysis reports for various process model areas contributing to the TSPA-LA. Therefore, the Regulatory Integration Team TWP (BSC 2004 [DIRS 170408]) is used to develop this analysis.

## 1.2 SCOPE

The scope of this analysis report is to describe, evaluate, and document screening decisions and technical bases for biosphere FEPs for TSPA-LA. For FEPs that are included in the TSPA-LA, this analysis report provides a TSPA-LA disposition, which is a consolidated summary of how the FEP has been included and addressed in the TSPA-LA model, based on the various supporting technical analysis reports and model reports that describe the inclusion of the FEP. It also presents a reference roadmap of the specific supporting technical reports where more detailed discussions of the FEP can be found. For FEPs excluded from the TSPA-LA, 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 or regulatory basis that supports that decision. It also provides appropriate references to project and nonproject information that supports the exclusion.

In cases where an FEP covers multiple technical areas and is shared with other FEP reports, this analysis report provides only a partial technical basis for the screening decision as it relates to the biosphere. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP reports. Information on shared FEPs is provided in Section 1.3. The biosphere technical bases for screening decisions are provided in Section 6.2 and subsequent subsections.

An overview of the Yucca Mountain Project (YMP) FEP analysis and scenario development process is available in *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes* (BSC 2004, Sections 2.4, 3, and 4 [DIRS 168706]), describing the TSPA-LA FEP identification and screening process that led to the development of the *LA FEP List* documented in DTN: MO0407SEPFEPLA.000 [DIRS 170760]. Changes in the FEP list, FEP names, and FEP descriptions can also be traced through that report. The corresponding list of biosphere FEPs is presented in Table 1-1 (DTN: MO0407SEPFEPLA.000 [DIRS 170760]). The list includes 48 biosphere-related FEPs identified in DTN: MO0407SEPFEPLA.000 [DIRS 170760] as well as three additional FEPs (FEPs 1.3.07.02.0A, 2.2.08.01.0A, and 2.2.08.07.0C) that were designated biosphere FEPs as a results of an agreement between the U.S. Department of Energy (DOE) and NRC (Reamer 2001 [DIRS 158380], Attachment 2) resulting in a total of 51 biosphere FEPs. Table 1-1 also includes the designation of shared FEPs.

Table 1-1. Biosphere Features, Events, and Processes for the TSPA-LA

| FEP Number | FEP Name | Addressed in Section | Features, Events, and Processes Analysis Reports that Share This FEP |
|---|---|---|---|
| 1.2.04.07.0A | Ashfall | 6.2.1 | *Features, Events, and Processes: Disruptive Events* (BSC 2004 [DIRS 170017]) |
| 1.3.01.00.0A | Climate change | 6.2.2 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 1.3.04.00.0A | Periglacial effects | 6.2.3 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 1.3.05.00.0A | Glacial and ice sheet effect | 6.2.4 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 1.3.07.02.0A[a] | Water table rise affects SZ | 6.2.5 | *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]) |
| 1.4.01.00.0A | Human influences on climate | 6.2.6 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 1.4.01.02.0A | Greenhouse gas effects | 6.2.7 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 1.4.01.03.0A | Acid rain | 6.2.8 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 1.4.01.04.0A | Ozone layer failure | 6.2.9 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 1.4.07.01.0A | Water management activities | 6.2.10 | *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]) |
| 1.4.07.02.0A | Wells | 6.2.11 | *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]) |
| 1.4.08.00.0A | Social and institutional developments | 6.2.12 | Not shared |
| 1.4.09.00.0A | Technological developments | 6.2.13 | Not shared |
| 1.5.02.00.0A | Species evolution | 6.2.14 | Not shared |
| 2.2.08.01.0A[a] | Chemical characteristics of groundwater in the SZ | 6.2.15 | *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]) |
| 2.2.08.07.0C[a] | Radionuclide solubility limits in the biosphere | 6.2.16 | Not shared |
| 2.2.08.11.0A | Groundwater discharge to surface within the reference biosphere | 6.2.17 | *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]) |
| 2.3.02.01.0A | Soil type | 6.2.18 | Not shared |
| 2.3.02.02.0A | Radionuclide accumulation in soils | 6.2.19 | Not shared |
| 2.3.02.03.0A | Soil and sediment transport in the biosphere | 6.2.20 | Not shared |
| 2.3.04.01.0A | Surface water transport and mixing | 6.2.21 | Not shared |
| 2.3.06.00.0A | Marine features | 6.2.22 | Not shared |
| 2.3.09.01.0A | Animal burrowing/intrusion | 6.2.23 | Not shared |
| 2.3.11.01.0A | Precipitation | 6.2.24 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]) |
| 2.3.11.04.0A | Groundwater discharge to surface outside the reference biosphere | 6.2.25 | *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]) |
| 2.3.13.01.0A | Biosphere characteristics | 6.2.26 | Not shared |

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

| FEP Number | FEP Name | Addressed in Section | Features, Events, and Processes Analysis Reports that Share This FEP |
|---|---|---|---|
| 2.3.13.02.0A | Radionuclide alteration during biosphere transport | 6.2.27 | Not shared |
| 2.3.13.04.0A | Radionuclide release outside the reference biosphere | 6.2.28 | Not shared |
| 2.4.01.00.0A | Human characteristics (physiology, metabolism) | 6.2.29 | Not shared |
| 2.4.04.01.0A | Human lifestyle | 6.2.30 | Not shared |
| 2.4.07.00.0A | Dwellings | 6.2.31 | Not shared |
| 2.4.08.00.0A | Wild and natural land and water use | 6.2.32 | Not shared |
| 2.4.09.01.0A | Implementation of new agricultural practices or land use | 6.2.33 | Not shared |
| 2.4.09.01.0B | Agricultural land use and irrigation | 6.2.34 | Not shared |
| 2.4.09.02.0A | Animal farms and fisheries | 6.2.35 | Not shared |
| 2.4.10.00.0A | Urban and industrial land and water use | 6.2.36 | Not shared |
| 3.1.01.01.0A | Radioactive decay and ingrowth | 6.2.37 | *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004 [DIRS 170012]); *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]); *Waste-Form Features, Events, and Processes* (BSC 2004 [DIRS 170020]) |
| 3.2.10.00.0A | Atmospheric transport of contaminants | 6.2.38 | Not shared |
| 3.3.01.00.0A | Contaminated drinking water, foodstuffs and drugs | 6.2.39 | Not shared |
| 3.3.02.01.0A | Plant uptake | 6.2.40 | Not shared |
| 3.3.02.02.0A | Animal uptake | 6.2.41 | Not shared |
| 3.3.02.03.0A | Fish uptake | 6.2.42 | Not shared |
| 3.3.03.01.0A | Contaminated non-food products and exposure | 6.2.43 | Not shared |
| 3.3.04.01.0A | Ingestion | 6.2.44 | Not shared |
| 3.3.04.02.0A | Inhalation | 6.2.45 | Not shared |
| 3.3.04.03.0A | External exposure | 6.2.46 | Not shared |
| 3.3.05.01.0A | Radiation doses | 6.2.47 | Not shared |
| 3.3.06.00.0A | Radiological toxicity and effects [b] | 6.2.48 | Not shared |
| 3.3.06.02.0A | Sensitization to radiation | 6.2.49 | Not shared |
| 3.3.07.00.0A | Non-radiological toxicity and effects [b] | 6.2.50 | Not shared |
| 3.3.08.00.0A | Radon and radon decay product exposure [b] | 6.2.51 | Not shared |

Sources: DTN: MO0407SEPFEPLA.000 [DIRS 170760] and Reamer (2001 [DIRS 158380], Attachment 2).

[a] These FEPs were not previously associated with the biosphere, but are included in the analysis report as discussed in Section 6.1.1.

[b] Name of this FEP is changed in this report from its name as it appears in DTN: MO0407SEPFEPLA.000 [DIRS 170760].

FEP = feature, event, or process; SZ = saturated zone; UZ = unsaturated zone

## 1.3 SCIENTIFIC ANALYSIS USE AND LIMITATIONS

The intended use of this report is to provide FEP screening information for a project-specific FEP database and to promote traceability and transparency for both included and excluded biosphere-related FEPs. This analysis report is intended for use as the source documentation for (1) documenting exclusion of biosphere-related FEPs from the TSPA-LA model and (2) providing description of incorporation of the included FEPs in the model. 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-LA biosphere model component and dispositioned in the TSPA-LA model, gives the associated list of parameters, and discusses 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:

- Because this analysis report cites other reports and controlled documents as direct input, the limitations of this analysis report inherently include limitations or constraints described in the cited reports or controlled documents.

- The scope of this analysis is limited to providing the decision and technical basis from the perspective of the biosphere model. Where an 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 full technical basis for all aspects of such a shared FEP is addressed collectively by all of the sharing FEP analysis reports.

- The results of the FEP screening presented herein are specific to the repository design and processes for YMP available at the time of the TSPA-LA. Changes in direct inputs listed in Section 4.1, in baseline conditions used for this evaluation, or in other biosphere-related conditions, will need to be evaluated to determine whether the changes are within the limits stated in the FEP evaluations. Engineering and design changes are subject to evaluation to determine whether there are any adverse impacts to safety, as codified at 10 CFR 63.73 and in Subparts F and G [DIRS 156605]. (See also the requirements at 10 CFR 63.44 [DIRS 156605]).

# 2. QUALITY ASSURANCE

Development of this report involves the analysis of technical information to support performance assessment, as described in the TWP (BSC 2004 [DIRS 170408]), 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 2004 [DIRS 170408], Section 4) were used to conduct and document the activities described in this analysis report. This analysis report was prepared in accordance with AP-SIII.9Q, *Scientific Analysis*. Electronic data used in this analysis were controlled in accordance with the methods specified in the TWP (BSC 2004 [DIRS 170408], Section 8).

The natural barriers and items identified in the *Q-List* (BSC 2004 [DIRS 168361]) are not pertinent to this analysis and a Safety Category per AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*, is not applicable.

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# 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 LP-SI.11Q-BSC, *Software Management*. No additional applications, routines, or macros were developed using this software.

In addition, the commercial off-the-shelf product Microsoft® Excel 2000 (Version 9.0.3821 SR-1) was used for data reduction. Standard functions of that software were used to calculate values presented in Section 6. The associated file is described in Appendix A and included on a CD as a part of that appendix. These results are not dependent on the software program used.

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# 4. INPUTS

Procedure AP-3.15Q, *Managing Technical Product Inputs,* categorizes technical product input usage as either direct input or indirect input. Direct input is used to develop the results or conclusions in a technical product. Indirect input is used to provide additional information that is not used in the development of results or conclusions. Direct inputs are addressed in this section.

Section 4.1 identifies direct inputs used in this FEP analysis report. The direct inputs were obtained from controlled source documents and other appropriate sources in accordance with the controlling procedure AP-3.15Q. Section 4.2 identifies the FEP screening criteria described in 10 CFR Part 63 [DIRS 156605], along with the regulatory-derived FEP screening criteria. Section 4.3 identifies applicable codes and standards.

## 4.1 DIRECT INPUTS

The *LA FEP List* (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) was used as a direct input to provide the initial list of biosphere-related FEPs for screening in this analysis report. The *LA FEP List* identifies a FEP analysis report or a set of sharing FEP analysis reports for each FEP. Also, a FEP-related agreement between DOE and NRC as documented in Reamer (2001 [DIRS 158380], Attachment 2) is a direct input. Both the *LA FEP List* (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) and Reamer (2001 [DIRS 158380], Attachment 2) are considered appropriate direct inputs to the analysis report. An overview of the YMP FEP analysis and scenario development process is available in *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes* (BSC 2004 [DIRS 168706]), which describes the TSPA-LA FEP identification and screening process. As part of that process, the *LA FEP List* (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) was developed. This data tracking number (DTN) was used as an initial input to the biosphere FEP analysis. The list of biosphere TSPA-LA FEPs, presented in Table 1-1, was derived from DTN: MO0407SEPFEPLA.000 [DIRS 170760] with subsequent modifications. These modifications include the addition of three FEPs (FEPs 1.3.07.02.0A, 2.2.08.01.0A, and 2.2.08.07.0C) that were not previously designated as biosphere FEPs. These FEPs were added as a result of an agreement between DOE and NRC (Reamer 2001 [DIRS 158380], Attachment 2), resulting in a total of 51 biosphere FEPs. These and other changes in the FEP List, FEP names, and FEP descriptions are documented in the “FEP History File” in the FEP database (BSC 2004 [DIRS 168706], Table 6-1) and will be incorporated into a subsequent revision of the *LA FEP List* (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) (see Section 7). Table 1-1 also includes the designation of shared FEPs.

Other direct inputs used for the FEP exclusion arguments (see Section 6.2) are listed in Table 4-1. Regulations used as direct input are listed in Table 4-2. Eight of the reports from the biosphere model documentation suite (see Figure 1-1) that provide details of how the included FEPs were incorporated in the biosphere and the TSPA-LA models are listed in Table 4-3.

Table 4-1. Direct Inputs Used for FEP Exclusion Arguments Not Based on Regulation

| Source | Used in Section Number | Description |
|---|---|---|
| Topical Report - *Evaluation of the Potentially Adverse Condition "Evidence of Extreme Erosion During the Quaternary Period" at Yucca Mountain, Nevada* (YMP 1993 [DIRS 100520], p. ii) | 6.2.3 | Erosion rate at Yucca Mountain. |
| *D&E / PA/C IED Subsurface Facilities* (BSC 2004 [DIRS 164519], Sheet 1) | 6.2.23 | Overburden thickness for the repository. |
| DTN: MO0407MWDBDCFG.000 [DIRS 171602], *Biosphere Dose Conversion Factors for the Groundwater Exposure Scenario* | 6.2.16 | Biosphere Dose Conversion Factors. |
| DTN: MO0407SPACRBSM.002 [DIRS 170677], *Characteristics of the Receptor for the Biosphere Model* | 6.2.16 | Radionuclide half-lives used in biosphere modeling. |
| DTN: MO0407SPASRPBM.002 [DIRS 170755], *Soil Related Parameters for the Biosphere Model* | 6.2.3 | Erosion rates for agricultural soils. |
| DTN: MO0408SPADCLRE.000 [DIRS 171601], *Dissolved Concentration Limits of 14 Radioactive Elements for LA* | 6.2.16 | Solubility data for radioactive elements for use in the TSPA-LA. |
| *Future Climate Analysis* (BSC 2004 [DIRS 170002], Section 6.6) | 6.2.3, 6.2.4, and 6.2.22 | Paleoclimate records. |
| *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013], Section 6.2.32) | 6.2.17 | Saturated zone screening argument. |

Table 4-2. Regulations Used for FEP Exclusion Arguments

| Source | Used in Section Number | Description |
|---|---|---|
| 10 CFR 63.2 [DIRS 156605] | 6.2.25, 6.2.28 | Definition of the reference biosphere. |
| 10 CFR 63.305(b) [DIRS 156605] | 6.2.12, 6.2.13, 6.2.14, 6.2.33, 6.2.49 | Regulatory exclusion of human effects on climate and changes in human society or biology. |
| 10 CFR 63.305(c) [DIRS 156605] | 6.2.6, 6.2.7, 6.2.8, 6.2.9 | Requires U.S. Department of Energy 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. |
| 10 CFR 63.311 [DIRS 156605] | 6.2.48, 6.2.50 | Defines individual protection standard. |
| 66 FR 55732 [DIRS 156671] | 6.2.6, 6.2.7, 6.2.8, 6.2.9 | Part of rule indicating that only natural evolution of the reference biosphere is to be included in the performance assessment and that changes caused by future human behaviors are not included. |

Table 4-3. Inputs Used to Document Disposition of Included FEPs

| Source | Used in Section Number | Description |
|---|---|---|
| BSC 2004 [DIRS 169460]<br>*Biosphere Model Report* | 6.2.1, 6.2.2, 6.2.5, 6.2.10, 6.2.11, 6.2.15, 6.2.18, 6.2.19, 6.2.20, 6.2.21, 6.2.24, 6.2.26, 6.2.27, 6.2.29, 6.2.30, 6.2.31, 6.2.32, 6.2.34, 6.2.35, 6.2.36, 6.2.37, 6.2.38, 6.2.39, 6.2.40, 6.2.41, 6.2.42, 6.2.43, 6.2.44, 6.2.45, 6.2.46, 6.2.47, 6.2.51 | The assessment of annual doses is carried out in the TSPA-LA model using the BDCFs generated in the biosphere model as input parameters. |
| BSC 2004 [DIRS 169673]<br>*Agricultural and Environmental Input Parameters for the Biosphere Model* | 6.2.2, 6.2.18, 6.2.19, 6.2.20, 6.2.24, 6.2.26, 6.2.34, 6.2.36, 6.2.38, 6.2.40, 6.2.46 | This report defines and justifies values for twelve parameters required in the biosphere model that are related to the use of contaminated groundwater to irrigate crops. |
| BSC 2004 [DIRS 169671]<br>*Characteristics of the Receptor for the Biosphere Model* | 6.2.26, 6.2.29, 6.2.30, 6.2.31, 6.2.32, 6.2.34, 6.2.36, 6.2.37, 6.2.39, 6.2.44, 6.2.45, 6.2.46, 6.2.47, 6.2.51 | The purpose of this analysis report is to define values for biosphere model parameters that are related to the dietary, lifestyle, and dosimetric characteristics of the receptor. |
| BSC 2004 [DIRS 169672]<br>*Environmental Transport Input Parameters for the Biosphere Model* | 6.2.1, 6.2.2, 6.2.18, 6.2.19, 6.2.20, 6.2.26 6.2.27, 6.2.31, 6.2.34, 6.2.35, 6.2.36, 6.2.38, 6.2.40, 6.2.41, 6.2.42, 6.2.45, 6.2.51 | The purpose of this analysis is to develop biosphere model parameter values related to radionuclide transport and accumulation in the environment. These parameters support calculations of radionuclide concentrations in the environmental media (e.g., soil, crops, animal products, and air) resulting from a given radionuclide concentration at the source of contamination (i.e., either in groundwater or in volcanic ash). |
| BSC 2004 [DIRS 169458]<br>*Inhalation Exposure Input Parameters for the Biosphere Model* | 6.2.1,6.2.20, 6.2.30, 6.2.32, 6.2.34, 6.2.36, 6.2.38, 6.2.45, | This analysis report defines and justifies values of mass loading for the biosphere model. Mass loading is the total mass concentration of resuspended particles (e.g., dust, ash) in a volume of air. |
| BSC 2004 [DIRS 169459]<br>*Soil-Related Input Parameters for the Biosphere Model* | 6.2.1, 6.2.18, 6.2.19, 6.2.20, 6.2.38, 6.2.40 | The purpose of this analysis is to develop the biosphere model parameters associated with the accumulation and depletion of radionuclides in the soil. These parameters support the calculation of radionuclide concentrations in soil from ongoing irrigation or ash deposition and, as a direct consequence, radionuclide concentration in other environmental media that are affected by radionuclide concentrations in soil. |

Table 4-3. Inputs Used to Document Disposition of Included FEPs (Continued)

| Source | Used in Section Number | Description |
|---|---|---|
| BSC 2004 [DIRS 169674]<br>*Nominal Performance Biosphere Dose Conversion Factor Analysis* | 6.2.2, 6.2.5, 6.2.10, 6.2.11, 6.2.18, 6.2.19, 6.2.20, 6.2.21, 6.2.24, 6.2.26, 6.2.27, 6.2.29, 6.2.30, 6.2.31, 6.2.32, 6.2.34, 6.2.35, 6.2.36, 6.2.37, 6.2.38, 6.2.39, 6.2.40, 6.2.41, 6.2.42, 6.2.43, 6.2.44, 6.2.45, 6.2.46, 6.2.47, 6.2.51 | The objectives of this analysis are to develop BDCFs for the groundwater exposure scenario for the three climate states considered in the TSPA-LA as well as conversion factors for evaluating compliance with the groundwater protection standard. The BDCFs will be used in performance assessment for calculating all-pathway annual doses for a given concentration of radionuclides in groundwater. |
| BSC 2004 [DIRS 167287]<br>*Disruptive Event Biosphere Dose Conversion Factor Analysis* | 6.2.1, 6.2.2, 6.2.18, 6.2.19, 6.2.20, 6.2.26, 6.2.27, 6.2.29, 6.2.30, 6.2.31, 6.2.34, 6.2.35, 6.2.36, 6.2.37, 6.2.38, 6.2.39, 6.2.40, 6.2.41, 6.2.43, 6.2.44, 6.2.45, 6.2.46, 6.2.47, 6.2.51 | The objectives of this analysis are to develop the BDCFs for the volcanic ash exposure scenario and the dose factors for calculating inhalation doses during volcanic eruption (eruption phase of the volcanic event). This report describes biosphere model calculations and their output, the BDCFs, for the volcanic ash exposure scenario. |

BDCF = biosphere dose conversion factor; TSPA = total system performance assessment; LA = license application

### 4.1.1 Evidence of Erosion at Yucca Mountain

The data on surface erosion rates were used in Section 6.2.3 to establish that the maximum potential erosion would be of low consequence to the repository. The data were taken from Topical Report - *Evaluation of the Potentially Adverse Condition "Evidence of Extreme Erosion During the Quaternary Period" at Yucca Mountain, Nevada* (YMP 1993 [DIRS 100520], Section 3.4). This report provides estimated erosion rates based on literature search for typical hillslope erosion rates in the U.S. and the world to establish a range of typical values and compares the Yucca Mountain erosion rates with these values. Long-term average hillslope erosion rates established for Yucca Mountain were determined to be 0.19 cm/ka (1 ka = 1,000 yr), using cation ratio dating of rock varnish on colluvial boulder deposits to establish age control and by measuring hillslope denudation and hillslope channel incision marginal to these boulder deposits. The topical report (YMP 1993 [DIRS 100520], Section 3.3.3) states that this value was calculated from the parameters in Table 5 of that report. The data in Table 5 have been qualified per data qualification report *Erosion Rates at Yucca Mountain, Technical Assessment, Qualification of Data* (CRWMS M&O 1992 [DIRS 171834]). The data qualification was conducted by implementing the guidance presented in NUREG-1298 *Qualification of Existing Data for High-Level Nuclear Waste Repositories: Generic Technical Position* (Altman et al. 1988 [DIRS 103750]). A summary of the data qualification report is documented in Appendix A of the topical report (YMP 1993 [DIRS 100520]). The conclusion of the data qualification report (CRWMS M&O 1992 [DIRS 171834], p. 15) states that:

- All five technical assessment team members unanimously agreed that the collection and evaluation would not differ under current quality assurance and technical procedures for Los Alamos National Laboratory and United States Geological Survey.

- The technical assessment team members unanimously agree that no significant differences would result from data collection and evaluation under current quality assurance and technical procedures.

- The technical assessment team members recommend allowing the technical data on extreme erosion to be formally accepted as qualified under current *Quality Assurance Requirements and Description* guidelines.

In addition to the reviews performed by the technical assessment team, an independent peer review group of leading geomorphologists was assembled to examine the rock varnish cation-ratio dating technique (Birkeland et al. 1989 [DIRS 171928]) that was used to determine rock age. This Peer Review Panel concluded that the age determinations being performed by this process were “the best presently being done” at that time in the scientific community.

The qualified data on erosion rates presented in the topical report (YMP 1993 [DIRS 100520]) are considered appropriate for use in this analysis.

### 4.1.2 Subsurface Facilities Drawing

Information on overburden thickness for the repository was used in Section 6.2.23 to establish that this thickness was greater than local animals would burrow such that burrowing animals would be of low consequence to the repository. The engineering drawing, *D&E / PA/C IED Subsurface Facilities* (BSC 2004 [DIRS 164519], Sheet 1) provides a typical repository layout (in plan view) and notes that the repository would have a 215 m overburden thickness. These data are considered appropriate for use in this analysis.

### 4.1.3 Biosphere Dose Conversion Factors and Biosphere Model Parameters

DTN: MO0407MWDBDCFG.000 [DIRS 171602], *Biosphere Dose Conversion Factors for the Groundwater Exposure Scenario*, contains biosphere dose conversion factors for the groundwater exposure scenario. These data are the output of the biosphere model and are appropriate for the intended use in this analysis. The half-lives used in the biosphere model are included in DTN: MO0407SPACRBSM.002 [DIRS 170677], *Characteristics of the Receptor for the Biosphere Model*. These values were appropriate for the intended use in this analysis because they are inputs and outputs of the biosphere model, as discussed in the *Biosphere Model Report* (BSC 2004 [DIRS 169460]). These data were used in Section 6.2.16 to support an exclusion argument for FEP 2.2.08.07.0C, *Radionuclide solubility limits in the biosphere*.

The biosphere model input data from DTN: MO0407SPASRPBM.002 [DIRS 170755], *Soil Related Parameters for the Biosphere Model*, were used in Section 6.2.3 in an exclusion argument for FEP 1.3.04.00.0A, *Periglacial effects*. These values were appropriate for the intended use in this analysis because they were developed as input for the biosphere model

### 4.1.4 Radioactive Element Solubility Limits

The solubility limits of 14 radioactive elements were determined in DTN: MO0408SPADCLRE.000 [DIRS 171601], *Dissolved Concentration Limits of 14 Radioactive Elements for LA*. These limits are appropriate for the intended use in this analysis because they are consistent with the data used in the other process model reports contributing to the TSPA-LA.

### 4.1.5 Future Climate Analysis

The *Future Climate Analysis* (BSC 2004 [DIRS 170002]) documents an analysis that was performed to estimate climatic variables for the next 10,000 years by forecasting the timing and nature of climatic change at Yucca Mountain. The future-climate estimates are based on an analysis of past-climate data from analog meteorological stations. Information on paleoclimate records for the Yucca Mountain were used in Sections 6.2.3, 6.2.4, and 6.2.22 to establish that the climate conditions necessary for forming permafrost, glaciers, and ice sheets, or to result in marine intrusion are not credible at Yucca Mountain over the next 10,000 years (BSC 2004 [DIRS 170002], Section 6.6). This is because the mean annual temperature forecasted for the Yucca Mountain region for the next 10,000 years exceeds $0^{\circ}$C (BSC 2004 [DIRS 170002], Section 6.6) and the future climate would not result in sufficiently increased precipitation to affect the location of current coastlines. These data are considered appropriate for use in this analysis.

### 4.1.6 Features, Events, and Processes in Saturated Zone Flow and Transport

Information on the screening argument for FEP 2.2.08.11.0A, *Groundwater discharge to surface within the reference biosphere* (Section 6.2.17), is provided in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013], Section 6.2.32) and is used to establish that this FEP is excluded from the biosphere model. That report provides an exclusion argument for FEP 2.2.08.11.0A (BSC 2004 [DIRS 170013], Section 6.2.32). An exclusion of this FEP from the saturated zone (SZ) flow and transport model causes exclusion of this FEP from the biosphere model. This information is considered appropriate for use in this analysis.

### 4.1.7 Code of Federal Regulations

Regulation 10 CFR 63 [DIRS 156605] and a portion of the Federal Register containing the preamble to 10 CFR 63, 66 FR 55732 [DIRS 156671], provide the regulatory requirements and the background information for licensing and operating the repository. These requirements and definitions were used throughout Section 6.2 to construct FEP exclusion arguments. Information from 10 CFR 63 [DIRS 156605] and the background information can be considered established fact and were appropriate for use in this analysis.

Portions of 10 CFR 63 [DIRS 156605] that contain definitions of concepts and requirements pertaining to biosphere modeling, such as the reference biosphere, the geologic setting, and the reasonably maximally exposed individual (RMEI) are listed below.

**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 and geologic setting 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**

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 3,000 acre-feet.

d. Drinks 2 liters of water per day from wells drilled into the groundwater 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 10 CFR 63 [DIRS 156605] used in FEPs screening include 10 CFR 63.113 [DIRS 156605], which defines postclosure performance objectives for the repository. 10 CFR 63.113 [DIRS 156605] includes a statement that radiological exposures to the RMEI are within the limits specified at 10 CFR 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.

## 4.2 CRITERIA

### 4.2.1 Criteria from the Projects Requirements Document and the Yucca Mountain Review Plan

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 *Project Requirements Document* (PRD) (Canori and Leitner 2003 [DIRS 166275]). The acceptance criteria that will be used by the NRC to evaluate the adequacy of technical arguments are identified in the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]). Table 4-4 provides a crosswalk between the regulatory requirements, the PRD (Canori and Leitner 2003 [DIRS 166275]), and the acceptance criteria provided in the Yucca Mountain Review Plan (YMRP) (NRC 2003 [DIRS 163274], Sections 2.2.1.2.1.3 and 2.2.1.2.2.3).

The PRD (Canori and Leitner 2003 [DIRS 166275]) documents and categorizes the regulatory requirements and other project requirements and provides a crosswalk to the various YMP organizations that are responsible for ensuring that the criteria have been addressed in the LA. The regulatory requirements include criteria relevant to performance assessment activities, in general, and to FEP-related activities as they pertain to performance assessment, in particular.

The cited YMRP (NRC 2003 [DIRS 163274]) criteria applicable to this analysis are provided in Table 4-5. Section 7.2 describes how these acceptance criteria were addressed. The YMRP acceptance criteria for FEP screening echo the regulatory screening criteria of low probability and low consequence but also allow for exclusion of a FEP if the process is specifically excluded by the regulations (see Section 4.2.2).

Acceptance criteria listed in Section 2.2.1.2.2.3 of the 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 4-4. Relationships of Regulations to the Project Requirements and the YMRP Acceptance Criteria

| Description of the Applicable Regulatory Requirement or Acceptance Criterion | 10 CFR Part 63 [DIRS 156605] | Canori and Leitner 2003 [DIRS 166275] | Associated Criteria in the YMRP (NRC 2003 [DIRS 163274]) |
|---|---|---|---|
| | Regulatory Citation | Associated PRD | |
| **General Requirements and Scope Pertinent to FEP Screening** | | | |
| Include data related to geology, hydrology, geochemistry, and geophysics. | 63.114(a) | PRD-002/T-015 | 2.2.1.2.1.3 Acceptance Criterion 1 |
| Include information of the design of the engineered barrier system used to define parameters and conceptual models. | 63.114(a) | PRD-002/T-015 | 2.2.1.2.1.3 Acceptance Criterion 1 |
| Account for uncertainties and variabilities in parameter values and provide the technical basis for parameter ranges, probability distributions, or bounding values. | 63.114(b) | PRD-002/T-015 | 2.2.1.2.1.3 Acceptance Criterion 2 |
| **FEP Screening Criteria** | | | |
| Provide the justification and technical basis for excluding FEPs specifically excluded by regulation. | Not Applicable | Not Applicable | 2.2.1.2.1.3 Acceptance Criterion 2 |
| Provide the technical basis for either inclusion or exclusion of FEPs. Provide the justification and technical basis for those excluded based on probability. | 63.114(e) | PRD-002/T-015 | 2.2.1.2.1.3 Acceptance Criterion 2 |
| Provide the technical basis for either inclusion or exclusion of FEPs. Provide the justification and the technical basis for those excluded based on lack of significant change in resulting radiological exposure or release to the accessible environment. | 63.114(e) | PRD-002/T-015 | 2.2.1.2.1.3 Acceptance Criterion 2 |

FEP = feature, event, or process; PRD = Project Requirements Document; YMRP = Yucca Mountain Review Plan

Table 4-5. YMRP Criteria Relevant to the Biosphere FEPs

| YMRP Section and Acceptance Criterion | Description |
|---|---|
| **Section 2.2.1.2.1.3**<br>**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. |

Table 4-5. YMRP Criteria Relevant to the Biosphere FEPs (Continued)

| YMRP Section and Acceptance Criterion | Description |
|---|---|
| **Section 2.2.1.2.1.3**<br>**Acceptance Criterion 2**<br>—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. |
| | (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 |
| | (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. |

Source: NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3.

FEP = feature, event, or process; NRC = U.S. Nuclear Regulatory Commission;

PRD = Project Requirements Document; YMRP = Yucca Mountain Review Plan

### 4.2.2 FEPs Screening Criteria

The NRC regulations and guidance specifically allow the exclusion of FEPs from the TSPA-LA 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 10 CFR 63 [DIRS 156605]. In this document, this exclusion is called “exclusion by regulation.” FEPs screening criteria are described further in the following three subsections.

#### 4.2.2.1 Exclusion by 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 shall 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 groundwater protection standards shall 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.

#### 4.2.2.2 Exclusion by 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, transport times, or other measures as well as overall expected annual dose), there is no single quantitative test of "significance."

#### 4.2.2.3 Exclusion by Regulation

The provisions and constraints provided within 10 CFR 63 [DIRS 156605] 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 10 CFR 63 [DIRS 156605] is described in the *Yucca Mountain Review Plan, Final Report* (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 portions of 10 CFR 63 [DIRS 156605] that define requirements and key concepts for performance assessment. In this context, portions of 10 CFR 63 [DIRS 156605] serve as criteria for screening related FEPs.

## 4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulations, other than those identified in the PRD (Canori and Leitner 2003 [DIRS 166275]) and determined to be applicable, were used in this analysis.

# 5. ASSUMPTIONS

This section addresses assumptions used in the FEP screening for the biosphere FEPs.

**Assumption 5.1**: 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 4.1.7 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 are either of "low probability" or "low consequence," and can be excluded from consideration.

**Use**: This assumption is used throughout Section 6.2.

**Assumption 5.2**: For naturally occurring FEPs, it is assumed that regulations expressed as a probability criterion can also be expressed as an annual-exceedance probability, which is defined as the probability that a specified value (such as for ground motions or fault displacement) will be exceeded during one year. More specifically, a stated probability-screening criterion of one chance in 10,000 in 10,000 years ($10^{-4}/10^{4}$ year) criterion is assumed equivalent to a $10^{-8}$ annual-exceedance probability.

**Justification:** The definition of annual exceedance probability and the following justification for this assumption are taken from the glossary in the report titled *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (BSC 2004 [DIRS 168030]).

The assumption of equivalence of annual-exceedance probability is appropriate if the possibility of an event is equal for any given year. This satisfies the definition of a Poisson distribution as "…a mathematical model of the number of outcomes obtained in a suitable interval of time and space, that has its mean equal to its variance…" (Merriam-Webster 1993 [DIRS 100468], p. 899). This is inferred to mean that naturally occurring, infrequent, and independent events can be represented as stochastic processes in which distinct events occur in such a way that the number of events occurring in a given period of time depends only on the length of the time period. The use of this assumption is justified in *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (BSC 2004 [DIRS 168030]), which indicates that the underlying assumption in all probabilistic hazard analyses is that the behavior of the Earth is generally Poissonian or random.

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

**Use:** This assumption is used for the following FEPs:

- Periglacial effects (1.3.04.00.0A), Section 6.2.3 (exclusion based on both low probability and low consequence)
- Glacial and ice sheet effect (1.3.05.00.0A), Section 6.2.4
- Marine features (2.3.06.00.0A), Section 6.2.22.

# 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 6.2 presents the technical basis for the FEP screening decisions.

## 6.1 METHODS AND APPROACH

The identification, development, and screening of a comprehensive list of FEPs potentially relevant to the postclosure performance of the Yucca Mountain repository is an ongoing, iterative process based on site-specific information, design, and regulations. FEP analysis uses the following definitions, as taken from the glossary in the YMRP (NRC 2003 [DIRS 163274]):

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

Event – 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.

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

FEP analysis for TSPA-LA is described in the report *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes* (BSC 2004 [DIRS 168706]).

FEPs must be included in the TSPA-LA unless they can be excluded by low probability, low consequence, or regulation (see Section 4.2). A FEP can be excluded from the TSPA-LA by low probability per 10 CFR 63.114(d) [DIRS 156605], by showing 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-LA 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 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.

### 6.1.1 Features, Events, and Processes Identification

The first step of FEP analysis is FEP identification and classification, which addresses Acceptance Criterion 1 of YMRP Section 2.2.1.2.1.3 that is relevant to FEP screening (NRC 2003 [DIRS 163274]). The TSPA-LA FEP identification and classification process is described in *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes* (BSC 2004 [DIRS 168706], Section 3). From this first step in the process, a version of the *LA FEP List* (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) was produced, which is the source of FEPs considered in this biosphere FEP analysis. As a part of the FEP identification process, Key Technical Issue (KTI) agreements were reviewed (Reamer 2001 [DIRS 158380], Attachment 2), and it was determined that three FEPs, not shown as biosphere

FEPs in DTN: MO0407SEPFEPLA.000 [DIRS 170760] should, in fact, be included as a part of this report, as discussed in the following paragraphs.

Two included FEPs, 1.3.07.02.0A, *Water table rise affects SZ*, and 2.2.08.01.0A, *Chemical characteristics of groundwater in the SZ*, were added as shared FEPs with the SZ FEPs because they address SZ conditions that potentially affect conditions in the reference biosphere. Addition of these FEPs satisfies the agreement items for KTI Items TSPAI 2.02, Comment 19, Parts 1 and 5. Because they are included FEPs, they have also been added for traceability purposes to the LA FEP list discussions documented in the supporting reports. The third FEP, 2.2.08.07.0C, *Radionuclide solubility limits in the biosphere*, has been specifically created to satisfy KTI Item TSPAI 2.03, Comment 20. This third FEP has been evaluated and excluded from consideration in the TSPA-LA. Furthermore, the name and description for FEP 3.3.08.00.0A, *Radon and radon decay products exposure*, has been modified in this FEPs analysis report based on review and recommendations from subject matter experts during document preparation. The name and description changes are captured in Section 6.2.51 of this FEP report.

The current TSPA-LA FEP list, DTN: MO0407SEPFEPLA.000 [DIRS 170760], contains 48 FEPs that are designated as biosphere FEPs. As described above, DOE and NRC agreed (Reamer 2001 [DIRS 158380], Attachment 2) that three other FEPs should also be designated biosphere FEPs resulting in a total of 51 biosphere FEPs. The list of the biosphere FEPs is shown in Table 1-1.

### 6.1.2 FEPs Screening

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 Acceptance Criterion 2 of the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3). The TSPA-LA FEP screening process is described in *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes* (BSC 2004 [DIRS 168706], Section 4).

For FEP screening, each FEP is screened against the specified exclusion criteria (see Section 4.2.2), summarized in the three following FEP screening statements:

1) FEPs having less than one chance in 10,000 of occurring over 10,000 years may be excluded (screened out) from the TSPA on the basis of low probability (as per 10 CFR 63.114(d) [DIRS 156605]).

2) FEPs whose omission would not significantly change the magnitude and time of the resulting radiological exposures to the RMEI, or radionuclide releases to the accessible environment, may be excluded (screened out) from the TSPA on the basis of low consequence (as per 10 CFR 63.114 (e and f) [DIRS 156605]).

3) FEPs that are inconsistent with the characteristics, concepts, and definitions specified in 10 CFR Part 63 [DIRS 156605] may be excluded (screened out) from the TSPA by regulation.

A FEP need only satisfy one of the exclusion screening criteria to be excluded from TSPA. A FEP that does not satisfy any of the exclusion screening criteria must be included in the TSPA-LA model.

This analysis report documents the screening decisions for the biosphere FEPs. In cases where a FEP covers multiple technical areas and is shared with other FEP reports, this analysis report provides only a partial technical basis for the screening decision as it relates to biosphere issues. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP analysis reports.

Documentation of the screening for each FEP is provided in Section 6.2. The following standardized format is used.

**Section 6.2.x FEP Name (FEP Number)**

**FEP Description:** This field describes the nature and scope of the FEP under consideration.

**Screening Decision:** Identifies the screening decision as one of:

- "Included"
- "Excluded – Low Probability"
- "Excluded – Low Consequence"
- "Excluded – By Regulation."

In a few cases, a FEP may be excluded by a combination of two criteria (e.g., Low Probability and Low Consequence).

**Screening Argument:** This field is used only for excluded FEPs. It provides the discussion for why a FEP has been excluded from TSPA-LA.

**TSPA Disposition:** This field is used only for included FEPs. It provides the consolidated discussion of how a FEP has been included in TSPA-LA, making reference to more detailed documentation in other supporting technical reports, as applicable.

**Supporting Reports:** This field is only used for included FEPs. It provides the list of supporting technical reports that identified the FEP as an included FEP and contain information relevant to the implementation of the FEP within the TSPA-LA model. This list of supporting technical reports provides traceability of the FEP through the document hierarchy. For excluded FEPs, it is indicated as "Not Applicable"

### 6.1.3 Biosphere Modeling Background and Supporting Documents

The included biosphere-related FEPs were used to develop the conceptual model of the biosphere (BSC 2004 [DIRS 169460], Section 6.3) and were also used to develop the model parameter values. The environmental radiation model for Yucca Mountain, Nevada (ERMYN) is a biosphere model supporting the TSPA-LA for the Yucca Mountain repository. A graphical representation of the biosphere model documentation hierarchy was presented in Figure 1-1. The

*Biosphere Model Report* (BSC 2004 [DIRS 169460]) describes in detail the biosphere conceptual and mathematical models as well as the model validation. The input parameter reports (BSC 2004 [DIRS 169672]; BSC 2004 [DIRS 169458]; BSC 2004 [DIRS 169673]; BSC 2004 [DIRS 169459]; BSC 2004 [DIRS 169671]) contain detailed descriptions of the model input parameters. The biosphere model calculations and their output, BDCFs, are documented in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]) and the *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]) for the groundwater and the volcanic ash exposure scenarios, respectively.

The assessment of annual doses is carried out in the TSPA-LA model using the BDCFs generated in the biosphere model as input parameters (BSC 2004 [DIRS 169460], Section 6.4.10.4; BSC 2004 [DIRS 169674], Section 7.1.2; BSC 2004 [DIRS 167287], Sections 7.1.2 and 7.1.3). 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-LA 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 2003 [DIRS 166296], pp. 51 to 52). 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 scenario 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 scenario BDCFs.

The biosphere analyses also develop conversion factors for evaluating compliance with the groundwater protection standard of 10 CFR 63 [DIRS 156605] and the dose factors for calculating inhalation doses during volcanic eruption (eruption phase of the volcanic event). The conversion factors are used by TSPA to calculate gross alpha particle activity in groundwater and the organ and whole-body annual dose from beta- and photon-emitting radionuclides resulting from drinking of 2 liters of water per day. The FEPs identified as applicable for the development of these factors constitute a subset of the FEPs included in development of the biosphere model for the groundwater exposure scenario. (Specifically, those are the FEPs related to the drinking water pathway and to the process of radioactive decay.) Despite this commonality, the conversion factors for the evaluation of compliance with the groundwater standard are not developed using the biosphere model. This is because the concepts of the reference biosphere and the RMEI, which are fundamental for the construction of the biosphere model, are only applicable to the individual protection standard of 10 CFR 63 [DIRS 156605]. The disposition of these FEPs in TSPA is through the conversion factors that are inputs for the TSPA-LA.

Inhalation dose factors are multipliers, similar to BDCFs, that are used in the TSPA to evaluate inhalation dose accrued during a volcanic eruption. The FEPs that are related to inhalation dose factors are a subset of the FEPs included in development of the biosphere model for the volcanic ash exposure scenario. The disposition of these FEPs in TSPA is through the dose factors that are the input to the TSPA model. The biosphere reports describing TSPA disposition of included FEPs are listed in Table 6-1.

Table 6-1. Documents Supporting Biosphere FEPs

| Report Title | Document Identifier | Reference |
|---|---|---|
| *Biosphere Model Report* | MDL-MGR-MD-000001 REV 01 | BSC 2004 [DIRS 169460] |
| *Agricultural and Environmental Input Parameters for the Biosphere Model* | ANL-MGR-MD-000006 REV 02 | BSC 2004 [DIRS 169673] |
| *Characteristics of the Receptor for the Biosphere Model* | ANL-MGR-MD-000005 REV 03 | BSC 2004 [DIRS 169671] |
| *Environmental Transport Input Parameters for the Biosphere Model* | ANL-MGR-MD-000007 REV 02 | BSC 2004 [DIRS 169672] |
| *Inhalation Exposure Input Parameters for the Biosphere Model* | ANL-MGR-MD-000001 REV 03 | BSC 2004 [DIRS 169458] |
| *Soil-Related Input Parameters for the Biosphere Model* | ANL-NBS-MD-000009 REV 02 | BSC 2004 [DIRS 169459] |
| *Nominal Performance Biosphere Dose Conversion Factor Analysis* | ANL-MGR-MD-000009 REV 03 | BSC 2004 [DIRS 169674] |
| *Disruptive Event Biosphere Dose Conversion Factor Analysis* | ANL-MGR-MD-000003 REV 03 | BSC 2004 [DIRS 167287] |

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 analysis and model reports, technical reports, and other documents and databases.

### 6.1.4 Assumptions and Simplifications

For included FEPs, the TSPA-LA dispositions may include statements regarding assumptions made to implement the FEP within the TSPA-LA model. Such statements are descriptive of the manner in which the FEP has been included and are not used as the basis of the screening decision to include the FEP with the TSPA-LA model.

Because individual FEPs are specific in nature, any discussion of applicable mathematical formulations, equations, algorithms, numerical methods, idealizations, or simplifications is provided within the individual FEP discussions in Section 6.2.

### 6.1.5 Intended Use and Limitations

The intended use of this analysis report is to provide FEP screening information for a project-specific FEP database, and to promote traceability and transparency regarding FEP screening. This analysis report is intended to be used as the source documentation for the FEP database described in the report *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes* (BSC 2004, [DIRS 168706]). For included FEPs, this document summarizes and consolidates the method of implementation of the FEP in TSPA-LA in the form of TSPA disposition statements, based on more detailed implementation information in the listed supporting technical reports. For excluded FEPs, this document provides the technical basis for exclusion in the form of screening arguments.

Inherent in this evaluation approach is the limitation that the repository will be constructed, operated, and closed according to the design used as the basis for the FEP screening and in accordance with NRC license requirements. This is inherent in performance evaluation of any engineering project, and design verification and performance confirmation are required as part of the construction and operation processes. The results of the FEP screening presented herein are specific to the repository design evaluated in this analysis report for TSPA-LA.

Any changes in direct inputs listed in Section 4.1, in baseline conditions used for this evaluation, or in other subsurface conditions will need to be evaluated to determine if the changes are within the limits stated in the FEP evaluations. Engineering and design changes are subject to evaluation to determine if there are any adverse impacts to safety as codified at 10 CFR 63.73 and in Subparts F and G [DIRS 156605]. See also the requirements at 10 CFR 63.44 and 10 CFR 63.131 [DIRS 156605].

### 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. No software beyond that listed in Section 3 was used in the development of this analysis.

## 6.2 BIOSPHERE FEP EVALUATION AND ANALYSIS

This section provides the technical basis for either inclusion or exclusion of specific biosphere FEPs (DTN: MO0407SEPFEPLA.000 [DIRS 170760]) in the TSPA-LA, as required by the NRC in 10 CFR Part 63 [DIRS 156605]. For a few FEPs, the descriptions in this section deviate slightly from those in DTN: MO0407SEPFEPLA.000 [DIRS 170760]. The differences are primarily editorial in nature. Substantive changes to the FEPs descriptions are documented where they occur. 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 4.2.2. 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-LA 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-LA model using, as input parameters, BDCFs generated in the biosphere model (BSC 2004 [DIRS 169460], Sections 6.4.10.4 and 6.5.8.3). For the TSPA-LA scenario 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], 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 present-day, monsoon, and glacial-transition climate states (BSC 2004 [DIRS 169460], Section 6.4.10.2).

For the TSPA-LA 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 2004 [DIRS 169460], Section 6.5). The TSPA-LA 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 2004 [DIRS 169460], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA-LA 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 resuspended particles at normal condition. The third is for the ash-thickness and time-dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

The preceding two paragraphs may be repeated in full or in part in the TSPA-LA 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.

### 6.2.1 Ashfall (FEP 1.2.04.07.0A)

**FEP Description:** Finely divided waste particles may be carried up a volcanic vent and deposited on the land surface from an ash cloud.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** Ashfall is incorporated in the TSPA-LA as part of the volcanic eruption modeling case of the igneous scenario class. For the volcanic eruption modeling case, the TSPA-LA 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. Volcanic ash is the source of inhalation dose during volcanic eruption and the inhalation dose is proportional to activity concentration in the airborne ash (BSC 2004 [DIRS 167287], Section 6.3 and Equation 6.3-2). These ashfall events and processes are directly modeled using ASHPLUME (BSC 2003 [DIRS 166296], Section 2.1). The TSPA-LA 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 the TSPA-LA through the use of volcanic ash exposure scenario BDCFs. BDCFs include inhalation exposure to resuspended ash and contaminated soil, external exposure, and ingestion exposure, and are calculated on the annual basis, regardless of the actual eruption time and day (BSC 2004 [DIRS 167287], Section 6.2). The eruption phase is treated separately from the effects of deposition of contaminated ash and its consequences are evaluated as those arising from the exposure occurring during an event of a limited duration (acute or near-acute exposure), rather than from a long-term, chronic exposure thereafter. The latter is evaluated using the BDCFs. The dose factor may be used in TSPA assessments to evaluate whether the doses received by the RMEI during an eruption need to be included in calculation of the expected dose (BSC 2004 [DIRS 167287], Section 6.3).

Ashfall is the initial source of radionuclides in the reference biosphere under the volcanic ash exposure scenario (BSC 2004 [DIRS 169460], Sections 6.1.3, 6.3.2, and 6.5; BSC 2004 [DIRS 167287], Equation 6.3-2). 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 2004 [DIRS 169460], Table 6.7–1) through the use of the following model input parameters: ash bulk density (BSC 2004 [DIRS 169459], Sections 4.1.6 and 6.6), mass loading for crops (BSC 2004 [DIRS 169458], Sections 6.1.5 and 6.2.5), soil-to-plant transfer factor (BSC 2004 [DIRS 169672], Sections 6.2.1.2 through 6.2.1.5), mass loading for receptor environments (BSC 2004 [DIRS 169458], Sections 6.2 and 6.5), and mass loading time function (BSC 2004 [DIRS 169458], Sections 6.3). It is also considered in developing inhalation dose factors (BSC 2004 [DIRS 167287], Section 6.3.2).

This FEP is dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios that constitute the output of the biosphere model (BSC 2004 [DIRS 167287], Table 1-1). Annual doses are calculated in TSPA-LA 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 2004 [DIRS 169460], Section 6.5), and initial ashfall depth is considered in development of the mass loading parameters (BSC 2004 [DIRS 169458], Section 6.2 and 6.3). The TSPA-LA 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 2004 [DIRS 169460], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2). This FEP is also dispositioned in the TSPA-LA through the inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672]).

### 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.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** Future climate forecasts (BSC 2004 [DIRS 170002], 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 glacial-transition (intermediate) climate states are predicted to last until 38,000 years A.P. (after present) (Sharpe 2003 [DIRS 161591], Table 6-5). Consistent with 10 CFR 63.305(c) [DIRS 156605], which requires that the DOE vary factors related to climate based on cautious, but reasonable assumptions, climate change is included in the TSPA-LA through the use of three discrete climate states: present-day, 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 present-day (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 influenced by temperature and precipitation (BSC 2004 [DIRS 169460], Table 6.6-2). In addition, different sets of BDCFs for the groundwater exposure scenario are calculated for the present-day and future climate states (BSC 2004 [DIRS 169674], 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 2004 [DIRS 169673], Section 6.5), overwatering rate (BSC 2004 [DIRS 169673], Section 6.9), growing time (BSC 2004 [DIRS 169673], Section 6.4), irrigation amount per application (BSC 2004 [DIRS 169673], Section 6.7), daily irrigation rate (BSC 2004 [DIRS 169673], Section 6.8), water concentration modifying factor (BSC 2004 [DIRS 169672], Sections 6.4.3 and 6.4.5), surface area of irrigated land (BSC 2004 [DIRS 169672], Section 6.7.2), and evaporative cooler use factor (BSC 2004 [DIRS 169671], Section 6.3.4.2). Distributions were developed for the parameters based in part on present-day and predicted future climatic conditions (BSC 2004 [DIRS 169673], Sections 6.4, 6.5, 6.7, 6.8 and 6.9; BSC 2004 [DIRS 169672], Sections 6.4 and 6.7; BSC 2004 [DIRS 169671], Section 6.3.4.2).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], 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 (BSC 2004 [DIRS 167287], Section 6.2.5). This set of BDCFs is a direct input to the TSPA-LA volcanic eruption modeling case model (BSC 2004 [DIRS 167287], Section 6.2.3).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 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.

**Screening Decision:** Excluded – Low Probability and Low Consequence

**Screening Argument:** This FEP refers to climate conditions that could produce a cold, but glacier-free environment. 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 (BSC 2004 [DIRS 170002], 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 (BSC 2004 [DIRS 170002], Section 6.6). The glacial-transition climate has the lowest predicted mean annual temperatures for the 10,000-year period (BSC 2004 [DIRS 170002], Section 6.6.2). For the glacial-transition climate, the mean annual temperature is no colder than and most likely warmer than 8°C (BSC 2004 [DIRS 170002], Section 6.2), which is too warm to sustain permafrost. Therefore, soil erosion and deposition at Yucca Mountain as a result of permafrost are not credible and can be excluded based on low probability.

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], Section 3.4), 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], Section 3.4), and, therefore, includes the effects of cooler climates.

The erosion rate is an input parameter for the biosphere model. It is one of the parameters that influence the radionuclide concentration in surface soils (BSC 2004 [DIRS 169460], Section 6.4.1.1). The value of this parameter, as used the biosphere model, is characteristic of agricultural soils in the Amargosa Valley area. The erosion rate is in the range from 0.19 $kg/m^2/yr$ to 1.1 $kg/m^2/yr$, which corresponds to $1.3\times10^{-4}$ m/yr to $7.3\times10^{-4}$ m/yr, when the soil density of 1,500 $kg/m^3$ is used (DTN: MO0407SPASRPBM.002 [DIRS 170755]). Over 10,000 years, this erosion rate would result in the removal of 1.3 to 7.3 m of cultivated soil. The additional effect of the seasonal freeze/thaw cycles, if such occurred, on the erosion rate would be insignificant in comparison with the erosion caused by agricultural activities. Consequently, the result of the biosphere model would not be affected by the omission of this FEP from the biosphere model. The effects of the seasonal freeze/thaw cycles can thus be excluded based on low consequence. In summary, 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.

**Screening Decision:** Excluded – 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 (BSC 2004 [DIRS 170002], Section 6.6). The glaciers closest to Yucca Mountain were glaciated mountain ranges, which include the White Mountains in California and possibly the Spring Range (BSC 2004 [DIRS 169734], Section 6.4.1.4), too far from Yucca Mountain (BSC 2004 [DIRS 169734], Figure 2-3) 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 processes 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 Water Table Rise Affects SZ (FEP 1.3.07.02.0A)

**FEP Description:** Climate change could produce increased infiltration, leading to a rise in the regional water table, possibly affecting radionuclide release from the repository by altering flow and transport pathways in the SZ. A regionally higher water table and change in SZ flow patterns might move discharge points closer to the repository.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** Water table rise is possible 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 and cooler from the present-day climate (BSC 2004 [DIRS 170002], Section 7.1). These conditions result in increased recharge to the SZ. The water table is estimated to raise by less than 120 m under future climates for the next 10,000 years (BSC 2004 [DIRS 170037], Section 6.4.5.1). 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 paleodischarge 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), consideration of groundwater level under future climate conditions is included consistent with 10 CFR 63.305(c) [DIRS 156605], which 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 2004 [DIRS 169460], Table 6.7-1). If the groundwater entering the biosphere through a spring or other discharge point were an additional source of radionuclides in the biosphere, it 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 2004 [DIRS 169460], Sections 6.4.1 to 6.4.6, and 6.4.9).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]).

### 6.2.6 Human Influences on Climate (FEP 1.4.01.00.0A)

**FEP Description:** Future human actions, either intentional or accidental, could influence global, regional, or local climate.

**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 10 CFR 63 [DIRS 156605] 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 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 the basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). The present knowledge of the factors related to climate does not allow prediction of the climate changes caused by human behavior. The climate change predictions are based on the geologic records and concern the natural evolution of the reference biosphere. 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 likely would be 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) [DIRS 156605] are also limited to naturally occurring FEPs. This FEP aggregates all human influences on climate into a single category. Technical discussions are presented separately for greenhouse gas effects (FEP 1.4.01.02.0A), acid rain (FEP 1.4.01.03.0A), and ozone layer failure (FEP 1.4.01.04.0A).

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]. In general, the exclusion of anthropogenic effects on climate is believed to be conservative because global warming would increase temperature and reduce precipitation in the Yucca Mountain region (NRC 2004 [DIRS 170243], Section 4.3.5.1).

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.7 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. Thus, these gases act much as the glass of a greenhouse, with the earth as the greenhouse. Human activities, such as burning fossil fuels, clearing forests, 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.

**Screening Decision:** Excluded – By Regulation

**Screening Argument:** Human influences on the concentrations of atmospheric gases 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 10 CFR 63 [DIRS 156605] 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 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 the basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). The present knowledge of the factors related to climate does not allow prediction of the climate changes caused by human behavior. The climate change predictions are based on the geologic records and concern the natural evolution of the reference biosphere. Prediction of the human-induced emissions of greenhouse gases and their potential to effect 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 likely would be 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) [DIRS 156605] are also limited to naturally occurring FEPs.

Because this FEP focuses on the consequences of human activities on the biosphere, it is excluded on the basis of inconsistency with the requirements of 10 CFR 63.305(c) [DIRS 156605]. In general, the exclusion of anthropogenic effects on climate is believed to be conservative because global warming would increase temperature and reduce precipitation in the Yucca Mountain region (NRC 2004 [DIRS 170243], Section 4.3.5.1).

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.8 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.

**Screening Decision:** Excluded – By Regulation

**Screening Argument:** Human influences on climate and other components of the reference biosphere 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 the background discussion of the 2002 amendment to 10 CFR 63 [DIRS 156605], 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 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 the basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). The present knowledge of the factors related to climate does not allow prediction of the climate changes caused by human behavior. The climate change predictions are based on the geologic records and concern the natural evolution of the reference biosphere. Prediction of the human-induced actions resulting in acid rain 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) [DIRS 156605] are also limited to naturally occurring FEPs.

Because this FEP focuses on the consequences of human activities on the biosphere, 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 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.

**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 10 CFR 63 [DIRS 156605], 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 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 the basis for predicting future biosphere changes (66 FR 55732 [DIRS 156671], p. 55757). The present knowledge of the factors related to climate does not allow prediction of the climate changes caused by human behavior. The climate change predictions are based on the geologic records and concern the natural evolution of the reference biosphere. Prediction of the human-induced ozone layer failure 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) [DIRS 156605] are also limited to naturally occurring FEPs.

Because this FEP focuses on the consequences of human activities on the biosphere, it is excluded on the basis of inconsistency with the requirements of 10 CFR 63.305(c) [DIRS 156605]. In general, the exclusion of anthropogenic effects on climate is believed to be conservative because global warming would increase temperature and reduce precipitation in the Yucca Mountain region (NRC 2004 [DIRS 170243], Section 4.3.5.1).

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.10 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.

**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], which requires that the reference biosphere be consistent with present knowledge of the conditions in the region, and with 10 CFR 63.305(b) [DIRS 156605], which requires that the DOE 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 (except those caused by the climate change) 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 dealing with the fraction of overhead irrigation (BSC 2004 [DIRS 169673], Section 6.3), the irrigation intensity (BSC 2004 [DIRS 169673], Section 6.6), and the water concentration-modifying factor (BSC 2004 [DIRS 169672], Sections 6.4.3 and 6.4.5). Parameter distributions were developed based in part on the types of water distribution and storage systems in Amargosa Valley for crop irrigation (BSC 2004 [DIRS 169673], Sections 6.3 and 6.6) and fish farming (BSC 2004 [DIRS 169672], Section 6.4). Climate change aspects of this FEP and related parameters are covered by FEP 1.3.01.00.0A, *Climate change*.

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], 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 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]).

### 6.2.11 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.

**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 2004 [DIRS 169460], Tables 6.2-1 and 6.7-1, and Section 6.3.1). Radionuclide concentration in groundwater is the corresponding parameter in the mathematical model used in the soil, air, plant, animal, fish, $^{14}C$, and ingestion submodels of the biosphere model (BSC 2004 [DIRS 169460], Sections 6.4.1 to 6.4.6, and 6.4.9). This FEP is also considered in the calculation of conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs and the conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Tables 1-1 and 1-2). The assessment of annual doses is carried out in the TSPA-LA model using the BDCFs generated in the biosphere model as input parameters (BSC 2004 [DIRS 169460], Section 6.4.10.4; BSC 2004 [DIRS 169674], Section 7.1.2; BSC 2004 [DIRS 167287], Sections 7.1.2 and 7.1.3). For the TSPA-LA scenario 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], 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 present-day, monsoon, and glacial-transition climate states (BSC 2004 [DIRS 169460], Section 6.4.10.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]).

### 6.2.12 Social and Institutional Developments (FEP 1.4.08.00.0A)

**FEP Description:** Social and institutional developments 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.

**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, "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

### 6.2.13 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 humans to intrude the site, and changes that might affect contaminant exposure and its health implications.

**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, "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

### 6.2.14 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.

**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

### 6.2.15 Chemical Characteristics of Groundwater in the SZ (FEP 2.2.08.01.0A)

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

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** 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, in a manner that is independent of the chemical characteristics of groundwater. Several biosphere model input parameters are dependent on the chemical species present in groundwater and in other environmental media. These parameters include partition coefficients ($K_d$s), soil-to-plant transfer factors, transfer coefficients for animal products, bioaccumulation factors, irrigation interception fraction, translocation factors, and dose conversion factors for radionuclide intakes. The approach to developing values for these parameters is as follows. If a sufficient technical basis exists to develop a distribution of parameter values encompassing a range of values that would be expected in the environment for different chemical species, such an approach is preferred (BSC 2004 [DIRS 169672], Sections 6.2.1.1, 6.2.1.2, 6.3.3 and 6.4.3; BSC 2004 [DIRS 169459], Section 6.2). The advantage of this approach is that, where appropriate, such a distribution applies to multiple environmental media (not only for groundwater) and to all chemical species in these environmental media (e.g., transfer coefficients are used to model radionuclide transfer to animal products from water, animal feed, and soil).

If a single value has to be assigned to a parameter, a value is selected for use in the biosphere model that represents the worst case with respect to the risk to the receptor. Such an approach ensures that if a parameter value is dependent on the chemical characteristics of a given environmental medium, including well water, by selecting the value for the worst case the risk to the receptor is not underestimated. This approach is used to select the values of dose conversion factors for inhalation and ingestion of radionuclides (BSC 2004 [DIRS 169671], Section 6.5.3) and also to select the values of empirical constants used in the equation for irrigation interception fraction for foliar uptake by crops (BSC 2004 [DIRS 169460], Section 6.4.3.2). Both approaches described above make the biosphere model insensitive to the exact details of the chemical characteristics of groundwater and, at the same time, do not underestimate the risk to the receptor.

This FEP is considered in the conceptual and mathematical models for the groundwater exposure scenario (BSC 2004 [DIRS 169460], Table 6.7-1) in the soil, plant, animal, fish, $^{14}C$, inhalation, and ingestion submodels (BSC 2004 [DIRS 169460], Sections 6.4.1 to 6.4.6, 6.4.8, and 6.4.9).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])

- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]).

### 6.2.16 Radionuclide Solubility Limits in the Biosphere (FEP 2.2.08.07.0C)

**FEP Description:** Solubility limits for radionuclides may be different in the biosphere pathways than in the water in the saturated zone.

**Screening Decision:** Excluded – Low Consequence

**Screening Argument:** In the groundwater exposure scenario, radionuclides are introduced into the biosphere with well water, either in solution or in suspension attached to colloids. The conditions that dictate aqueous solubility levels in the SZ could be different from those prevailing in the surface soils of the biosphere. In particular, pH values have an effect on solubility. Data on the pH of water in the SZ (DTN: LA0206AM831234.001 [DIRS 160051]) indicate that pH ranges between 6.3 and 9.9. The values in the upper region of this range are not representative for the SZ water and considered outliers in the SZ flow and transport models, however, in this analysis a full range of the measured pH values is considered for the purpose of the FEP screening. For the soils in Amargosa Valley (DTN: SN9912USDASOIL.000 [DIRS 142440]), the pH values range between 7.4 and 9.6. If the conditions in the SZ are such that the solubility of a radionuclide in the water being pumped is less than the solubility in the water in the biosphere, there will be no effect resulting from the change in solubility and the model used in the biosphere will not be impacted. However, if the conditions in the biosphere result in the solubility of the radionuclide being less in the biosphere than in the SZ, then for sufficiently high concentrations of the radionuclide in the well water, there is a possibility of the radionuclide being precipitated once introduced into the soils by irrigation water. This precipitation process is not considered in the biosphere model. The ramifications of precipitation would be to reduce the quantity of radionuclides in solution available for uptake by crops, while increasing the concentration of radionuclides in surface soil that would be available for (a) resuspension and subsequent inhalation by the receptor and foliar deposition, and (b) increasing the source term for external radiation from surface soil. The rationale for exclusion of this FEP is documented herein.

The initial screening approach to evaluate the significance of this FEP is to estimate the annual dose to the RMEI for radionuclide concentrations in groundwater that would result in precipitation in the surface soils. If the predicted dose for a radionuclide at the solubility limit in the surface soil is greater than the compliance dose of 0.15 mSv (15 mrem), then this FEP can be excluded on the basis of low consequence.

Solubility data for use in TSPA-LA are provided in DTN: MO0408SPADCLRE.000 [DIRS 171601]. These data were developed in the report *Dissolved Concentration Limits of Radioactive Elements* (BSC 2004 [DIRS 169425]). The objective of this report was to provide solubility values (distributions) for use in modeling the interaction of infiltration water with exposed waste forms. It was identified that for technetium, carbon, iodine, cesium, and strontium, solubility is high under all conditions and is not a limiting factor

(DTN: MO0408SPADCLRE.000 [DIRS 171601]). For radium, solubility is described by a simple distribution.

For the actinides, solubility is presented as a table of logarithm of solubility (mg/L) with variables being pH and carbon dioxide ($CO_2$) fugacity. The range of the two variables determining solubility are $3.0 \le pH \le 10.5$ and $-1.5 \ge \log(fugacity\ CO_2) \ge -5.0$. For the biosphere environment, the atmospheric value of the partial pressure of carbon dioxide is $10^{-3.5}$ bars (BSC 2004 [DIRS 169425], Section 6.4.3.4) and log(fugacity $CO_2$) = -3.5. Solubility of each element was determined by using log(fugacity $CO_2$) = -3.5 and taking the minimum log (solubility) over all pH values.

In the case of the actinides, DTN: MO0408SPADCLRE.000 [DIRS 171601] also provides uncertainty term(s) to be applied when generating solubility. For plutonium, neptunium, and uranium, the generalized equation from which solubility is calculated is

$$\log(Sol) = S(pH, \log(f_{CO_2})) + \varepsilon_1 + (\varepsilon_2 \times N) \quad \text{(Eq. 6-1a)}$$

and for americium, thorium, and protactinium, the uncertainty is added to the solubilities by the following equation

$$\log(Sol) = S(pH, \log(f_{CO_2})) + \varepsilon_1 + \varepsilon_2 \quad \text{(Eq. 6-1b)}$$

where

| | | |
|---|---|---|
| *log(Sol)* | = | logarithm of solubility (mg/L) for a given element |
| *S* | = | interpolated value of log solubility (mg/L) from lookup table |
| $\log(f_{CO_2})$ | = | logarithm of $CO_2$ fugacity (bars) |
| $\varepsilon_1$ | = | first uncertainty term distribution |
| $\varepsilon_2$ | = | second uncertainty term distribution |
| *N* | = | the factor by which the $\varepsilon_2$ is normalized for pH |

As noted before, to ensure that solubility values are not overestimated, the minimum solubility values over all pH values for *S(pH, -3.5)* were selected for thorium, protactinium, uranium, plutonium, neptunium, and americium. This value is further reduced to reflect the uncertainty terms $\varepsilon_1$ and $\varepsilon_2$, if applicable. A value for $\varepsilon_1$ was selected such that only 5% of the samples were expected to fall below the value. For a normal distribution, this value is approximately 1.66 standard deviations below the mean and was calculated as 1.66 times the standard deviation. The lower limit for the distribution of the second uncertainty term, $\varepsilon_2$, is equal to zero for all actinides mentioned above, so this correction does not affect the solubility value. For radium, the solubility value of 0.0792 corresponding to the pH range expected to occur in the surface soils in Amargosa Valley ($7.75 \le pH \le 9.75$) was selected (DTN: MO0408SPADCLRE.000 [DIRS 171601]). For protactinium, the lower limit of the solubility range (-0.749) (DTN: MO0408SPADCLRE.000 [DIRS 171601]) was used. The values of S and the uncertainty terms from the data given in DTN: MO0408SPADCLRE.000 [DIRS 171601] are summarized in Table 6-2. The first five elements in Table 6-2 are defined as having “high” solubility. The exact solubility values for these elements are not given in the source DTN because solubility is not a process that limits the transport of these elements. For the purpose of this analysis, the solubility for these elements was taken to be no lower than the maximum solubility of the other element for which it was considered necessary to quantify solubility (i.e., the value for uranium, $S$ = 0.099 mg/L). The same value was used for actinium, whose solubility was not provided in the source DTN. If the concentration of a given element in surface soil water is not greater than the limit given in the final column of Table 6-2, then there will be no precipitation of that element in the surface soil.

Estimating doses arising from these concentration limits requires the conversion from mass concentration in groundwater to activity concentration. This is a two-step process. First, mass concentration, $C_m$ (g/L), is converted to atomic concentration, $Ca$ (atoms/L), using Equation 6-2.

$$Ca = Cm \times \frac{Av}{AW} \qquad \text{(Eq. 6-2)}$$

where

| | | |
|---|---|---|
| $Av$ | = | Avogadro's number ($6.02 \times 10^{23}$ atoms/mole) |
| $AW$ | = | atomic weight of radionuclide under consideration |

Table 6-2. Solubility Limits of Various Radionuclides in Groundwater and the Values Selected/Calculated for the Assessment of Precipitation in the Biosphere

| Radionuclide | S(pH, log($f_{CO2}$)) [a] | Distribution of $\varepsilon_1$ [a] | $\varepsilon_1$ [b] | Mass Solubility log (Sol) [b] | Mass Solubility Sol (mg/L) [b] |
|---|---|---|---|---|---|
| C-14 | high (0.099) | N/A | N/A | 0.099 | 1.26E+00 |
| Sr-90 | high (0.099) | N/A | N/A | 0.099 | 1.26E+00 |
| Tc-99 | high (0.099) | N/A | N/A | 0.099 | 1.26E+00 |
| I-129 | high (0.099) | N/A | N/A | 0.099 | 1.26E+00 |
| Cs-135 | high (0.099) | N/A | N/A | 0.099 | 1.26E+00 |
| Cs-137 | high (0.099) | N/A | N/A | 0.099 | 1.26E+00 |
| Ra-226 | 0.0792 | N/A | N/A | 0.0792 | 1.20E+00 |
| Ac-227 | (0.099) | N/A | N/A | 0.099 | 1.26E+00 |
| Th-229 | -2.99 | normal (0.0, 0.7) | -1.162 | -4.152 | 7.05E-05 |
| Pa-231 | -0.749 | uniform (-1.02, 3.04) | -1.02 | -1.769 | 1.70E-02 |
| U-232 | 0.099 | normal (0.0, 0.5) | -0.83 | -0.731 | 1.86E-01 |
| U-233 | 0.099 | normal (0.0, 0.5) | -0.83 | -0.731 | 1.86E-01 |
| U-234 | 0.099 | normal (0.0, 0.5) | -0.83 | -0.731 | 1.86E-01 |
| U-238 | 0.099 | normal (0.0, 0.5) | -0.83 | -0.731 | 1.86E-01 |
| Np-237 | -0.778 | normal (0.0, 0.8) | -1.328 | -2.106 | 7.83E-03 |
| Pu-238 | -2.67 | normal (0.0, 1.0) | -1.66 | -4.33 | 4.68E-05 |
| Pu-239 | -2.67 | normal (0.0, 1.0) | -1.66 | -4.33 | 4.68E-05 |
| Pu-240 | -2.67 | normal (0.0, 1.0) | -1.66 | -4.33 | 4.68E-05 |

Table 6-2. Solubility Limits of Various Radionuclides in Groundwater and the Values Selected/Calculated for the Assessment of Precipitation in the Biosphere (Continued)

| Radionuclide | S(pH, log($f_{CO2}$)) [a] | Distribution of $\varepsilon_1$ [a] | $\varepsilon_1$ [b] | Mass Solubility | |
|---|---|---|---|---|---|
| | | | | log (Sol) [b] | Sol (mg/L) [b] |
| Am-241 | -2.12 | normal (0.0, 1.0) | -1.66 | -3.78 | 1.66E-04 |
| Am-243 | -2.12 | normal (0.0, 1.0) | -1.66 | -3.78 | 1.66E-04 |

[a] Source: DTN: MO0408SPADCLRE.000 [DIRS 171601].
[b] Values calculated as described in the text.

Having the atomic concentration in groundwater, it is necessary to convert to activity concentration from the radionuclide half-life (DTN: MO0407SPACRBSM.002 [DIRS 170677]). The standard equation for the number of atoms of a radionuclide involved in radioactive decay is given as

$$N(t) = N_o e^{-\lambda t} \qquad \text{(Eq. 6-3)}$$

where

| | | |
|---|---|---|
| $N(t)$ | = | number of atoms remaining after time $t$ |
| $N_0$ | = | number of atoms at time zero |
| $\lambda$ | = | characteristic decay constant for the radionuclide (1/s) |
| $t$ | = | time (s) |

The characteristic decay constant and the half–life ($T_{½}$) for the radionuclide are related as

$$0.5 = e^{-\lambda T_{1/2}} \qquad \text{(Eq. 6-4)}$$

The solution of Equation 6-4 is

$$\lambda = \frac{\ln(2)}{T_{1/2}} \qquad \text{(Eq. 6-5)}$$

Equation 6-3 is also required to define the activity associated with a number of atoms with a characteristic decay constant, $\lambda$. The activity at time $t$, $A(t)$, is given by the negative of the differential of Equation 6-3 with respect to time.

$$A(t) = -\frac{dN(t)}{dt}$$

$$A(t) = \lambda N_o e^{-\lambda t}$$

$$A(t) = \lambda N(t) \qquad \text{(Eq. 6-6)}$$

The solubility values in terms of mg/L in Table 6-2 can be converted to atoms per L by use of Equation 6-2. This value can then be further converted to activity per L (Bq/L) from the appropriate half-life by use of Equations 6-5 and 6-6. These sequential values are provided in Table 6-3. The dose associated with the concentration of each radionuclide can be calculated from the equation given in the *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674], Equation 6.3-2), by using the biosphere dose conversion factors for the present-day climate from DTN: MO0407MWDBDCFG.000 [DIRS 171602]. The only other conversion constant required for the calculation is 1 pCi = $3.7 \times 10^{-2}$ Bq.

The final column of Table 6-3 provides the annual dose estimate for each radionuclide expected at the concentration limit below which precipitation in the biosphere may occur. For the majority of radionuclides of interest to TSPA-LA, precipitation does not occur until the predicted annual dose is tens of rem or more. The expected annual dose is evaluated against the individual protection standard of 0.15 mSv (15 mrem) (10 CFR 63.311 [DIRS 156605]). Thus, for the majority of radionuclides of concern for postclosure safety, solubility limits within the biosphere are of no concern for a repository system compliant with the regulations, and the FEP 2.2.08.07.0C can be excluded based on low consequence.

There is only one radionuclide for which the solubility-limited concentrations are predicted to result in an annual dose of less than one rem, $^{238}$U. For this radionuclide, the estimated annual dose is 4.7 times above the 0.15 mSv (15 mrem) limit. Given the conservative interpretation of the solubility abstractions, the margins for this radionuclide are considered sufficient to disregard precipitation in the biosphere.

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.17 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.

**Screening Decision:** Excluded – Low Consequence.

**Screening Argument:** This FEP is shared with the SZ flow and transport model and has been excluded within that process model. See *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]) for the exclusion argument. As a consequence, this FEP is also excluded from the biosphere model.

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports: N/A**

Table 6-3. Solubility, Activity, and Dose Calculation

| Radionuclide | Half-life [a] yr | Decay constant 1/s | Mass solubility [b] mg/L | Mass solubility g/L | Atomic weight | Molar solubility mole/L | Atom solubility atom/L | Activity concentration | | BDCF [c] rem/yr per pCi/L | Annual dose rem |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Bq/L | pCi/L | | |
| C-14 | 5.73E+03 | 3.83E-12 | 1.26E+00 | 1.26E-03 | 14 | 8.97E-05 | 5.40E+19 | 2.07E+08 | 5.60E+09 | 9.10E-06 | 5.09E+04 |
| Sr-90 | 2.91E+01 | 7.54E-10 | 1.26E+00 | 1.26E-03 | 90 | 1.40E-05 | 8.40E+18 | 6.34E+09 | 1.71E+11 | 1.64E-04 | 2.81E+07 |
| Tc-99 | 2.13E+05 | 1.03E-13 | 1.26E+00 | 1.26E-03 | 99 | 1.27E-05 | 7.64E+18 | 7.88E+05 | 2.13E+07 | 2.26E-06 | 4.81E+01 |
| I-129 | 1.57E+07 | 1.40E-15 | 1.26E+00 | 1.26E-03 | 129 | 9.74E-06 | 5.86E+18 | 8.20E+03 | 2.22E+05 | 3.36E-04 | 7.45E+01 |
| Cs-135 | 2.30E+06 | 9.55E-15 | 1.26E+00 | 1.26E-03 | 135 | 9.30E-06 | 5.60E+18 | 5.35E+04 | 1.45E+06 | 5.57E-05 | 8.05E+01 |
| Cs-137 | 3.00E+01 | 7.32E-10 | 1.26E+00 | 1.26E-03 | 137 | 9.17E-06 | 5.52E+18 | 4.04E+09 | 1.09E+11 | 4.82E-04 | 5.27E+07 |
| Ra-226 | 1.60E+03 | 1.37E-11 | 1.20E+00 | 1.20E-03 | 226 | 5.31E-06 | 3.20E+18 | 4.39E+07 | 1.19E+09 | 9.69E-02 | 1.15E+08 |
| Ac-227 | 2.18E+01 | 1.01E-09 | 1.26E+00 | 1.26E-03 | 227 | 5.53E-06 | 3.33E+18 | 3.36E+09 | 9.08E+10 | 3.11E-02 | 2.83E+09 |
| Th-229 | 7.34E+03 | 2.99E-12 | 7.05E-05 | 7.05E-08 | 229 | 3.08E-10 | 1.85E+14 | 5.55E+02 | 1.50E+04 | 3.41E-02 | 5.11E+02 |
| Pa-231 | 3.28E+04 | 6.70E-13 | 1.70E-02 | 1.70E-05 | 231 | 7.37E-08 | 4.44E+16 | 2.98E+04 | 8.04E+05 | 1.01E-01 | 8.12E+04 |
| U-232 | 7.20E+01 | 3.05E-10 | 1.86E-01 | 1.86E-04 | 232 | 8.01E-07 | 4.82E+17 | 1.47E+08 | 3.98E+09 | 5.82E-03 | 2.31E+07 |
| U-233 | 1.59E+05 | 1.39E-13 | 1.86E-01 | 1.86E-04 | 233 | 7.97E-07 | 4.80E+17 | 6.65E+04 | 1.80E+06 | 1.86E-03 | 3.34E+03 |
| U-234 | 2.45E+05 | 8.98E-14 | 1.86E-01 | 1.86E-04 | 234 | 7.94E-07 | 4.78E+17 | 4.30E+04 | 1.16E+06 | 1.28E-03 | 1.49E+03 |
| U-238 | 4.47E+09 | 4.92E-18 | 1.86E-01 | 1.86E-04 | 238 | 7.81E-07 | 4.70E+17 | 2.31E+00 | 6.25E+01 | 1.13E-03 | 7.06E-02 |
| Np-237 | 2.14E+06 | 1.03E-14 | 7.83E-03 | 7.83E-06 | 237 | 3.31E-08 | 1.99E+16 | 2.04E+02 | 5.52E+03 | 6.98E-03 | 3.85E+01 |
| Pu-238 | 8.77E+01 | 2.50E-10 | 4.68E-05 | 4.68E-08 | 238 | 1.97E-10 | 1.18E+14 | 2.96E+04 | 8.01E+05 | 4.69E-03 | 3.76E+03 |
| Pu-239 | 2.41E+04 | 9.13E-13 | 4.68E-05 | 4.68E-08 | 239 | 1.96E-10 | 1.18E+14 | 1.08E+02 | 2.91E+03 | 9.25E-03 | 2.69E+01 |
| Pu-240 | 6.54E+03 | 3.36E-12 | 4.68E-05 | 4.68E-08 | 240 | 1.95E-10 | 1.17E+14 | 3.94E+02 | 1.07E+04 | 9.01E-03 | 9.60E+01 |
| Am-241 | 4.32E+02 | 5.08E-11 | 1.66E-04 | 1.66E-07 | 241 | 6.89E-10 | 4.15E+14 | 2.11E+04 | 5.70E+05 | 6.83E-03 | 3.89E+03 |
| Am-243 | 7.38E+03 | 2.98E-12 | 1.66E-04 | 1.66E-07 | 243 | 6.83E-10 | 4.11E+14 | 1.22E+03 | 3.31E+04 | 9.57E-03 | 3.17E+02 |

Sources: [a] DTN: MO0407SPACRBSM.002 [DIRS 170677].
[b] From Table 6-2.
[c] DTN: MO0407MWDBDCFG.000 [DIRS 171602].

NOTE: The other values were calculated as described in the text in the Excel spreadsheet *Solubility Calculation.xls* (see Appendix A).

### 6.2.18 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 and pH) may influence the mobility of radionuclides.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** Soil is a feature constituting 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 containing 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, the soil type is considered in the soil, plant, and $^{14}C$ submodels of the biosphere model. Characteristics of soils are based, in part, on the characteristics of soil types in northern Amargosa Valley (BSC 2004 [DIRS 169460], Table 6.2-1).

Parameters relevant to this FEP are surface soil (tillage) depth (BSC 2004 [DIRS 169673], Section 6.10), rooting depth (BSC 2004 [DIRS 169673], Section 6.12), soil bulk density (BSC 2004 [DIRS 169459], Sections 4.1.1 and 6.1), ash bulk density (BSC 2004 [DIRS 169459], Sections 4.1.6 and 6.6), surface soil erosion rate (BSC 2004 [DIRS 169459], Sections 4.1.3 and 6.3), soil water content at field capacity (BSC 2004 [DIRS 169459], Sections 4.1.5 and 6.5), irrigation intensity (BSC 2004 [DIRS 169673], Section 6.6), and $^{14}C$ emission rate from soil (BSC 2004 [DIRS 169672], Section 6.7.1).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.19 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.

**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 concentrations in the soil (BSC 2004 [DIRS 169460], Section 6.4.1). 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 2004 [DIRS 169460], 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 (BSC 2004 [DIRS 169460], Section 6.3.1.4). 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 present-day 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. Other mechanisms of radionuclide loss from surface soil, such as runoff, are not directly included in the biosphere model.

Relevant parameters are the annual average irrigation rate (BSC 2004 [DIRS 169673], Section 6.5), overwatering rate (BSC 2004 [DIRS 169673], Section 6.9), surface soil depth (tillage depth) (BSC 2004 [DIRS 169673], Section 6.10), rooting depth (BSC 2004 [DIRS 169673], Section 6.12), soil solid-liquid partition coefficient (BSC 2004 [DIRS 169459], Sections 4.1.2 and 6.2), soil bulk density (BSC 2004 [DIRS 169459], Sections 4.1.1 and 6.1), ash bulk density (BSC 2004 [DIRS 169459], Sections 4.1.6 and 6.6), soil water content at field capacity (BSC 2004 [DIRS 169459], Sections 4.1.5 and 6.5), surface soil erosion rate (BSC 2004 [DIRS 169459], Sections 4.1.3 and 6.3), and critical thickness for the resuspension (BSC 2004 [DIRS 169672], 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.4.3.1), i.e., all radionuclides (solutes and colloids) in groundwater (BSC 2004 [DIRS 169460], Section 6.4.3.1) are in solution and available for plant uptake. This is a conservative approach for cases where colloids are present because the activity associated with colloids is made available for plant uptake.

For the volcanic ash exposure scenario, the mode of radionuclide release into the biosphere is a volcanic eruption through the repository with the resulting entrainment of contaminated waste in the tephra (BSC 2004 [DIRS 167287], Section 1.0). 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 assumes that all radionuclides in soil on agricultural lands are available for transport to crop via root uptake (BSC 2004 [DIRS 169460], Section 6.5.3.1), thus implying that they are in solution.

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.20 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.

**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. This FEP is addressed in the soil and air submodels (BSC 2004 [DIRS 169460], Table 6.7-1).

Although the region around Yucca Mountain currently 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 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 2004 [DIRS 169460], Section 6.4.1.4). Soil erosion may result from various individual transport processes 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 2004 [DIRS 169459], Section 6.4). Soil erosion includes soil loss and gain on farm fields (groundwater scenario (BSC 2004 [DIRS 169460], Equation 6.4.1-11); volcanic ash scenario (BSC 2004 [DIRS 169460], Equation 6.5.1-4)). (The environmental radiation model for Yucca Mountain, Nevada, ERMYN, does not develop thickness of ash deposited on the ground (BSC 2004 [DIRS 169460], Equation 6.5.1-4)). 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 description of 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 2004 [DIRS 169459], Sections 4.1.3 and 6.3), soil bulk density (BSC 2004 [DIRS 169459], Sections 4.1.1 and 6.1), ash bulk density (BSC 2004 [DIRS 169459], Sections 4.1.6 and 6.6), dry deposition velocity (BSC 2004 [DIRS 169672], Section 6.2.2.1), critical thickness for resuspension (BSC 2004 [DIRS 169672], Section 6.8), tillage depth (BSC 2004 [DIRS 169673], Section 6.10), rooting depth (BSC 2004 [DIRS 169673], Section 6.12), and mass loading decrease constant (BSC 2004 [DIRS 169458], Section 6.3). Distributions of mass loading decrease constant were developed based in part on the influence of ash redistribution on changes in mass loading through time (BSC 2004 [DIRS 169458], Section 6.3).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.21 Surface Water Transport and Mixing (FEP 2.3.04.01.0A)

**FEP Description:** Radionuclides 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 radionuclides in the biosphere. Transport and mixing includes dilution, sedimentation, aeration, streamflow, and river meander.

**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], which 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 (BSC 2004 [DIRS 170002], 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). The water table is estimated to raise less than 120 m under future climates for the next 10,000 years (BSC 2004 [DIRS 170037], Section 6.4.5.1). 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. This 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. The conceptual and mathematical models for the groundwater scenario are applicable to water discharged to the surface, and the subsequent transport of radionuclides in surface water. Mixing is not considered because there are no sources of uncontaminated water in the reference biosphere (BSC 2004 [DIRS 169460], Section 6.3.1).

This FEP is considered in the conceptual and mathematical models for the groundwater exposure scenario (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169460], Table 6.7-1).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]).

### 6.2.22 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.

**Screening Decision:** Excluded – Low Probability

**Screening Argument:** The *Yucca Mountain Site Description* (BSC 2004 [DIRS 169734], Figure 2–1a) 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 (BSC 2004 [DIRS 170002], 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 present-day interglacial climate, the change is expected to have no effect on current coastlines relative to Yucca Mountain and thus this FEP is not credible.

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.23 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.

**Screening Decision:** Excluded – Low Probability and Low Consequence

**Screening Argument:** The overburden thickness at the repository is approximately 215 m (BSC 2004 [DIRS 164519], Sheet 1). 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 negligible. Therefore, this FEP is excluded based on low consequence, per 10 CFR 63.114(e) [DIRS 156605].

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.24 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.

**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 (BSC 2004 [DIRS 170002], 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 2004 [DIRS 169460], Table 6.2-1). Specifically, precipitation rate, along with irrigation rate and evapotranspiration rate, are used to calculate the overwatering rate (BSC 2004 [DIRS 169673], Section 6.9), a parameter that controls infiltration of water and thus radionuclide transport below the root zone. Distributions of parameters were developed based in part on variation and uncertainty in precipitation for the present-day and predicted future climate states (BSC 2004 [DIRS 169673], Sections 6.5, 6.7, 6.8, and 6.9).

Within the biosphere model, precipitation is addressed in the soil, plant, and $^{14}$C submodels. The relevant parameters are annual average irrigation rate (BSC 2004 [DIRS 169673], Section 6.5), overwatering rate (BSC 2004 [DIRS 169673], Section 6.9), irrigation amount per application (BSC 2004 [DIRS 169673], Section 6.7), and daily irrigation rate (BSC 2004 [DIRS 169673], Section 6.8).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]).

### 6.2.25 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.

**Screening Decision:** Excluded – By Regulation

**Screening Argument:** The 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 as well as the doses to the RMEI and, therefore, are not included. Postclosure individual protection standard is formulated in terms of annual dose to the RMEI (10 CFR 63.311(b) [DIRS 156605]). Since the performance assessment uses the characteristics of the reference biosphere to demonstrate compliance with the individual protection standard (66 FR 55732 [DIRS 156671], p. 55784) the FEPs related to any processes occurring outside the reference biosphere are implicitly excluded. As the result, groundwater discharge to surface outside the reference biosphere is excluded on the basis of inconsistency with the requirements for demonstration of compliance with the postclosure performance objectives per 10 CFR 63.113(b) [DIRS 156605]).

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.26 Biosphere Characteristics (FEP 2.3.13.01.0A)

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

**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 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 2004 [DIRS 169460], Table 6.7-1).

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 2004 [DIRS 169673], Sections 6.4, 6.5, 6.6, 6.7, 6.8, and 6.9; BSC 2004 [DIRS 169671], Section 6.3.4.2; BSC 2004 [DIRS 169672], 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, inhalation and $^{14}C$ submodels (BSC 2004 [DIRS 169460], Table 6.7-1) through many parameters such as the annual average irrigation rate (BSC 2004 [DIRS 169673], Section 6.5), overwatering rate (BSC 2004 [DIRS 169673], Section 6.9), water evaporation rate (use rate) for evaporative coolers (BSC 2004 [DIRS 169672], Section 6.5.2), dry deposition velocity (BSC 2004 [DIRS 169672], Section 6.2.2.1), daily irrigation rate (BSC 2004 [DIRS 169673], Section 6.8), irrigation application (BSC 2004 [DIRS 169673], Section 6.7), irrigation intensity (BSC 2004 [DIRS 169673], Section 6.6), growing time (BSC 2004 [DIRS 169673], Section 6.4), water concentration modifying factor (BSC 2004 [DIRS 169672], Sections 6.4.3 and 6.4.5), annual average wind speed (BSC 2004 [DIRS 169672], Section 6.7.2), and evaporative cooler use factor (BSC 2004 [DIRS 169671], 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-LA model through the use of groundwater exposure scenario BDCFs (BSC 2004 [DIRS 169674], Table 1-1). For the TSPA-LA 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], 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 present-day, monsoon, and glacial-transition climate states (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.27 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.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** The biosphere model is constructed around the radionuclide transfer interaction matrix (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.4.6) and from the surface water (fish ponds) to the air (BSC 2004 [DIRS 169672], Section 6.4.4), the plant uptake of carbon dioxide from the air (BSC 2004 [DIRS 169460], Section 6.4.6.3), and release of gaseous species during operation of evaporative coolers (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169672], Section 6.2.1.2), and steady-state radionuclide-specific and animal-product-specific transfer factors (BSC 2004 [DIRS 169672], Section 6.3.3) in the plant and animal submodels, respectively as identified in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Sections 6.4 and 6.5). In addition, this FEP is addressed in the following parameters: bioaccumulation factor for aquatic food (BSC 2004 [DIRS 169672], Sections 6.4.3 and .6.4.4), water concentration modification factor for fishpond water (BSC 2004 [DIRS 169672], Sections 6.4.3 and 6.4.5), fraction of radionuclides in evaporative cooler water transferred to air (BSC 2004 [DIRS 169672], Section 6.5.2), carbon emission rate constant for soil (BSC 2004 [DIRS 169672], Section 6.7.1), fraction of air-derived and soil-derived carbon in plants (BSC 2004 [DIRS 169672], Section 6.7.3), and correlation coefficient for transfer factors and partition coefficients (BSC 2004 [DIRS 169672], Section 6.2.1.5).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.28 Radionuclide Release Outside the Reference Biosphere (FEP 2.3.13.04.0A)

**FEP Description:** Radionuclide 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, discharge areas such as playas (e.g., Franklin Playa), or forests, grasslands, or wetlands that occur in 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 may be bioaccumulated and enter the food chain. Intermittent use of these areas by humans may also lead to exposure.

**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]). 10 CFR 63 [DIRS 156605] 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 10 CFR 63 [DIRS 156605] 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) [DIRS 156605] (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

### 6.2.29 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.

**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 (BSC 2004 [DIRS 169460], Table 6.7-1) through the use of dose coefficients (BSC 2004 [DIRS 169671], Section 6.5.3.2), dose conversion factors (BSC 2004 [DIRS 169671], Sections 6.5.3.1 and 6.5.4), and breathing rates (BSC 2004 [DIRS 169671], Section 6.3.3), which are based on adult human physiologic and metabolic characteristics. These parameters are used to calculate the values of BDCFs. This FEP is also considered in the discussion of the dependence of inhalation dose conversion factors on particle sizes (BSC 2004 [DIRS 169460], Section 6.5.5). 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 by BSC (2004 [DIRS 169460], Section 6.6.3).

Human characteristics are also included in the calculation of conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2). Physiology and metabolism of the human receptor were considered in developing the values of dose conversion factors for ingestion, which are used as input to calculate the values of the conversion factors used in the dose calculations related to the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2). Physiology and metabolism of the human receptor were considered in developing the values of breathing rates and dose conversion factors for inhalation, which are used as input to calculate the values of inhalation dose factors (BSC 2004 [DIRS 167287], Equation 6.3-3).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models and through the use of the conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Tables 1-1 and 1-2). Annual doses are calculated as the product of radionuclide concentration in groundwater and BDCFs or conversion factors. There are three sets of BDCFs for the groundwater exposure scenario corresponding to the present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios BDCFs (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2). This FEP is also dispositioned in the TSPA-LA through inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.30 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 humans.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** Aspects of human lifestyle including work and leisure activities 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 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 (BSC 2004 [DIRS 169460], Table 6.7-1).

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 2004

[DIRS 169458], Sections 6.1 and 6.2; BSC 2004 [DIRS 169671], Sections 6.3 and 6.4). Influence of human lifestyle on external exposure is considered in the report by BSC (2004 [DIRS 169460], Equation 6.4.7-1) for the groundwater exposure scenario and BSC (2004 [DIRS 169460], Equation 6.5.5-1) for the volcanic ash exposure scenario. Influences on inhalation pathway are considered in the *Biosphere Model Report* (BSC 2004 [DIRS 169460], Equations 6.4.8-2 to 6.4.8-7) for the groundwater exposure scenario and Equations 6.5.6-2 and 6.5.6-3 for the volcanic ash exposure scenario). Influences on the ingestion pathway are considered in BSC (2004 [DIRS 169460], Equations 6.4.9-2 to 6.4.9-6) for the groundwater exposure scenario and BSC (2004 [DIRS 169460], Equations 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 2004 [DIRS 169458], Sections 6.1 and 6.2), population proportion (BSC 2004 [DIRS 169671], Section 6.3.1), and exposure time (BSC 2004 [DIRS 169671], Section 6.3.2).

Lifestyles and characteristics of people living in Amargosa Valley were considered in developing the values of population proportions and exposure times, which are used as input to calculate the values of the inhalation dose factors (BSC 2004 [DIRS 167287], Equation 6.3-3).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1). This FEP is also considered in the calculation of conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenario (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

This FEP is also dispositioned in the TSPA-LA through inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])

- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.31 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.

**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 residences 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 Town of 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 (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 manufactured housing 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 2004 [DIRS 169460], Tables 6.2-1 and 6.7-1).

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 (BSC 2004 [DIRS 169671], Sections 6.3.4.1, 6.3.4.2, and 6.6; BSC 2004 [DIRS 169672], Sections 6.5.2 and 6.6.2). Specifically, this FEP is addressed through the following parameters: evaporative cooler water evaporation rate (BSC 2004 [DIRS 169672], Section 6.5.2), evaporative cooler air flow rate (BSC 2004 [DIRS 169672], Section 6.5.2), interior wall height (BSC 2004 [DIRS 169672], Sections 6.5.2 and 6.6.2), house ventilation rate (BSC 2004 [DIRS 169672], Section 6.6.2), correlation coefficient for airflow and water use in evaporative coolers (BSC 2004 [DIRS 169672], Section 6.5.2), building shielding factor (shielding provided by building materials) (BSC 2004 [DIRS 169671], Section 6.6), fraction of houses with evaporative coolers

(BSC 2004 [DIRS 169671], Section 6.3.4.1), and evaporative cooler use factor (BSC 2004 [DIRS 169671], Section 6.3.4.2).

Dwellings produce mitigating effects on inhalation dose, which is considered in the value of the indoor reduction factor for activity concentration in indoor air relative to that of the outdoor air, used to calculate the values of inhalation dose factors (BSC 2004 [DIRS 167287], Equation 6.3-3).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

This FEP is also dispositioned in the TSPA-LA through the inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.32 Wild and Natural Land and Water Use (FEP 2.4.08.00.0A)

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

**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], which requires that the reference biosphere 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 outdoor environment (BSC 2004 [DIRS 169460], Section 6.4.4). This FEP is addressed in the air, external exposure, inhalation, and ingestion submodels of the biosphere model. The parameters that address this FEP are mass loading for receptor environments (BSC 2004 [DIRS 169458], Sections 6.1 and 6.2), exposure time (BSC 2004 [DIRS 169671], Section 6.3.2), and annual consumption rate of locally produced animal products (BSC 2004 [DIRS 169671], Sections 6.4 and 6.4.2). Parameter distributions were developed and based in part on uncertainty and variation in the use of wild and natural lands, and the rate of consumption of wild game by the receptor (BSC 2004 [DIRS 169458], Sections 6.1 and 6.2; and BSC 2004 [DIRS 169671], Sections 6.3.2 and 6.4.2).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.33 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.

**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

### 6.2.34 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.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** The lifestyle and behaviors of the current residents of Amargosa Valley include agricultural land use and irrigation (BSC 2004 [DIRS 169673], Appendix A). In accordance 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], which requires that the reference biosphere be consistent with present knowledge of the conditions in the region, future agricultural practices are assumed to be consistent with the current practices.

This FEP is considered in the soil, air, plant, animal, $^{14}C$, fish, external exposure and inhalation submodels of the biosphere model (BSC 2004 [DIRS 169460], Table 6.7-1). Agricultural land use and irrigation are represented in the model through the fraction of overhead irrigation (BSC 2004 [DIRS 169673], Section 6.3), exposure times for conducting site activities (BSC 2004 [DIRS 169671], Section 6.3.2), annual average irrigation rate (BSC 2004 [DIRS 169673], Section 6.5), overwatering rate (BSC 2004 [DIRS 169673], Section 6.9), mass loading for receptor environments (BSC 2004 [DIRS 169458], Sections 6.1 and 6.2), mass loading for crops (BSC 2004 [DIRS 169458], Sections 6.1.5 and 6.2.5), crop growing time (BSC 2004 [DIRS 169673], Section 6.4), tillage depth (BSC 2004 [DIRS 169673], Section 6.10), irrigation intensity (BSC 2004 [DIRS 169673], Section 6.6), irrigation amount per application (BSC 2004 [DIRS 169673], Section 6.7), daily irrigation rate (BSC 2004 [DIRS 169673], Section 6.8), animal consumption rate of water (BSC 2004 [DIRS 169672], Section 6.3.2), surface area of irrigated land (BSC 2004 [DIRS 169672], Section 6.7.2), and water concentration modifying factor (BSC 2004 [DIRS 169672], Section 6.4.3). Irrigation rates are developed based, in part, on variation and uncertainty in cultivated land and water use practices in Amargosa Valley (BSC 2004 [DIRS 169458], Sections 6.1 and 6.2; BSC 2004 [DIRS 169673], Sections 6.3 to 6.9; BSC 2004 [DIRS 169671], Section 6.3.2; BSC 2004 [DIRS 169672], Section 6.7.2). Agricultural use of water is included in the soil (BSC 2004 [DIRS 169460], Equation 6.4.1-2), plant (BSC 2004 [DIRS 169460], Equations 6.4.3-3 to 6.4.3-5), animal (BSC 2004 [DIRS 169460], Equation 6.4.4-3), fish (BSC 2004 [DIRS 169460], Equation 6.4.5-2), and $^{14}C$ (BSC 2004 [DIRS 169460], Equation 6.4.6-1) submodels of the groundwater scenario.

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.35 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 could then enter the food chain.

**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], which requires that the reference biosphere 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 2004 [DIRS 169460], Table 6.7-1) and is represented in the model by animal consumption rates of locally produced feed, contaminated water, and contaminated soil (BSC 2004 [DIRS 169672], Section 6.3.2), and water concentration modifying factor (BSC 2004 [DIRS 169672], Section 6.4.3). Relevant parameters are developed based in part on variation and uncertainty in animal and fish farming practices in Amargosa Valley (BSC 2004 [DIRS 169672], Sections 6.3.2, 6.4.3, and 6.4.5).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

#### 6.2.36 Urban and Industrial Land and Water Use (FEP 2.4.10.00.0A)

**FEP Description:** Urban and industrial uses of land and water (industry, urban development, earthworks, energy production, etc.) 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.).

**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], which requires that the reference biosphere 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 2004 [DIRS 169458], Sections 6.1 and 6.2; BSC 2004 [DIRS 169671], Section 6.3.2; BSC 2004 [DIRS 169672], Section 6.5). The use of contaminated water in residential and urban environments is included in the soil submodel (BSC 2004 [DIRS 169460], Equation 6.4.1-2) and air submodel (BSC 2004 [DIRS 169460], Equation 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 2004 [DIRS 169673], Section 6.5), mass loading for the receptor environments (BSC 2004 [DIRS 169458], Sections 6.1.1 to 6.1.4 and 6.2.1 to 6.2.4), evaporative cooler water evaporation rate (BSC 2004 [DIRS 169672], Section 6.5.2), and exposure time (BSC 2004 [DIRS 169671], Section 6.3.2).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.37 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.

**Screening Decision:** Included

**Screening Argument:** N/A

**TSPA Disposition:** The biosphere model was constructed for the primary long-lived radionuclide considered important for the TSPA (BSC 2004 [DIRS 169460], Section 6.1.3) and it includes consideration of the short-lived decay products of these radionuclides (BSC 2004 [DIRS 169460], Section 6.3.5). Radionuclide decay and ingrowth in surface soils are included in the soil (BSC 2004 [DIRS 169460], Equation 6.4.1-9), external exposure (BSC 2004 [DIRS 169460], Equation 6.4.7-1), inhalation (BSC 2004 [DIRS 169460], Equations 6.4.8-2 to 6.4.8-7), and ingestion (BSC 2004 [DIRS 169460], Equations 6.4.9-3 to 6.4.9-6) submodels of the groundwater exposure scenario. They are also included in the external exposure (BSC 2004 [DIRS 169460], Equation 6.5.5-1), inhalation (BSC 2004 [DIRS 169460], Equations 6.5.6-2 to 6.5.6-4), and ingestion (BSC 2004 [DIRS 169460], Equations 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 2004 [DIRS 169671], 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) (BSC 2004 [DIRS 169460], Tables 6.4-3 and 6.4-4). These factors include dose contributions from short-lived decay products of the primary radionuclides. Radionuclide decay and ingrowth are also included in calculations of radionuclide build-up in the soil. The associated input parameters include dose coefficients (BSC 2004 [DIRS 169671], Section 6.5.3.2), dose conversion factors (BSC 2004 [DIRS 169671], Sections 6.5.3.1 and 6.5.4) and radionuclide half-lives and branching fractions (BSC 2004 [DIRS 169671], Section 6.5.1).

The contribution from long-lived and short-lived decay products of primary radionuclides is also considered in the calculations of the organ and the whole body conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2) and in the values of inhalation dose factors (BSC 2004 [DIRS 167287, Section 6.3.2), primarily through the use of effective dose conversion factors for ingestion and inhalation.

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1). Radioactive decay and ingrowth is also included in the TSPA-LA through the use of the conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Table 1-2).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2). This FEP is also dispositioned in the TSPA-LA through the inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])

- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.38 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.

**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 matter, 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 2004 [DIRS 169460], Equations 6.4.2-1 to 6.4.2-8), the air submodel for the volcanic ash exposure scenario (BSC 2004 [DIRS 169460], Equations 6.5.2-1 to 6.5.2-8), and the $^{14}C$ special submodel for the groundwater exposure scenario (BSC 2004 [DIRS 169460], Equations 6.4.6-2 and 6.4.6-3). The associated parameters include mass loading for crops (BSC 2004 [DIRS 169458], Sections 6.1.5 and 6.2.5), mass loading for the receptor environments (BSC 2004 [DIRS 169458], Sections 6.1 and 6.2), soil bulk density (BSC 2004 [DIRS 169459], Sections 4.1.1 and 6.1), ash bulk density (BSC 2004 [DIRS 169459], Sections 4.1.6 and 6.6), tillage depth (BSC 2004 [DIRS 169673], Section 6.10), rooting depth (BSC 2004 [DIRS 169673], Section 6.12), resuspension enhancement factor (BSC 2004 [DIRS 169459], Sections 4.1.4 and 6.4), fraction of radionuclides in evaporative cooler water transferred to air (BSC 2004 [DIRS 169672], Section 6.5.2), water evaporation rate for evaporative coolers (BSC 2004 [DIRS 169672], Section 6.5.2), evaporative cooler air flow rate (BSC 2004 [DIRS 169672], Section 6.5.2), radon release factor (BSC 2004 [DIRS 169672], Section 6.6.1), interior wall height (BSC 2004 [DIRS 169672], Sections 6.5.2 and 6.6.2), house ventilation rate (BSC 2004 [DIRS 169672], Section 6.6.2), fraction of $^{222}Rn$ from soil entering the house (BSC 2004 [DIRS 169672], Section 6.6.2), ratio of $^{222}Rn$ concentration in air to flux density from soil (BSC 2004 [DIRS 169672], Section 6.6.1), $^{14}C$ emission rate for soil (BSC 2004 [DIRS 169672], Section 6.7.1), surface area of irrigated land (BSC 2004 [DIRS 169672], Section 6.7.2), annual average wind speed (BSC 2004 [DIRS 169672], Section 6.7.2), $^{14}C$ mixing height (BSC 2004 [DIRS 169672], Section 6.7.2), concentration of stable carbon in air (BSC 2004 [DIRS 169672], Section 6.7.3) and correlation coefficient for airflow and water use in evaporative coolers section (BSC 2004 [DIRS 169672], Section 6.5.2). Atmospheric transport of contaminants was also considered in developing the values of inhalation dose factors (BSC 2004 [DIRS 167287], Equation 6.3-3).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2). This FEP is also dispositioned in the TSPA-LA through the inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.39 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.

**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 2004 [DIRS 169671], 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. The ingestion submodel includes the intake of food, water, and soil for the groundwater scenario (BSC 2004 [DIRS 169460), Equations 6.4.9-2 to 6.4.9-6) and for the volcanic ash scenario (BSC 2004 [DIRS 169460), Equations 6.5.7-2 to 6.5.7-4). Also included is the calculation of radionuclide concentrations in foodstuffs (BSC 2004 [DIRS 169460), Sections 6.4.3 through 6.4.6, 6.5.3, and 6.5.4) and doses from ingestion of water (BSC 2004 [DIRS 169674], Equations 6.3-2 and 6.3-4). The parameters related to consumption of contaminated drinking water and foodstuffs include consumption rates of locally produced food and water (BSC 2004 [DIRS 169671], Section 6.4), and inadvertent soil ingestion rate (BSC 2004 [DIRS 169671], Section 6.4.3). This FEP is also considered in the calculations of conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1). The contaminated water aspect of this FEP is also included in the TSPA-LA through the use of the conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Table 1-2).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.40 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.

**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 2004 [DIRS 169460], Sections 6.3.1.6 and 6.3.2.6). 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 2004 [DIRS 169460], Equations 6.4.3-1 to 6.4.3-8) and volcanic ash exposure scenarios (BSC 2004 [DIRS 169460], Equations 6.5.3-1 to 6.5.3-5), and in the $^{14}C$ special submodel for the groundwater exposure scenario (BSC 2004 [DIRS 169460], Equations 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 2004 [DIRS 169672], Sections 6.2.1.2 through 6.2.1.5), dry-to-wet ratio (BSC 2004 [DIRS 169673], Section 6.2), fraction of overhead irrigation (BSC 2004 [DIRS 169673], Section 6.3), translocation factor (BSC 2004 [DIRS 169672], Section 6.2.2.2), weathering rate constant (BSC 2004 [DIRS 169672], Section 6.2.2.3), crop growing time (BSC 2004 [DIRS 169673], Section 6.4), crop wet yield (BSC 2004 [DIRS 169673], Section 6.11), daily irrigation rate (BSC 2004 [DIRS 169673], Section 6.8), crop dry biomass (BSC 2004 [DIRS 169673], Section 6.1), irrigation amount per application (BSC 2004 [DIRS 169673], Section 6.7), irrigation intensity (BSC 2004 [DIRS 169673], Section 6.6), dry deposition velocity (BSC 2004 [DIRS 169672], Section 6.2.2.1), soil bulk density (BSC 2004 [DIRS 169459], Sections 4.1.1 and 6.1), ash bulk density (BSC 2004 [DIRS 169459], Sections 4.1.6 and 6.6), tillage depth (BSC 2004 [DIRS 169673], Section 6.10), rooting depth (BSC 2004 [DIRS 169673], Section 6.12), fraction of air-derived carbon in plants (BSC 2004 [DIRS 169672], Section 6.7.3), fraction of soil-derived carbon in plants (BSC 2004 [DIRS 169672], Section 6.7.3), fraction of stable carbon in crops (BSC 2004 [DIRS 169672], Section 6.7.3), fraction of stable carbon in soil (BSC 2004 [DIRS 169672], Section 6.7.3), concentration of stable carbon in air (BSC 2004 [DIRS 169672], Section 6.7.3), and correlation coefficient for transfer factors and partition coefficients (BSC 2004 [DIRS 169672], Section 6.2.1.5).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Soil-Related Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169459])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.41 Animal Uptake (FEP 3.3.02.02.0A)

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

**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 2004 [DIRS 169460], Sections 6.3.1.6 and 6.3.2.6). This FEP is addressed in the animal and $^{14}C$ submodels of the biosphere model (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169460], Equations 6.4.4-1 to 6.4.4-4). For the volcanic ash exposure scenario, the ingestion of contaminated water by animals is not included (BSC 2004 [DIRS 169460], Equations 6.5.4-1 to 6.5.4-3). Animal uptake is also included in the $^{14}C$ special submodel for the groundwater exposure scenario (BSC 2004 [DIRS 169460], Equation 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 2004 [DIRS 169460], 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 2004 [DIRS 169672], Section 6.3.3), animal consumption rate of feed, water and soil (BSC 2004 [DIRS 169672], Section 6.3.2), fraction of stable carbon in animal products (BSC 2004 [DIRS 169672], Section 6.7.4), fraction of air-derived carbon in plants (BSC 2004 [DIRS 169672], Section 6.7.3), fraction of soil-derived carbon in plants (BSC 2004 [DIRS 169672] Section 6.7.3), and concentration of stable carbon in farm animal water (BSC 2004 [DIRS 169672], Section 6.7.4).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.42 Fish Uptake (FEP 3.3.02.03.0A)

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

**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 2004 [DIRS 169460], Section 6.4.5), which includes the bioaccumulation of radionuclides in fish (BSC 2004 [DIRS 169460], Equations 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 2004 [DIRS 169672], Sections 6.4.3 and 6.4.4). 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 2004 [DIRS 169672], Section 6.4.3) and fishpond water concentration-modifying factor (BSC 2004 [DIRS 169672], Sections 6.4.3 and 6.4.4).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674]).

### 6.2.43 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.

**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 2004 [DIRS 169460], Section 6.4.7) and volcanic ash (BSC 2004 [DIRS 169460], Section 6.5.5) exposure scenarios. Parameters that address this FEP are the same as those for FEP 3.3.04.03.0A, *External Exposure*. 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-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.44 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.

**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 produce, 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.3.1.6). For the volcanic activity scenario, only the ingestion of locally produced plant foodstuffs, animal products, and inadvertent soil ingestion are considered (BSC 2004 [DIRS 169460], Section 6.3.2.6).

Within the mathematical representation of this submodel for the groundwater exposure pathway (BSC 2004 [DIRS 169460], Section 6.4.9, Equations 6.4.9-1 to 6.4.9-6), the annual water consumption rate is defined at 2 liters per day, as specified at 10 CFR 63.312(d) [DIRS 156605]. Exposure to contaminated plant foodstuffs is addressed through annual consumption rate of each of four locally grown crop food types (leafy vegetables, other vegetables, fruits, and grains) (BSC 2004 [DIRS 169671], Section 6.4.2) and their associated radionuclide-specific activity concentration (BSC 2004 [DIRS 169460], Section 6.4.3). Selection of crop types used in the biosphere model is addressed by BSC (2004 [DIRS 169460], 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 (meat, milk, poultry, and eggs) (BSC 2004 [DIRS 169671], Section 6.4.2) and their associated radionuclide-specific activity concentration (BSC 2004 [DIRS 169460], Section 6.4.4). Selection of animal product types used in the biosphere model is discussed in the report by BSC (2004 [DIRS 169460], Section 6.4.4). Ingestion of fish is addressed within this submodel as the annual consumption rate of locally produced fish (BSC 2004 [DIRS 169671], Section 6.4.2) times the radionuclide-specific activity concentration in fish (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.4.1) times the annual consumption rate of soil (BSC 2004 [DIRS 169671], Section 6.4.3). Related parameters also include dose conversion factors for ingestion of radionuclides (BSC 2004 [DIRS 169671], Section 6.5.3.1).

The mathematical representation of the ingestion submodel for the volcanic activity scenario is similar to that for the groundwater exposure scenario (BSC 2004 [DIRS 169460], Section 6.5.7, Equations 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 also considered in the calculations of conversion factors for calculating beta-photon dose from drinking 2 L of water per day, which are used for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models and through the use of the conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Tables 1-1 and 1-2). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA model. One of them is for the time-independent component, which includes ingestion (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.45 Inhalation (FEP 3.3.04.02.0A)

**FEP Description:** Inhalation pathways for repository-derived radionuclides should be considered. Two possible pathways are: inhalation of gases and vapors emanating directly from the ground after transport through the far-field; and inhalation of suspended, contaminated particulate matter (e.g., decay products of radon, dust, smoke, pollen, and soil particles).

**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 2004 [DIRS 169460], Section 6.4.8) and the volcanic ash (BSC 2004 [DIRS 169460], Section 6.5.6) exposure scenarios. 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 2004 [DIRS 169460], Equations 6.4.8-1 to 6.4.8-7). For the volcanic ash exposure scenario (BSC 2004 [DIRS 169460], Equations 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. In addition, inhalation of atmospheric aerosols produced by evaporative coolers is not considered in this scenario because the groundwater is uncontaminated (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169671], Section 6.3.3), fraction of houses with evaporative coolers (BSC 2004 [DIRS 169671], Section 6.3.4.1), evaporative cooler use factor (BSC 2004 [DIRS 169671], Section 6.3.4.2), population proportions (BSC 2004 [DIRS 169671], Section 6.3.1), and environment- and population group-specific exposure times (BSC 2004 [DIRS 169671], 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 2004 [DIRS 169460], Sections 6.4.2.1 and 6.5.2.1), activity concentration in air for radionuclides resulting from the use of an evaporative cooler (BSC 2004 [DIRS 169460], Section 6.4.2.2), activity concentration of $^{14}C$ in air (BSC 2004 [DIRS 169460], Section 6.4.6.2), and activity concentration of $^{222}Rn$ in air (BSC 2004 [DIRS 169460], Sections 6.4.2.3 and 6.5.2.2). The other parameters of the inhalation submodel include dose conversion factor for inhalation of radon and decay products (BSC 2004 [DIRS 169671], Section 6.5.4), dose conversion factors for inhalation of other radionuclides (BSC 2004 [DIRS 169671], Table 6-24 and Section 6.5.3.1), mass loading time function for the receptor environments (BSC 2004 [DIRS 169458], Section 6.3 and Table 7-1), equilibrium factor for $^{222}Rn$ decay products (BSC 2004 [DIRS 169672], Section 6.6.3), and critical thickness of soil for resuspension (BSC 2004 [DIRS 169672], Section 6.8).

The inhalation process is also fundamental for developing dose factors for evaluating exposure of the receptor arising from inhalation of airborne particles resulting from a volcanic eruption (BSC 2004 [DIRS 167287], Equation 6.3-2). The eruption phase is treated separately from the effects of deposition of contaminated ash and its consequences are evaluated as those arising from the exposure occurring during an event of a limited duration (acute or near-acute exposure), rather than from a long-term, chronic exposure thereafter. The latter is evaluated using the BDCFs. The dose factor may be used in TSPA assessments to evaluate whether the doses received by the RMEI during an eruption need to be included in calculation of the expected dose (BSC 2004 [DIRS 167287], Section 6.3).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA model. The first one is for the time-independent component, which includes inhalation of radon decay products. The second one is for the ash thickness dependent component, which includes inhalation of resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2). This FEP is also dispositioned in the TSPA-LA through the inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])

- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Inhalation Exposure Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169458])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.46 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.

**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 2004 [DIRS 169460], Section 7.4.8).

This FEP is addressed in the external exposure submodel for the groundwater (BSC 2004 [DIRS 169460], Section 6.4.7) and the volcanic ash (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.4.7.1). For the volcanic ash exposure scenario, it is assumed that all of the radioactivity deposited on the soil surface can be treated as the surface contamination regardless of ash thickness (BSC 2004 [DIRS 169460], Section 6.5.5.1). Within the mathematical representation of this FEP (BSC 2004 [DIRS 169460], Equations 6.4.7-1 and 6.5.5-1), parameters such as building shielding factor (BSC 2004 [DIRS 169671], Section 6.6), exposure time (BSC 2004 [DIRS 169671], Section 6.3.2), and population proportion (BSC 2004 [DIRS 169671], 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 soil contaminated to an infinite depth and exposure to a contaminated ground surface (BSC 2004 [DIRS 169671], Section 6.5.3.2). Other parameters supporting this FEP are tillage depth (BSC 2004 [DIRS 169673], Section 6.10) and rooting depth (BSC 2004 [DIRS 169673], Section 6.12).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA model. One of them is for the time-independent component, which includes external exposure (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.47 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, and duration of exposure.

**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 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.4.10, Equations 6.4.10-1 and 6.4.10-2 for the groundwater exposure scenario, and Section 6.5.8, Equations 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 2004 [DIRS 169460], Sections 6.4.8, 6.4.9, 6.5.6, and 6.5.7). Effective dose conversion factors are calculated using dose conversion factors and radionuclide branching fractions to account for the contribution from the short-lived decay products (BSC 2004 [DIRS 169671], Section 6.5.3.1). 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 2004 [DIRS 169460], Sections 6.4.7 and 6.5.5). Effective dose coefficients are calculated using dose coefficients and radionuclide branching fractions to account for the contribution from the short-lived decay products (BSC 2004 [DIRS 169671], Section 6.5.3.2). This FEP is also considered in the calculations of conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Section 6.3.2) and inhalation dose factors (BSC 2004 [DIRS 167287], Section 6.3.2).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs and through the use of the conversion factors for evaluating compliance with the groundwater protection standard (BSC 2004 [DIRS 169674], Tables 1-1 and 1-2). For the TSPA-LA 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], 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 present-day, monsoon, and glacial-transition climate states (BSC 2004 [DIRS 169460], Section 6.4.10.2).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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 2004 [DIRS 169460], 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 2004 [DIRS 169460], Section 6.5). For the volcanic ash exposure scenario, three BDCF components are provided to the TSPA-LA 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 resuspended particles at normal condition. The third is for the ash thickness and time dependent component, which includes inhalation of resuspended particles under postvolcanic conditions (BSC 2004 [DIRS 169460], Section 6.5.8.2). This FEP is also dispositioned in the TSPA-LA through the inhalation dose factors (BSC 2004 [DIRS 167287], Table 1-2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

### 6.2.48 Radiological Toxicity and Effects (FEP 3.3.06.00.0A)

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

**Screening Decision:** Excluded – By Regulation

**Screening Argument:** The regulation 10 CFR 63.311 [DIRS 156605] defines the individual protection standard in terms of the annual dose. The groundwater protection standard 10 CFR 63.331 [DIRS 156605] is based on radionuclide concentrations in groundwater and on a radiation dose. Radiological toxicity refers to the radiation effects. Effects of radiation are not evaluated in the performance assessment because there are no applicable performance standards. Because regulation requires calculating radiation doses, but it does not require estimating health effects resulting from radiological toxicity of the waste, this FEP is excluded on the basis of inconsistency with the regulation, per 10 CFR 63.114(e) [DIRS 156605].

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.49 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.

**Screening Decision:** Excluded – By Regulation

**Screening Argument:** The regulation 10 CFR 63.311 [DIRS 156605] defines the individual protection standard in terms of the annual dose. The groundwater protection standard 10 CFR 63.331 [DIRS 156605] is based on radionuclide concentrations in groundwater and on a radiation dose. Sensitization to radiation refers to the radiation effects. Effects of radiation are not evaluated in the performance assessment because there are no applicable performance standards. Because regulation requires calculating radiation doses, but it does not require estimating health effects, or their changes resulting from sensitization to radiation, this FEP is excluded on the basis of inconsistency with the regulation, per 10 CFR 63.114(e) [DIRS 156605].

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.50 Non-Radiological Toxicity and 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.

**Screening Decision:** Excluded – By Regulation

**Screening Argument:** The regulation 10 CFR 63.311 [DIRS 156605] defines the individual protection standard in terms of the annual dose. The groundwater protection standard 10 CFR 63.331 [DIRS 156605] is based on radionuclide concentrations in groundwater and on a radiation dose. There are no applicable standards based on non-radiological toxicity effects. Because regulation requires calculating radiation doses, but it does not require the estimating health effects resulting from non-radiological toxicity of the waste, this FEP is excluded on the basis of inconsistency with the regulation, per 10 CFR 63.114(e) [DIRS 156605].

**TSPA Disposition:** N/A

**Supporting Analysis and Model Reports:** N/A

### 6.2.51 Radon and Radon Decay Products 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 decay products of which can result in radiation doses to humans upon inhalation.

**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 2004 [DIRS 169460], Table 6.3-7). Human exposure to radon and radon decay products occurs through inhalation. (Note the change of the FEP description – the previous description included the reference to possible effects to animals upon inhalation of radon and its decay products. This portion of the description was deleted because there are no applicable performance standards in 10 CFR 63 [DIRS 156605] both in terms of considering harm to animals and in terms of considering effects of radiation.)

Exposure to radon ($^{222}Rn$) and radon decay products is included in the air and inhalation submodels of the groundwater (BSC 2004 [DIRS 169460], Sections 6.4.2.3 and 6.4.8.4) and volcanic ash (BSC 2004 [DIRS 169460], 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 2004 [DIRS 169460], Equations 6.4.2-4 through 6.4.2-8) and volcanic ash exposure scenario (BSC 2004 [DIRS 169460], Equations 6.5.2-5 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 2004 [DIRS 169460], Equations 6.4.8-5 through 6.4.8-7) and the volcanic ash exposure scenario (BSC 2004 [DIRS 169460], Equations 6.5.6-3 and 6.5.6-4). The parameters supporting this FEP include radon release factor (BSC 2004 [DIRS 169672], Section 6.6.1), interior wall height (BSC 2004 [DIRS 169672], Sections 6.5.2 and 6.6.2), house ventilation rate (BSC 2004 [DIRS 169672], Section 6.6.2), fraction of $^{222}Rn$ from soil entering the house (BSC 2004 [DIRS 169672], Section 6.6.2), ratio of $^{222}Rn$ concentration in air to flux density from soil (BSC 2004 [DIRS 169672], Section 6.6.1), equilibrium factor for $^{222}Rn$ decay products (BSC 2004 [DIRS 169672], Section 6.6.3), fraction of radionuclide transfer from water to air for evaporative coolers (BSC 2004 [DIRS 169672], Section 6.5.2), and dose conversion factor for radon decay products (BSC 2004 [DIRS 169671], Section 6.5.4).

This FEP is dispositioned in the biosphere component of the TSPA-LA model through the use of groundwater exposure scenario BDCFs that are direct inputs to the TSPA-LA nominal scenario class, seismic scenario class, and igneous intrusion modeling case models (BSC 2004 [DIRS 169674], Table 1-1). 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 present-day, monsoon, and glacial-transition climates (BSC 2004 [DIRS 169674], Section 7.1).

This FEP is also dispositioned in the TSPA-LA volcanic eruption modeling case through BDCFs for the volcanic ash exposure scenarios (BSC 2004 [DIRS 167287], Table 1-1). 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-LA model. One of them is for the time-independent component, which includes inhalation of radon decay products (BSC 2004 [DIRS 169460], Section 6.5.8.2).

**Supporting Analysis and Model Reports:**

- *Biosphere Model Report* (BSC 2004 [DIRS 169460])
- *Characteristics of the Receptor for the Biosphere Model* (BSC 2004 [DIRS 169671])
- *Environmental Transport Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169672])
- *Nominal Performance Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 169674])
- *Disruptive Event Biosphere Dose Conversion Factor Analysis* (BSC 2004 [DIRS 167287]).

# 7. CONCLUSIONS

## 7.1 SUMMARY OF SCREENING RESULTS FOR THE BIOSPHERE FEPS

Of the 51 FEPs identified in Table 1-1, 32 are screened as included and are implemented in the biosphere and TSPA models and 19 are screened as excluded. A summary of the reason(s) for FEP exclusion is included in Table 7-1 for those FEPs that are identified as excluded. The status of, or changes to, any referenced document may affect the conclusions in this document.

For each of the 19 excluded FEPs, justification for excluding the FEP is provided in Section 6.2 (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. 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.

The conclusions from this analysis report (FEP Screening Decision, TSPA Disposition for included FEPs, or Screening Argument for excluded FEPs), will be submitted to the Technical Data Management System by the Yucca Mountain FEP database team as a final LA FEP list represented by a DTN. Documentation of the FEP database is given in a separate report (BSC 2004 [DIRS 168706]).

Table 7-1. Screening Results for Biosphere-Related Features, Events, and Processes Considered for Use in the TSPA-LA

| Addressed in Section | FEP Number | FEP Name | Screening Decision |
|---|---|---|---|
| 6.2.1 | 1.2.04.07.0A | Ashfall | Included |
| 6.2.2 | 1.3.01.00.0A | Climate change | Included |
| 6.2.3 | 1.3.04.00.0A | Periglacial effects | Excluded – Low Probability and Low Consequence |
| 6.2.4 | 1.3.05.00.0A | Glacial and ice sheet effect | Excluded – Low Probability |
| 6.2.5 | 1.3.07.02.0A[a] | Water table rise affects SZ | Included |
| 6.2.6 | 1.4.01.00.0A | Human influences on climate | Excluded – By Regulation |
| 6.2.7 | 1.4.01.02.0A | Greenhouse gas effects | Excluded – By Regulation |
| 6.2.8 | 1.4.01.03.0A | Acid rain | Excluded – By Regulation |
| 6.2.9 | 1.4.01.04.0A | Ozone layer failure | Excluded – By Regulation |
| 6.2.10 | 1.4.07.01.0A | Water management activities | Included |
| 6.2.11 | 1.4.07.02.0A | Wells | Included |
| 6.2.12 | 1.4.08.00.0A | Social and institutional developments | Excluded – By Regulation |
| 6.2.13 | 1.4.09.00.0A | Technological developments | Excluded – By Regulation |
| 6.2.14 | 1.5.02.00.0A | Species evolution | Excluded – By Regulation |
| 6.2.15 | 2.2.08.01.0A[a] | Chemical characteristics of groundwater in the SZ | Included |
| 6.2.16 | 2.2.08.07.0C[a] | Radionuclide solubility limits in biosphere | Excluded – Low Consequence |

Table 7-1. Screening Results for Biosphere-Related Features, Events, and Processes Considered for Use in the TSPA-LA (Continued)

| Addressed in Section | FEP Number | FEP Name | Screening Decision |
|---|---|---|---|
| 6.2.17 | 2.2.08.11.0A | Groundwater discharge to surface within the reference biosphere | Excluded – By low consequence |
| 6.2.18 | 2.3.02.01.0A | Soil type | Included |
| 6.2.19 | 2.3.02.02.0A | Radionuclide accumulation in soils | Included |
| 6.2.20 | 2.3.02.03.0A | Soil and sediment transport in the biosphere | Included |
| 6.2.21 | 2.3.04.01.0A | Surface water transport and mixing | Included |
| 6.2.22 | 2.3.06.00.0A | Marine features | Excluded – Low Probability |
| 6.2.23 | 2.3.09.01.0A | Animal burrowing/intrusion | Excluded – Low Probability and Low Consequence |
| 6.2.24 | 2.3.11.01.0A | Precipitation | Included |
| 6.2.25 | 2.3.11.04.0A | Groundwater discharge to surface outside the reference biosphere | Excluded – By Regulation |
| 6.2.26 | 2.3.13.01.0A | Biosphere characteristics | Included |
| 6.2.27 | 2.3.13.02.0A | Radionuclide alteration during biosphere transport | Included |
| 6.2.28 | 2.3.13.04.0A | Radionuclide release outside the reference biosphere | Excluded – By Regulation |
| 6.2.29 | 2.4.01.00.0A | Human characteristics (physiology, metabolism) | Included |
| 6.2.30 | 2.4.04.01.0A | Human lifestyle | Included |
| 6.2.31 | 2.4.07.00.0A | Dwellings | Included |
| 6.2.32 | 2.4.08.00.0A | Wild and natural land and water use | Included |
| 6.2.33 | 2.4.09.01.0A | Implementation of new agricultural practices or land use | Excluded – By Regulation |
| 6.2.34 | 2.4.09.01.0B | Agricultural land use and irrigation | Included |
| 6.2.35 | 2.4.09.02.0A | Animal farms and fisheries | Included |
| 6.2.36 | 2.4.10.00.0A | Urban and industrial land and water use | Included |
| 6.2.37 | 3.1.01.01.0A | Radioactive decay and ingrowth | Included |
| 6.2.38 | 3.2.10.00.0A | Atmospheric transport of contaminants | Included |
| 6.2.39 | 3.3.01.00.0A | Contaminated drinking water, foodstuffs and drugs | Included |
| 6.2.40 | 3.3.02.01.0A | Plant uptake | Included |
| 6.2.41 | 3.3.02.02.0A | Animal uptake | Included |
| 6.2.42 | 3.3.02.03.0A | Fish uptake | Included |
| 6.2.43 | 3.3.03.01.0A | Contaminated non-food products and exposure | Included |
| 6.2.44 | 3.3.04.01.0A | Ingestion | Included |
| 6.2.45 | 3.3.04.02.0A | Inhalation | Included |
| 6.2.46 | 3.3.04.03.0A | External exposure | Included |
| 6.2.47 | 3.3.05.01.0A | Radiation doses | Included |
| 6.2.48 | 3.3.06.00.0A | Radiological toxicity and effects | Excluded – By Regulation |
| 6.2.49 | 3.3.06.02.0A | Sensitization to radiation | Excluded – By Regulation |
| 6.2.50 | 3.3.07.00.0A | Non-radiological toxicity and effects | Excluded – By Regulation |
| 6.2.51 | 3.3.08.00.0A | Radon and radon decay products exposure | Included |

[a] These FEPs were not previously associated with the biosphere, but are included in the analysis report as discussed in Section 6.1.1.

FEP = feature, event, or process; SZ = saturated zone; UZ = unsaturated zone

## 7.2 HOW THE ACCEPTANCE CRITERIA WERE ADDRESSED

The purpose of this analysis report was to evaluate and document the inclusion or exclusion of biosphere FEPs with respect to modeling used to support the TSPA-LA. A screening decision, either *Included* or *Excluded*, was given for each FEP along with the corresponding technical basis for the excluded FEPs and the descriptions of how the included FEPs were incorporated in the biosphere model. This information was required by the NRC regulations at 10 CFR 63.114 (d, e, and f) [DIRS 156605].

The acceptance criteria, identified as applicable to this analysis in Section 4.2, that are related to the FEPs screening process were addressed in this analysis. The specific acceptance criteria were addressed as summarized in Table 7-2.

Table 7-2. YMRP Criteria Relevant to the Biosphere FEPs and How They Were Addressed

| YMRP Section and Acceptance Criterion [a] | How Addressed in This Analysis |
|---|---|
| **Section 2.2.1.2.1.3**<br>**Acceptance Criterion 1** —The Identification of a List of Features, Events, and Processes Is Adequate.<br>Subcriterion 1 | Documentation of the origin of the FEPs list is provided in Section 6.1.1; FEP descriptions are provided in Section 6.2. This analysis contains a list of biosphere-related FEPs (Table 1-1). This list of FEPs includes those related to the geologic setting. The list of biosphere FEPs is consistent with the site characterization data and it includes FEPs related to igneous activity and climatic change. |
| **Section 2.2.1.2.1.3**<br>**Acceptance Criterion 2** —Screening of the List of Features, Events, and Processes Is Appropriate.<br>Subcriterion 1 | The relevant FEPs related to the geologic setting were identified. These FEPs were screened for inclusion in the biosphere model with the appropriate documentation of the technical exclusion argument and the implementation of the included FEPs in the model. See Table 7-1 for a list of excluded biosphere FEPs. |
| **Section 2.2.1.2.1.3**<br>**Acceptance Criterion 2** —Screening of the List of Features, Events, and Processes Is Appropriate.<br>Subcriterion 2 | For the FEPs that were excluded from the model by either low probability, low consequence, or by regulation, appropriate justification was provided in the subsections of Section 6.2. See the method and approach discussion provided in Section 6.1.2 for an explanation of the use of various types of justification. |
| **Section 2.2.1.2.1.3**<br>**Acceptance Criterion 2** —Screening of the List of Features, Events, and Processes Is Appropriate.<br>Subcriterion 3 | For the FEPs that were excluded from the model by either low probability, low consequence, or by regulation, the appropriate technical basis was provided in the subsections of Section 6.2, documenting the basis for the exclusion. See the method and approach discussion provided in Section 6.1.2 for an explanation of various types of justification. |

[a] Source: NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3.

FEP = feature, event, or process; YMRP = Yucca Mountain Review Plan

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# APPENDIX A

# DESCRIPTION OF AN EXCEL FILE USED IN THIS ANALYSIS

The file described here is included in the Appendix A compact disk.

The Excel file *Solubility Calculation.xls* contains calculations of solubility for the elements of interest in terms of molar solubility and atom solubility, and calculations of annual doses that would result from activity concentration at the minimum solubility limit, as described in Section 6.2.16. The spreadsheet included in this file contains calculations of the values presented in Tables 6-2 and 6-3. Figure A-1 shows the details for this Excel file. The file is reproduced on a CD included in this appendix.

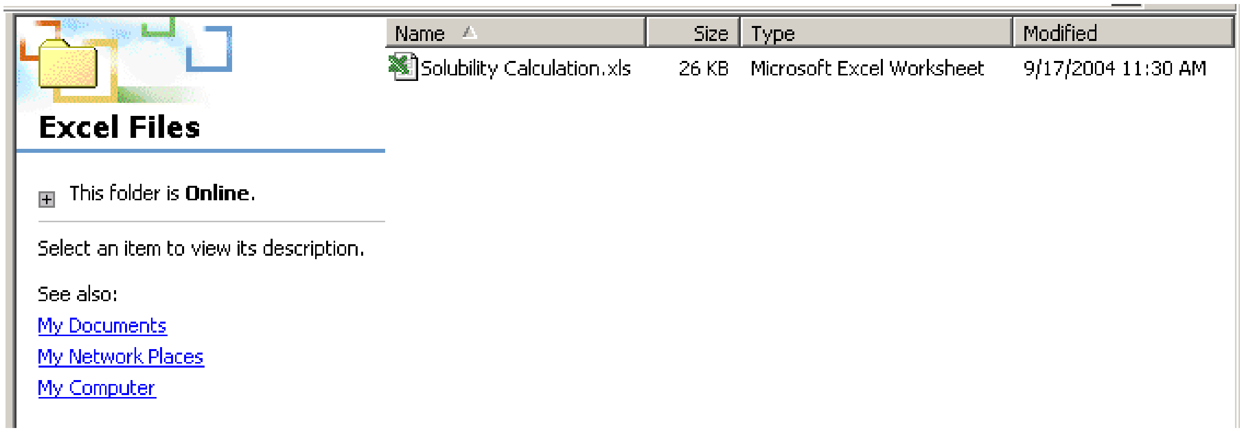


Figure A-1. Excel File *Solubility Calculation.xls*

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