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Key Technical Issue Letter Report (Response to TSPAI 2.01, 2.02, 2.03, 2.04, and 2.07)

Revision 2

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Note Regarding the Status of Supporting Technical Information

This document was prepared using the most current information available at the time of its development. This Technical Basis Document and its appendices providing Key Technical Issue Agreement responses that were prepared using preliminary or draft information reflect the status of the Yucca Mountain Project's scientific and design bases at the time of submittal. In some cases this involved the use of draft Analysis and Model Reports (AMRs) and other draft references whose contents may change with time. Information that evolves through subsequent revisions of the AMRs and other references will be reflected in the License Application (LA) as the approved analyses of record at the time of LA submittal. Consequently, the Project will not routinely update either this Technical Basis Document or its Key Technical Issue Agreement appendices to reflect changes in the supporting references prior to submittal of the LA.

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TABLES

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ACRONYMS

AMR	analysis and model report
CLST	Container Life and Source Term
DOE	U.S. Department of Energy
ENFE	Evolution of Near-Field Environment
FEPs	features, events, and processes
KTI	Key Technical Issue
NRC	U.S. Nuclear Regulatory Commission
RDTME	Repository Design and Thermal-Mechanical Effects
RMEI	reasonably maximally exposed individual
RT	Radionuclide Transport
SDS	Structural Deformation and Seismicity
TSPA	total system performance assessment
TSPAI	Total System Performance Assessment and Integration
TSPA-LA	total system performance assessment for the license application
TSPA-SR	total system performance assessment for the site recommendation
USFIC	Unsaturated and Saturated Flow Under Isothermal Conditions

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1. RESPONSE TO TSPAI 2.01, 2.02, 2.03, 2.04, AND 2.07

This letter report addresses Key Technical Issue (KTI) agreements Total System Performance Assessment and Integration (TSPAI) 2.01, 2.02, 2.03, 2.04, and 2.07. These agreements were reached during the U.S. Nuclear Regulatory Commission (NRC)/U.S. Department of Energy (DOE) Technical Exchange and Management Meetings on TSPAI held May 15 to 17, 2001 (Reamer 2001a) and August 6 to 10, 2001 (Reamer 2001b). The subject of the agreements is features, events, and processes (FEPs) and their supporting analysis and model reports (AMRs).

Wording of the agreements is as follows.

TSPAI 2.01

> Provide clarification of the screening arguments, as summarized in Attachment 2. See Comment # 5, 7, 8, 9, 10, 13, 18, 19 (Part 5), 21, 32, 41, 47, 50, 53, 58, 67, J-5, J-16, and J-18.
>
> DOE will clarify the screening arguments, as summarized in Attachment 2, for the highlighted FEPs. The clarifications will be provided in the referenced FEPs AMR and will be provided to the NRC in FY03.

TSPAI 2.02

> Provide the technical basis for the screening argument, as summarized in Attachment 2. See Comment # 3, 4, 11, 12, 19 (Parts 1, 2, and 6), 25, 26, 29, 34, 35, 36, 37, 38, 39, 42, 43, 44, 48, 49, 51, 54, 55, 56, 57, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 78, 79, J-1, J-2, J-3, J-4, J-7, J-8, J-9, J-10, J-11, J-12, J-13, J-14, J-15, J-17, J-20, J-21, J-22, J-23, J-24, J-25, J-26, and J-27.
>
> DOE will provide the technical basis for the screening argument, as summarized in Attachment 2, for the highlighted FEPs. The technical basis will be provided in the referenced FEPs AMR and will be provided to the NRC in FY03.

TSPAI 2.03

> Add the FEPs highlighted in Attachment 2 to the appropriate FEPs AMRs. See Comment 19 (Part 7 and 8), 20, and J-6.
>
> DOE will add the FEPs highlighted in Attachment 2 to the appropriate FEPs AMRs. The FEPs will be added to the appropriate FEPs AMRs and the AMRs will be provided to the NRC in FY03.

TSPAI 2.04

Provide a clarification of the description of the primary FEP. See Comments 24, 31, and 33.

DOE will clarify the description of the primary FEPs, as summarized in Attachment 2, for the highlighted FEPs. The clarifications will be provided in the referenced FEPs AMR and will be provided to the NRC in FY03.

TSPAI 2.07

Provide results of the implementation of the Enhanced FEP Plan (e.g., the revised FEP descriptions, screening arguments, the mapping of FEPs to TSPA keywords, and a searchable index of FEP components), in updates to the FEP AMR documents and the FEP Database.

DOE agrees to provide the results of their implementation of the Enhanced FEP Plan (e.g., the revised FEP descriptions, screening arguments, improved database navigation through, for example, the mapping of FEPs to TSPA keywords, a searchable index of FEP components, etc.), information requested in updates to the FEP documents and the FEP Database (or other suitable documents) in FY03.

These agreements are based on comments made by NRC following a review of the FEPs that supported DOE's total system performance assessment for site recommendation (TSPA-SR). During the technical exchange meetings, DOE and NRC agreed upon paths forward to resolve issues related to specific FEPs. These paths forward were listed in the NRC summary highlights of the technical exchange (Reamer 2001b, Attachment 2).

2. RELATED KEY TECHNICAL ISSUE AGREEMENTS

Agreements TSPAI 2.01, 2.02, 2.03, and 2.04 are responses to specific NRC comments regarding FEPs. Some of these comments are directly related to other KTI agreements, as specified in the responses.

TSPAI 2.07 is closely related to agreements TSPAI 2.05 and 2.06. These agreements deal with issues involved in implementation of *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002a), and both were given the status "complete" in an NRC letter of January 13, 2004 (Schlueter 2004). TSPAI 2.07 documents the final implementation of the enhanced FEP plan (BSC 2002a), as described in DOE responses to agreements TSPAI 2.05 and 2.06.

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3. PROPOSED RESOLUTION

TSPAI 2.01, 2,02, 2.03, and 2.04

FEPs related to Yucca Mountain are described and screened in a series of AMRs known as FEPs AMRs. Each of these four KTI agreements states that a response, in the form of a clarification, an addition, or a technical basis will be provided in one or more of these reports. This report is to summarize the DOE responses and document the locations of these responses in the FEPs AMRs.

The specific information required by the above KTI agreements is in the following FEPs AMRs:

- *Clad Degradation–FEPs Screening Arguments* (BSC 2004a)
- *Engineered Barrier System Features, Events, and Processes* (BSC 2004b)
- *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a)
- *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c)
- *Features, Events and Processes: Disruptive Events* (BSC 2004d)
- *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e)
- *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f)
- *Miscellaneous Waste-Form FEPs* (BSC 2004g)
- *Features, Events, and Processes: System Level* (BSC 2004h)

FEPs are screened by DOE and classified as either included or excluded. Those FEPs that are expected to materially affect compliance with 10 CFR 63.113 or be potentially adverse to repository performance are included. FEPs may be excluded on the basis of low probability, low consequence, or direction by regulation. The screening decision for each FEP is reported in the appropriate FEPs AMR and is summarized in this report.

In the case of excluded FEPs, the screening arguments for exclusion are presented entirely in the FEPs AMRs. FEPs that are included have their dispositions in the total system performance assessment (TSPA) described in the FEPs AMRs, but the complete technical bases for their dispositions is contained in supporting AMRs that are identified in the applicable FEPs AMRs.

The information provided in this report for each of the FEPs related to NRC comments listed in KTI Agreements TSPAI 2.01 to TSPAI 2.04 is as follows:

- NRC comment number
- Path forward agreed upon by DOE and NRC for resolution of the NRC comment

- Original FEP number used in the TSPA-SR
- Original FEP name used in the TSPA-SR
- Original FEP screening decision for TSPA-SR
- Current FEP number used in the total system performance for license application (TSPA-LA)
- Current FEP name used in the TSPA-LA
- The FEP AMR that addresses the current FEP
- The current FEP screening decision for TSPA-LA
- Summary of the FEP screening argument
- Summary of action taken by DOE to resolve the NRC comment.

Some FEPs used in TSPA-SR have been modified for TSPA-LA by division into more than one FEP, combination with another FEP, or replacement with a new FEP, partly in response to prior NRC comments. These instances are noted in the responses to NRC comments.

The responses for TSPA 2.01, 2.02, 2.03, and 2.04 are summarized in Sections 4 to 7 and are reflected in the AMRs listed above.

Tables 3-1 to 3-4 list the FEP associated with each NRC comment for agreements TSPAI 2.01 to 2.04. The original TSPA-SR FEP is listed for each comment, followed by the current TSPA-LA FEP or FEPs, the FEP name, and the associated AMR or AMRs.

Table 3-1. TSPA-SR and TSPA-LA FEPs for TSPAI 2.01

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
5	2.1.09.21.00	2.1.09.21.0A	Transport of particles larger than colloids in engineered barrier system	Engineered Barrier System (BSC 2004b)
		2.1.09.21.0B	Transport of particles larger than colloids in saturated zone	Saturated Zone (BSC 2004e)
		2.1.09.21.0C	Transport of particles larger than colloids in unsaturated zone	Unsaturated Zone (BSC 2004f)
7	1.4.06.01.00	1.4.06.01.0A	Altered soil or surface water chemistry	Unsaturated Zone (BSC 2004f)
8	1.2.04.07.00	1.2.04.07.0A	Ashfall	Disruptive Events (BSC 2004d)
				Biosphere (BSC 2003a)
		1.2.04.07.0B	Ash redistribution in groundwater	Saturated Zone (BSC 2004e)
		1.2.04.07.0C	Ash redistribution via soil and sediment transport	Disruptive Events (BSC 2004d)
9	2.2.10.06.00	2.2.10.06.0A	Thermo-chemical alteration in the unsaturated zone (solubility, speciation, phase changes, precipitation/dissolution)	Unsaturated Zone (BSC 2004f)
		2.2.10.08.0A	Thermo-chemical alteration in the saturated zone (solubility, speciation, phase changes, precipitation/dissolution)	Saturated Zone (BSC 2004e)

Table 3-1. TSPA-SR and TSPA-LA FEPs for TSPAI 2.01 (Continued)

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
10	2.3.11.04.00	2.3.11.04.0A	Groundwater discharge to surface outside the reference biosphere	Saturated Zone (BSC 2004e)
				Biosphere (BSC 2003a)
13	2.2.10.02.00	2.2.10.02.0A	Thermal convection cell develops in Saturated Zone	Saturated Zone (BSC 2004e)
18	1.4.07.01.00	1.4.07.01.0A	Water management activities	Saturated Zone (BSC 2004e)
				Biosphere (BSC 2003a)
19 Part 5	2.2.08.01.00	2.2.08.01.0A	Chemical characteristics of groundwater in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.01.0B	Chemical characteristics of groundwater in the unsaturated zone	Unsaturated Zone (BSC 2004f)
21	2.3.13.01.00	2.3.13.01.0A	Biosphere characteristics	Biosphere (BSC 2003a)
32	2.1.13.01.00	2.1.13.01.0A	Radiolysis	Waste Form Miscellaneous (BSC 2004g)
				Waste Package (BSC 2004c)
				Engineered Barrier System (BSC 2004b)
41	2.1.02.20.00	2.1.02.20.0A	Internal pressurization of cladding	Waste Form Cladding (BSC 2004a)
47	2.1.02.17.00	2.1.02.17.0A	Localized (crevice) corrosion of cladding	Waste Form Cladding (BSC 2004a)
50	2.1.02.13.00	2.1.02.13.0A	General corrosion of cladding	Waste Form Cladding (BSC 2004a)
53	2.1.02.22.00	2.1.02.22.0A	Hydride cracking of cladding	Waste Form Cladding (BSC 2004a)
58	Various	NA	(Disruptive Events and engineered barrier system FEPs with preliminary arguments)	Engineered Barrier System (BSC 2004b)
67	2.2.10.05.00	2.2.10.05.0A	Thermo-mechanical stresses alter characteristics of rocks above and below the repository	Unsaturated Zone (BSC 2004f)
				Saturated Zone (BSC 2004e)
J-5	2.1.09.21.00	2.1.09.21.0A	Transport of particles larger than colloids in engineered barrier system	Engineered Barrier System (BSC 2004b)
		2.1.09.21.0B	Transport of particles larger than colloids in the saturated zone	Saturated Zone (BSC 2004e)
		2.1.09.21.0C	Transport of particles larger than colloids in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-16	1.2.07.01.00	1.2.07.01.0A	Erosion/denudation	Unsaturated Zone (BSC 2004f)
J-18	1.3.04.00.00	1.3.04.00.0A	Periglacial effects	Biosphere (BSC 2003a)
				Unsaturated Zone (BSC 2004f)

Table 3-2. TSPA-SR and TSPA-LA FEPs for TSPAI 2.02

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
3	2.2.10.03.00	2.2.10.03.0A	Natural geothermal effects on flow in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.10.03.0B	Natural geothermal effects on flow in the unsaturated zone	Unsaturated Zone (BSC 2004f)
4	1.2.06.00.00	1.2.06.00.0A	Hydrothermal activity	Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
11	1.3.07.01.00	1.3.07.01.0A	Water table decline	Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
12	2.2.10.13.00	2.2.10.13.0A	Repository-induced thermal effects on flow in the saturated zone	Saturated Zone (BSC 2004e)
19 Part 1	1.3.07.02.00	1.3.07.02.0A	Water table rise affects saturated zone	Saturated Zone (BSC 2004e)
		1.3.07.02.0B	Water table rise affects unsaturated zone	Unsaturated Zone (BSC 2004f)
19 Part 2	2.3.11.04.00	2.3.11.04.0A	Groundwater discharge to surface outside the reference biosphere	Saturated Zone (BSC 2004e)
				Biosphere (BSC 2003a)
19 Part 6	2.2.08.11.00	2.2.08.11.0A	Groundwater discharge to surface within the reference biosphere	Biosphere (BSC 2003a)
				Saturated Zone (BSC 2004e)
25	2.4.07.00.00	2.4.07.00.0A	Dwellings	Biosphere (BSC 2003a)
26	3.3.08.00.00	3.3.08.00.0A	Radon and radon daughter exposure	Biosphere (BSC 2003a)
29	2.1.06.07.00	2.1.06.07.0A	Chemical effects at engineered barrier system component interfaces	Engineered Barrier System (BSC 2004b)
		2.1.06.07.0B	Mechanical effects at engineered barrier system component interfaces	Waste Package (BSC 2004c)
				Engineered Barrier System (BSC 2004b)
34	2.1.03.02.00	2.1.03.02.0A	Stress corrosion cracking of waste packages	Waste Package (BSC 2004c)
		2.1.03.02.0B	Stress corrosion cracking of drip shields	Waste Package (BSC 2004c)
35	2.1.03.08.00	2.1.03.08.0A	Early failure of waste packages	Waste Package (BSC 2004c)
		2.1.03.08.0B	Early failure of drip shields	Waste Package (BSC 2004c)

Table 3-2. TSPA-SR and TSPA-LA FEPs for TSPAI 2.02 (Continued)

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
36	2.1.09.03.00	2.1.09.03.0A	Volume increase of corrosion products impacts cladding	Waste Form Cladding (BSC 2004a)
		2.1.09.03.0B	Volume increase of corrosion products impacts waste package	Waste Package (BSC 2004c)
		2.1.09.03.0C	Volume increase of corrosion products impacts other engineered barrier system components	Engineered Barrier System (BSC 2004b)
37	2.1.07.05.00	2.1.07.05.0A	Creep of metallic materials in the waste package	Waste Package (BSC 2004c)
		2.1.07.05.0B	Creep of metallic materials in the drip shield	Waste Package (BSC 2004c)
38	2.1.11.05.00	2.1.11.05.0A	Thermal expansion/stress of in-package engineered barrier system components	Waste Form Miscellaneous (BSC 2004g)
				Waste Form Cladding (BSC 2004a)
	Applicable?	2.1.11.07.0A	Thermal expansion/stress of in-drift engineered barrier system components	Engineered Barrier System (BSC 2004b)
				Waste Package (BSC 2004c)
39	2.1.06.06.00	2.1.06.06.0A	Effects of drip shield on flow	Engineered Barrier System (BSC 2004b)
		2.1.06.06.0B	Oxygen embrittlement of drip shields	Waste Package (BSC 2004c)
42	2.1.08.07.00	2.1.08.07.0A	Unsaturated flow in the engineered barrier system	Engineered Barrier System (BSC 2004b)
43	2.1.02.27.00	2.1.02.27.0A	Localized (fluoride enhanced) corrosion of cladding	Waste Form Cladding (BSC 2004a)
44	2.1.02.16.00	2.1.02.16.0A	Localized (pitting) corrosion of cladding	Waste Form Cladding (BSC 2004a)
48	2.1.01.04.00	2.1.01.04.0A	Repository-scale spatial heterogeneity of emplaced waste	Waste Form Miscellaneous (BSC 2004g)
49	2.1.02.15.00	2.1.02.15.0A	Localized (radiolysis enhanced) corrosion of cladding	Waste Form Cladding (BSC 2004a)
51	2.1.02.14.00	2.1.02.14.0A	Microbially influenced corrosion of cladding	Waste Form Cladding (BSC 2004a)
54	2.1.09.02.00	2.1.09.02.0A	Chemical interaction with corrosion products	Waste Form Miscellaneous (BSC 2004g)
				Engineered Barrier System (BSC 2004b)
55	2.1.09.07.00	2.1.09.07.0A	Reaction kinetics in engineered barrier system	Waste Form Miscellaneous (BSC 2004g)
				Engineered Barrier System (BSC 2004b)
56	2.1.07.06.00	2.1.07.06.0A	Floor buckling	Engineered Barrier System (BSC 2004b)
57	1.1.02.03.00	1.1.02.03.0A	Undesirable materials left	Engineered Barrier System (BSC 2004b)

Table 3-2. TSPA-SR and TSPA-LA FEPs for TSPAI 2.02 (Continued)

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
59	2.1.08.04.00	2.1.08.04.0A	Condensation forms on roofs of drifts (drift-scale cold traps)	Engineered Barrier System (BSC 2004b)
		2.1.08.04.0B	Condensation forms at repository edges (repository-scale cold traps)	Engineered Barrier System (BSC 2004b)
60	2.1.12.01.00	2.1.12.01.0A	Gas generation (repository pressurization)	Waste Form Miscellaneous (BSC 2004g)
				Engineered Barrier System (BSC 2004b)
61	2.2.10.12.00	2.2.10.12.0A	Geosphere dry-out due to waste heat	Unsaturated Zone (BSC 2004f)
62	2.2.01.02.00	2.2.01.02.0A	Thermally induced stress changes in the near-field	Engineered Barrier System (BSC 2004b)
				Unsaturated Zone (BSC 2004f)
63	2.1.09.12.00	2.1.09.12.0A	Rind (chemically altered zone) forms in the near-field	Unsaturated Zone (BSC 2004f)
64	2.2.10.06.00	2.2.10.06.0A	Thermo-chemical alteration in the unsaturated zone (solubility, speciation, phase changes, precipitation/dissolution)	Unsaturated Zone (BSC 2004f)
65	2.1.11.02.00	2.1.11.02.0A	Non-uniform heat distribution in engineered barrier system	Engineered Barrier System (BSC 2004b)
66	2.2.06.01.00	2.2.06.01.0A	Seismic activity changes porosity and permeability of rock	Disruptive Events (BSC 2004d)
				Unsaturated Zone (BSC 2004f)
				Saturated Zone (BSC 2004e)
68	1.2.02.01.00	1.2.02.01.0A	Fractures	Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
69	2.2.01.01.00	2.2.01.01.0A	Mechanical effects of excavation/construction in the near field	Unsaturated Zone (BSC 2004f)
		2.2.01.01.0B	Chemical effects of excavation/construction in the near field	Unsaturated Zone (BSC 2004f)
70	2.2.10.04.00	2.2.10.04.0A	Thermo-mechanical stresses alter characteristics of fractures near repository	Unsaturated Zone (BSC 2004f)
				Saturated Zone (BSC 2004e)
78	1.2.03.02.00	1.2.03.02.0A	Seismic ground motion damages engineered barrier system components	Disruptive Events (BSC 2004d)
				Engineered Barrier System (BSC 2004b)
		1.2.03.02.0B	Seismic induced rockfall damages engineered barrier system components	Disruptive Events (BSC 2004d)
				Engineered Barrier System (BSC 2004b)
		1.2.03.02.0C	Seismic-induced drift collapse damages engineered barrier system components	Disruptive Events (BSC 2004d)
		1.2.03.02.0D	Seismic-induced drift collapse alters in-drift thermohydrology	Disruptive Events (BSC 2004d)

Table 3-2. TSPA-SR and TSPA-LA FEPs for TSPAI 2.02 (Continued)

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
79	2.1.07.01.00	2.1.07.01.0A	Rockfall	Waste Form Cladding (BSC 2004a)
				Waste Package (BSC 2004c)
				Waste Package (BSC 2004c)
				Engineered Barrier System (BSC 2004b)
J-1	2.1.03.11.00	2.1.03.11.0A	Physical form of waste package and drip shield	Waste Package (BSC 2004c)
J-2	2.1.06.05.00	2.1.06.05.0A	Mechanical degradation of pedestal	Engineered Barrier System (BSC 2004b)
		2.1.06.05.0B	Mechanical degradation of invert	Engineered Barrier System (BSC 2004b)
		2.1.06.05.0C	Chemical degradation of pedestal	Engineered Barrier System (BSC 2004b)
		2.1.06.05.0D	Chemical degradation of invert	Engineered Barrier System (BSC 2004b)
J-3	2.1.06.01.00	2.1.06.01.0A	Chemical effects of rock reinforcement and cementitious materials in engineered barrier system	Engineered Barrier System (BSC 2004b)
J-4	2.1.06.05.00	2.1.06.05.0A	Mechanical degradation of pedestal	Engineered Barrier System (BSC 2004b)
		2.1.06.05.0B	Mechanical degradation of invert	Engineered Barrier System (BSC 2004b)
		2.1.06.05.0C	Chemical degradation of pedestal	Engineered Barrier System (BSC 2004b)
		2.1.06.05.0D	Chemical degradation of invert	Engineered Barrier System (BSC 2004b)
J-7	2.2.08.01.00	2.2.08.01.0A	Chemical characteristics of groundwater in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.01.0B	Chemical characteristics of groundwater in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-8	2.2.08.02.00	Deleted	Redundant with FEPs 2.2.08.01.0x and 2.2.08.03.0x	Saturated Zone (BSC 2004e)
		2.2.08.01.0A	Chemical characteristics of groundwater in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.01.0B	Chemical characteristics of groundwater in the unsaturated zone	Unsaturated Zone (BSC 2004f)
		2.2.08.03.0A	Geochemical interactions and evolution in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.03.0B	Geochemical interactions and evolution in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-9	2.2.08.03.00	2.2.08.03.0A	Geochemical interactions and evolution in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.03.0B	Geochemical interactions and evolution in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-10	2.2.08.06.00	2.2.08.06.0A	Complexation in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.06.0B	Complexation in the unsaturated zone	Unsaturated Zone (BSC 2004f)

Table 3-2. TSPA-SR and TSPA-LA FEPs for TSPAI 2.02 (Continued)

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
J-11	2.2.08.07.00	2.2.08.07.0A	Radionuclide solubility limits in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.07.0B	Radionuclide solubility limits in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-12	2.2.10.01.00	2.2.10.01.0A	Repository-induced thermal effects on flow in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-13	2.2.10.06.00	2.2.10.06.0A	Thermal-chemical alteration in the unsaturated zone (solubility, speciation, phase changes, precipitation/dissolution)	Unsaturated Zone (BSC 2004f)
J-14	2.2.10.07.00	2.2.10.07.0A	Thermo-chemical alteration of the Calico Hills unit	Unsaturated Zone (BSC 2004f)
J-15	2.2.10.09.00	2.2.10.09.0A	Thermal-chemical alteration of the Topopah Spring basal vitrophyre	Unsaturated Zone (BSC 2004f)
J-17	1.2.10.02.00	1.2.10.02.0A	Hydrologic response to igneous activity	Disruptive Events (BSC 2004d)
				Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
J-20	2.2.07.05.00	2.2.07.05.0A	Flow in the unsaturated zone from episodic infiltration	Unsaturated Zone (BSC 2004f)
J-21	2.2.11.02.00	2.2.11.02.0A	Gas effects in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-22	1.2.04.02.00	1.2.04.02.0A	Igneous activity changes rock properties	Disruptive Events (BSC 2004d)
				Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
J-23	1.2.06.00.00	1.2.06.00.0A	Hydrothermal activity	Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
J-24	1.2.04.07.00	1.2.04.07.0A	Ashfall	Disruptive Events (BSC 2004d)
				Biosphere (BSC 2003a)
		1.2.04.07.0B	Ash redistribution in groundwater	Saturated Zone (BSC 2004e)
		1.2.04.07.0C	Ash redistribution via soil and sediment transport	Disruptive Events (BSC 2004d)
J-25	1.2.02.02.00	1.2.02.02.0A	Faults	Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
J-26	1.2.02.03.00	1.2.02.03.0A	Fault displacement damages engineered barrier system components	Disruptive Events (BSC 2004d)
				Engineered Barrier System (BSC 2004b)
J-27	1.2.03.01.00	Deleted	See Disruptive Events FEPs AMR	Disruptive Events (BSC 2004d)

Table 3-3. TSPA-SR and TSPA-LA FEPs for TSPAI 2.03

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
19 Pt 7	3.1.01.01.00	3.1.01.01.0A	Radioactive decay and ingrowth	Waste Form Miscellaneous (BSC 2004g)
				Saturated Zone (BSC 2004e)
				Unsaturated Zone (BSC 2004f)
				Biosphere (BSC 2003a)
19 Pt 8	1.2.04.07.00	1.2.04.07.0A	Ashfall	Disruptive Events (BSC 2004d)
				Biosphere (BSC 2003a)
		1.2.04.07.0B	Ash redistribution in groundwater	Saturated Zone (BSC 2004e)
		1.2.04.07.0C	Ash redistribution via soil and sediment transport	Disruptive Events (BSC 2004d)
20	2.2.08.07.00	2.2.08.07.0A	Radionuclide solubility limits in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.08.07.0B	Radionuclide solubility limits in the unsaturated zone	Unsaturated Zone (BSC 2004f)
J-6	2.2.07.15.00	2.2.07.15.0A	Advection and dispersion in the saturated zone	Saturated Zone (BSC 2004e)
		2.2.07.15.0B	Advection and dispersion in the unsaturated zone	Unsaturated Zone (BSC 2004f)

Table 3-4. TSPA-SR and TSPA-LA FEPs for TSPAI 2.04

Comment Number	Original FEP	Current FEP(s)	FEP Name	FEP AMR
24	2.3.13.02.00	2.3.13.02.0A	Radionuclide alteration during biosphere transport	Biosphere (BSC 2003a)
31	1.2.03.02.00	1.2.03.02.0A	Seismic ground motion damages engineered barrier system components	Disruptive Events (BSC 2004d)
				Engineered Barrier System (BSC 2004b)
		1.2.03.02.0B	Seismic induced rockfall damages engineered barrier system components	Disruptive Events (BSC 2004d)
				Engineered Barrier System (BSC 2004b)
		1.2.03.02.0C	Seismic-induced drift collapse Damages engineered barrier system components	Disruptive Events (BSC 2004d)
				Engineered Barrier System (BSC 2004b)
		1.2.03.02.0D	Seismic-induced drift collapse alters in-drift thermohydrology	Disruptive Events (BSC 2004d)
				Engineered Barrier System (BSC 2004b)
33	NA	2.1.03.01.0A	General corrosion of waste packages	Waste Package (BSC 2004c)
		2.1.03.01.0B	General corrosion of drip shields	Waste Package (BSC 2004c)
		2.1.03.03.0A	Localized corrosion of waste packages	Waste Package (BSC 2004c)
		2.1.03.03.0B	Localized corrosion of drip shields	Waste Package (BSC 2004c)
		2.1.03.02.0A	Stress corrosion cracking of waste packages	Waste Package (BSC 2004c)
		2.1.03.02.0B	Stress corrosion cracking of drip shields	Waste Package (BSC 2004c)

TSPAI 2.07

In response to KTI Agreements TSPAI 2.05 and 2.06, DOE transmitted *The Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002a) to the NRC. This plan described DOE's proposal for developing the documentation of FEPs. After reviewing this plan, NRC identified additional requirements that were addressed by DOE in *KTI Letter Report, Response to Additional Information Needs on TSPAI 2.05 and TSPAI 2.06* (Freeze 2003). These KTI agreements were reported as complete in an NRC letter in January 2004 (Schlueter 2004).

The DOE enhanced FEP plan (BSC 2002a), combined with responses to TSPAI 2.05 and 2.06, describes the FEPs documents and database that are being implemented for TSPA-LA, including the features identified in TSPAI 2.07, as discussed below.

The enhanced FEP plan (BSC 2002a) resulted in the reevaluation of all FEPs to eliminate factors that obscured the definitions of FEPs or relationships between FEPs. For example, under the enhanced FEP plan (BSC 2002a), there are no longer secondary FEPs, FEP components, or combined included and excluded FEPs.

The results of the enhanced FEP plan (BSC 2002a) implementation for revised FEP descriptions and screening arguments are provided in the FEP AMRs listed at the beginning of this section, which were updated in 2004. This information is under development as the AMRs undergo final pre–license application revisions to be completed in September 2004. The current versions of the AMRs will made be available for NRC review on the Office of Civilian Radioactive Waste Management Yucca Mountain Project web site (www.ocrwm.doe.gov). Future revisions will likewise be made available for NRC review as they are published.

The preliminary FEPs database provides interactive navigability of FEPs by process, subsystem or keyword, summary information regarding the revised FEP descriptions and screening arguments, and traceability mapping to TSPA-SR FEPs. A preliminary copy of the database is available for NRC review in the Las Vegas and Rockville offices. A fully approved version of the database will be provided in the Technical Data Management System. Software to navigate the database will be baselined in the Software Configuration Management System at the same time.

In summary, the enhanced FEP plan (BSC 2002a) has been implemented through reevaluation of FEPs, revision of FEP AMRs, and construction of the enhanced FEPs database. Items defined in agreements TSPAI 2.05 and 2.06 have been implemented, as agreed in TSPAI 2.07.

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4. CLARIFICATION OF SCREENING ARGUMENTS (RESPONSE TO TSPAI 2.01)

This section addresses KTI Agreement TSPAI 2.01. This agreement is concerned with clarification of certain screening arguments that were presented in the AMRs for FEPs that were prepared for DOE's TSPA-SR.

Wording of the agreement is as follows.

TSPAI 2.01

> Provide clarification of the screening arguments, as summarized in Attachment 2. See Comment # 5, 7, 8, 9, 10, 13, 18, 19 (Part 5), 21, 32, 41, 47, 50, 53, 58, 67, J-5, J-16, and J-18. DOE will clarify the screening arguments, as summarized in Attachment 2, for the highlighted FEPs. The clarifications will be provided in the referenced FEPs AMR and will be provided to the NRC in FY03.

Responses to individual NRC comments follow.

4.1 COMMENT 5

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification for the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 to address the NRC comments.

4.1.1 TSPA-SR

FEP 2.1.09.21.00, Suspensions of Particles Larger than Colloids

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), *Waste Form Colloid-Associated Concentrations Limits: Abstraction and Summary* (CRWMS M&O 2001b), and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Waste Form Colloid–Excluded because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

4.1.2 TSPA-LA

FEP 2.1.09.21.0A, Transport of Particles Larger than Colloids in Engineered Barrier System

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.54).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–A detailed discussion on the potential role of particles larger than colloids was presented in *Waste Form Colloid-Associated Concentrations Limits: Abstraction and Summary* (CRWMS M&O 2001b, Attachment IX). If particles larger than colloids form during the degradation of waste form and waste package materials, these particles are likely to sorb radionuclides following the same principles as radionuclide sorption onto colloids. In terms of mobility, however, several differences exist between colloids and larger particles, making it unlikely that the larger particles could unfavorably affect performance. First, their large size would require relatively high-energy groundwater flow conditions to entrain (rinse) and transport the particles out of the waste package. Second, their large size makes them more susceptible to filtration.

In summary, the effects of suspensions of particles larger than colloids in the engineered barrier system have been excluded from TSPA-LA on the basis of low consequence. Omission of the effects of suspensions of particles larger than colloids will not significantly change radiological exposures or radionuclide releases because the formation of suspensions in the near-field and far-field environments are likely to be localized and not widespread. Furthermore, even if these suspensions were to form, it is likely that these large particles would quickly settle by gravity within a small distance, and their transport by moving water would not be extensive.

FEP 2.1.09.21.0B, Transport of Particles Larger than Colloids in the Saturated Zone

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.13).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Transport of particles larger than colloids is screened out on low consequence because (1) no radionuclide-bearing particles larger than colloids are introduced into the saturated zone from the unsaturated zone, (2) large particles will not be suspended for great distances along the flow paths given the variable vertical velocity component that would be encountered along the transport path, and (3) the highly variable size, shape, orientation, and roughness of the transporting fracture voids promote both settling and filtering. Transport of particles larger than colloids is excluded based on low consequence because it will not significantly change radiological exposures to the reasonably maximally exposed individual (RMEI) or radionuclide releases to the accessible environment.

FEP 2.1.09.21.0C, Transport of Particles Larger than Colloids in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.3.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Particles larger than colloids are not expected to show much mobility in the unsaturated zone because of the large gravitational settling that occurs relative to diffusive movement for such particles.

Calculation of the diffusive movement and gravitational settling velocity for a colloid (BSC 2004f, Section 6.3.4) shows that, for a colloid of diameter 0.836 μm, gravitational settling and diffusion will be roughly in balance. For particles larger than colloids (greater than 100 μm), gravitational settling will dominate particle movement. Therefore, particles larger than colloids are not mobile.

The effects of perturbed thermal-hydrologic conditions or other perturbed flow conditions (e.g., groundwater rinse) on colloid movement (or movement of particles larger than colloids) are expected to be negligible because of the limited entrainment expected. Tests with fine, cohesive sediments show that although entrainment does occur, for a wide variety of conditions this appears to be a very limited transient response. Entrainment is observed for a few days, and then the system stabilizes with no further initiation of motion, as compared with unretarded colloid transport. The limited time frame for enhanced colloid movement is negligible with respect to the time frames for waste release and transport. Therefore, this FEP may be excluded based on low consequence.

4.1.3 Resolution of Comment 5

The TSPA-SR FEP was divided into three separate FEPs for TSPA-LA in order to address transport of particles larger than colloids in the unsaturated zone, saturated zone, and engineered barrier system. This division facilitated clarification of screening arguments, which are contained in the corresponding FEP AMRs. *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f) and *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e) provide quantitative analysis of gravitational settling of particles larger than colloids, while *Engineered Barrier System Features, Events, and Processes* (BSC 2004b) conservatively assumes that no colloid settling or filtration occurs in the engineered barrier system (i.e., all colloids are available for transport).

4.2 COMMENT 7

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 to address the NRC comments. The AMR will also address the aggregate affects of this FEP on UZ and SZ.

4.2.1 TSPA-SR

FEP 1.4.06.01.00, Altered Soil or Surface Water Chemistry

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Biosphere–Excluded by regulation
- Unsaturated Zone–Excluded because of low consequence.

4.2.2 TSPA-LA

FEP 1.4.06.01.0A, Altered Soil or Surface Water Chemistry

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.5.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded by regulation

Summary of Screening Argument–Human activities may affect soil and surface water chemistry because of agricultural activities or pollution from industrial activities. Current land use at Yucca Mountain does not include activities such as these that may lead to large-scale changes in soil or water chemistry. There is no expectation that such activities would occur at Yucca Mountain because the site does not offer known mineral resources, commercial or industrial land uses, or land that is suitable for agricultural development due to the rough terrain, thin soils, low rainfall, and deep water table. Furthermore, 10 CFR 63.305(b) states that "DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology. In all analyses done to demonstrate compliance with this part, the DOE must assume that all of those factors remain constant as they are at the time of submission of the license application." Therefore, human activities (changes in the social and institutional attributes of society, lifestyle, land use, and water use) that would alter soil or surface water chemistry are excluded on the basis of the regulatory requirements (10 CFR 63.305(b)).

4.2.3 Resolution of Comment 7

While the previous basis for low consequence has not been invalidated, this FEP is now excluded by regulation, in order to comply with the provisions of 10 CFR Part 63 that preclude DOE from projecting factors that would alter soil or surface water chemistry. Because of the regulatory exclusion, aggregate effects in the unsaturated and saturated zones are not considered.

4.3 COMMENT 8

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 to address the NRC comment.

4.3.1 TSPA-SR

FEP 1.2.04.07.00, Ashfall

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) and *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Included; does not satisfy a screening criterion (for ash cloud and surface deposition)
- Pyroclastic Flow–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

4.3.2 TSPA-LA

FEP 1.2.04.07.0A, Ashfall

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.6) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.1).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Biosphere–Included.

Summary of Screening Disposition–The TSPA-LA approach for addressing igneous intrusion includes consideration of exposure from an ash-fall event.

Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003b, Table 22) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3×10^{-8} (see Assumption 5.1 of *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 5)). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003c; BSC

2003d). Additionally, the lateral extent of ash fall is sufficient to reach the location of the RMEI, so the FEP has been included.

The two igneous events (with individual probabilities and consequences) being modeled by the TSPA-LA are: (1) an igneous intrusion groundwater transport modeling case featuring the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to the repository level where it intersects drifts, and (2) a volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. The potential consequence of the second event (volcanic eruption modeling case) is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the RMEI. The conceptual model for the eruptive process is discussed under FEP 1.2.04.06.0A (BSC 2004d, Section 6.2.2.5), Eruptive Conduit to Surface Intersects Repository.

Characterize Eruptive Processes at Yucca Mountain, Nevada (BSC 2003e, Section 6) provides the technical basis for inclusion of the FEP in the TSPA-LA. The properties of basaltic eruptions, based on the observed characteristics of past basaltic eruptions in the Yucca Mountain region and other analogous eruptions, and results of field investigations dealing with physical volcanology and with ash and tephra redistribution (including the conceptual models for eruptive processes and for ash and tephra redistribution) are used to develop parameter value distributions appropriate for analysis of the consequences of volcanic eruptions through a repository at Yucca Mountain.

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

FEP 1.2.04.07.0B, Ash Redistribution in Groundwater

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–If a volcanic eruption were to occur within the repository entraining radioactive waste, contaminated radionuclide-bearing ash deposited on the surface could leach and be transported through the unsaturated zone and saturated zone to the compliance point. Assuming the contents of six commercial spent nuclear fuel waste packages are entrained in the volcanic eruption (which is the median number of packages brought to the surface by a single volcanic eruption intersecting one drift) and that all of the waste is uniformly distributed in the ash blanket on the ground surface, the resulting estimated conditional dose rate is 20.5 mrem/yr. The resulting probability-weighted dose rate due to leaching of radionuclides from contaminated ash is less than 3×10^{-3} mrem/yr. In addition, the conservative assumption is made that all radionuclides derived from the volcanic ash blanket are captured in the hypothetical pumping wells of the RMEI. This is consistent with the TSPA nominal class scenario model, in which radionuclide contamination of groundwater in the saturated zone is assumed to be completely captured in the groundwater usage of the hypothetical future farming community. This is significantly less than the probability-weighted doses resulting from other igneous pathways during this period. The effects of nonuniform distribution of the ash blanket are addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4). The effects of ash fall on saturated zone transport are excluded on the basis of low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

FEP 1.2.04.07.0C, Ash Redistribution via Soil and Sediment Transport

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.7).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included.

Summary of Screening Disposition–The TSPA-LA includes consideration of exposure from redistributed ash.

Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003b, Table 22) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3×10^{-8} (see Assumption 5.1 of *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 5)). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003c; BSC 2003d). Additionally, the lateral extent of ash fall from such an event and subsequent ash redistribution is sufficient to reach the location of the RMEI, so the FEP has been included.

For the volcanic eruption modeling case, the TSPA-LA assumes 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. The TSPA-LA model, using ASHPLUME V2.0, estimates radionuclide concentrations in contaminated ash falling at the location of the RMEI. The TSPA-LA approach for calculating exposure through the use of volcanic-specific biosphere dose conversion factors is further outlined in *Total System Performance Assessment-License Application Methods and Approach* (BSC 2002b, Section 8.1.2).

This hypothetical direct deposition of ash and waste in the vicinity of the RMEI presumably represents the greatest degree of exposure from an eruptive process. Other mechanisms (e.g., eolian or fluvial processes) allow for mixing and dilution of the ash and waste through distance and with time. Presumably, a volume of transported sediment with a highly diluted ash component would have less impact on the RMEI than would primary ash fall that fell directly on, or nearby, the RMEI. Accordingly, the worst-case conceptual model would be one in which winds blow the initial eruption column south from the repository toward the RMEI. This is the only conceptual model in which ash would directly fall on the RMEI without additional dilution.

To assess the degree to which redistribution and mixing processes (primarily fluvial processes) might affect the percent of ash and waste in reworked and transported sediment and its contribution to exposure, a study was performed using the ash deposits and tephra sheet of the Lathrop Wells Cone and ^{137}Cs studies in the Fortymile Wash alluvial fan. The results of these studies are documented in *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* (BSC 2003e, Section 6.5) and *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003f). Both reports include the results of field investigations and present the conceptual and technical basis for the ash redistribution model implemented within TSPA-LA. The technical basis for the TSPA ash redistribution model is supported by geomorphic data and analyses.

4.3.3 Resolution of Comment 8

The TSPA-SR FEP was divided into three FEPs for TSPA-LA in order to include the effects of ash fall in disruptive events and biosphere analyses, while excluding them in the saturated zone. The portion of the NRC comment regarding uniform versus nonuniform distribution of ash fall is addressed in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4).

4.4 COMMENT 9

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 to address the NRC comment.

4.4.1 TSPA-SR

FEP 2.2.10.06.00, Thermo-Chemical Alteration (Solubility Speciation, Phase Changes, Precipitation/Dissolution)

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included (in-drift geochemical model that uses water chemistry and gas-phase composition from the drift-scale thermal-hydrologic-chemical model that includes thermal-chemical alteration)
- Near Field Environment–Excluded (thermal-hydrologic models) because of low consequence
- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

4.4.2 TSPA-LA

FEP 2.2.10.08.0A, Thermo-Chemical Alteration in the Saturated Zone (Solubility, Speciation, Phase Changes, Precipitation/Dissolution)

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.39).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–A numerical model of the mountain-scale effects of thermal loading on the host rock due to waste emplacement is evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003g, Section 6.5). The model encompasses a domain extending from the ground surface to the water table and assesses changes in the water chemistry and mineralogy due to thermal loading at the repository. A heat wave is produced, originating at the repository and propagating outward. These elevated temperatures cause CO_2 to exsolve out of solution above and below the repository. Just above the water table, within the repository footprint, temperatures peak around 2,000 years and locally vary between 32°C and 34°C. Variability in temperature can cause significant variability in CO_2 concentrations and promote precipitation and (or) dissolution of calcite in fractures and pore spaces. Modeling results indicate CO_2 concentrations just above the water table do not vary significantly during the modeled time period. Concurrently, no significant precipitation or dissolution of calcite-bearing minerals in fracture fillings is seen. It is concluded that if there is no measurable precipitation or dissolution of calcite in fracture fillings just above the water table due to thermal loading, there will be no measurable precipitation or dissolution of calcite along the saturated zone transport path due to thermal loading.

These reasons support excluding this FEP due to low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

4.4.3 Resolution of Comment 9

This FEP has been split into two FEPs: 2.2.10.06.0A, thermal-chemical alteration in the unsaturated zone (solubility, speciation, phase changes, precipitation–dissolution, and 2.2.10.08.0A, thermal-chemical alteration in the saturated zone (solubility, speciation, phase changes, precipitation–dissolution). Both were screened as excluded due to low consequence. Updated screening arguments are contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e). Screening arguments are no longer based on to-be-verified assumptions.

4.5 COMMENT 10

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 to address the NRC comment.

4.5.1 TSPA-SR

FEP 2.3.11.04.00, Groundwater Discharge to Surface

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

4.5.2 TSPA-LA

FEP 2.3.11.04.0A, Groundwater Discharge to Surface Outside the Reference Biosphere

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.43) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.22).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded by regulation
- Biosphere–Excluded by regulation.

Summary of Screening Argument–Reference biosphere is defined as the description of the environment inhabited by the RMEI (10 CFR 63.2). 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 of 10 CFR 63.113(b). The rule also specifies criteria that pertain to the characteristics of a reference biosphere that are required to show compliance with the postclosure standards for disposal (66 FR 55733). Similarly, the preamble to the rule states that 10 CFR 63.305 specifies characteristics of the reference biosphere to be used by DOE in its performance assessment to demonstrate compliance with the requirements specified at 10 CFR 63.113(b) and (d) (66 FR 55732, p. 55784). Since the demonstration of compliance specifies conditions of the reference biosphere, the FEPs related to any processes occurring outside the reference biosphere are implicitly excluded. Therefore, groundwater discharge to the surface outside the reference biosphere is excluded on the basis of inconsistency with the requirements of 10 CFR 63.113(b).

4.5.3 Resolution of Comment 10

FEP 2.3.11.04.0A is now screened as excluded by regulation because the dose to the RMEI is not calculated outside the reference biosphere. Groundwater discharges within the reference biosphere, where dose to the RMEI is calculated, are screened as included under FEP 2.2.08.11.0A. Updated screening arguments and dispositions for these FEPs are contained in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4.3) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.22).

4.6 COMMENT 13

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002.

4.6.1 TSPA-SR

FEP 2.2.10.02.00, Thermal Convection Cell Develops in Saturated Zone

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

4.6.2 TSPA-LA

FEP 2.2.10.02.0A, Thermal Convection Cell Develops in Saturated Zone

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.34).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–A numerical model of the mountain-scale effects of thermal loading on the host rock due to waste emplacement is evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003g, Section 6.5). The numerical model encompasses a domain extending from the ground surface to the water table. The model assessed changes in thermal, chemical, and hydrologic properties as a result of heat-induced stresses on the host rock. At the water table, temperatures peak around 2,000 years and, depending on location within the repository footprint, locally vary between 32°C and 34°C. These elevated temperatures are, at most, only 0 C° to 4 C° above ambient water table temperatures beneath the repository. Temperatures decrease to within 1 C° to 2 C° of ambient levels at about 5,000 years after waste emplacement. Relative to the scale of the saturated zone flow domain, this increase in water table temperatures is local and small relative to the large variability in water table temperatures along the saturated zone flow and transport path, which ranges between 30°C and 34°C. The resulting temperature perturbation will not create a thermally induced convection cell that will alter saturated zone flow paths.

In conclusion, waste emplacement will not produce saturated zone thermal convection cells that will affect saturated zone flow paths; this FEP is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

4.6.3 Resolution of Comment 13

This FEP is now screened as excluded on the basis of low consequence, because no significant change in dose is anticipated as a result of thermal convection effects. The screening argument has been updated in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.3.4). The screening argument has been clarified by presenting results of thermal modeling that show no generation of convection cells.

4.7 COMMENT 18

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 to address the NRC comment.

4.7.1 TSPA-SR

FEP 1.4.07.01.00, Water Management Activities

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a) and *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included (existing water management activities)
- Saturated Zone–Excluded (water management activities) by regulation
- Biosphere–Excluded by regulation.

4.7.2 TSPA-LA

FEP 1.4.07.01.0A, Water Management Activities

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.11) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.9).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Included
- Biosphere–Included.

Summary of Screening Disposition–The living style (hereafter called the lifestyle) and behaviors of the current residents of the Town of Amargosa Valley (hereafter called Amargosa Valley) explicitly include certain aspects of water management activities, such as irrigation and fish farming, and implicitly include 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), which requires that the reference biosphere be consistent with present knowledge of the conditions in the region, and with 10 CFR 63.305(b), which requires that the DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology, future projection of water management activities in Amargosa Valley are assumed to be the same as the current activities.

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

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario biosphere dose conversion factors that are direct inputs to the TSPA nominal scenario, seismic scenario, and igneous intrusion case. Annual doses are calculated as the product of radionuclide concentration in groundwater and biosphere dose conversion factors. There are three sets of biosphere dose conversion factors for the groundwater exposure scenario corresponding to the present-day, monsoon, and glacial-transition climates.

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 (BSC 2004e, Section 6.2.12).

4.7.3 Resolution of Comment 18

This FEP is now screened as included for both the saturated zone and the biosphere, as described in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.11) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.9), respectively. The NRC comment is addressed, and the screening disposition clarified, by specifying the inclusion of this FEP in the biosphere component of the TSPA model.

4.8 COMMENT 19 (PART 5)

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP). ANL-MGR-MD-000011, for FEP 2.2.08.02.00 (Groundwater Chemistry/ Composition in Unsaturated Zone and Saturated Zone).

4.8.1 TSPA-SR

FEP 2.2.08.01.00, Groundwater Chemistry/Composition in Unsaturated Zone and Saturated Zone

This FEP was erroneously listed as 2.2.08.02.00 by Reamer (2001b, Appendix 2). This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Included (effects of ambient condition geochemistry)
- Unsaturated Zone–Excluded because of low consequence (changes in geochemical conditions).

4.8.2 TSPA-LA

FEP 2.2.08.01.0A, Chemical Characteristics of Groundwater in the Saturated Zone

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.25).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated zone–Included.

Summary of Screening Disposition–Variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater affect sorption of radionuclides onto the rock surface and colloids, which, in turn, affects the sorption coefficient, K_d, and, thus, the retardation factor, R_f, for each radionuclide. In *Site-Scale Saturated Zone Transport* (BSC 2003h, Sections 6.2 and 6.5.2.4.1), these coefficients are entered directly in the transport base-case model that describes radionuclide transport via the distribution coefficients and the retardation factors, which describe reactive transport through porous media. The effects of thermal-hydrologic-chemical and dissolved gases within the saturated zone are implicitly included in the variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater. Appropriate ranges and distributions of values for K_ds are chosen based on expert elicitation and laboratory and field studies for the sorption coefficient K_d.

Geochemical analysis indicates that current saturated zone groundwater under the repository and along the saturated zone transport path is the result of recharge under paleoclimate conditions. Spatial variability in the composition of the groundwater reflects, in part, temporal variability in recharge when data from Fortymile Wash are included. Uncorrected ^{14}C groundwater ages range from a few thousand years in the vicinity of the Fortymile Wash to more than 15,000 years under portions of Yucca Mountain. Using the reasonable approach that spatial variability within the recharge domain brackets the temporal variability expected to occur at a given location within the domain, the observed variability in geochemistry among the wells in the model area brackets the temporal variations expected to occur in the water composition.

FEP 2.2.08.01.0B, Chemical Characteristics of Groundwater in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.28).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–Thermal-hydrologic-chemical seepage model simulations feeding the drift-scale coupled processes abstraction were run explicitly using five input water compositions spanning the range of compositions at Yucca Mountain. This variability of pore-water compositions in repository host units implicitly reflects spatial variations in rock mineralogy and infiltration rates. Therefore, the results of the Thermal-hydrologic-chemical seepage model and its abstraction explicitly reflect the natural variability of pore-water compositions and implicitly reflect the natural variability of rock mineralogy.

The effects of groundwater chemical characteristics are included in the radionuclide sorption coefficients under ambient conditions. The sorption coefficient data on which the distributions are based on laboratory experiments in which crushed rock samples from the Yucca Mountain site are contacted with groundwaters (or simulated groundwaters) representative of the site, spiked with one or more of the elements of interest. The chemistry of pore waters and perched waters in the unsaturated zone along potential flow paths to the accessible environment is discussed in *Analysis of Geochemical Data for the Unsaturated Zone* (BSC 2002c). In the unsaturated zone, two water types exist in the ambient system: perched water and pore water. Perched water is generally more dilute than pore water. The well J-13 and UE-25 p#1 waters were used in sorption experiments as end-member compositions intended to bracket the impact of water composition on sorption coefficients. Some spatial trends in water composition for the TSw and CHn hydrogeologic units have been noted. However, the uncertainty in these spatial trends and the uncertainty with respect to the effects of the bounding water compositions on sorption have led to the treatment of natural variability in water composition as uncertainty in the probability distributions sampled by TSPA-LA. Sorption experiments have been carried out as a function of time, element concentration, atmospheric composition, particle size, and temperature.

In some cases, the solids remaining from sorption experiments were contacted with unspiked groundwater in desorption experiments. Experimental data were used to determine the sorption. The sorption and desorption experiments together provide information on the equilibration rates of the forward and backward sorption reactions. For elements that sorb primarily through surface complexation reactions, the experimental data are augmented with the results of modeling calculations using PHREEQC V2.3 (BSC 2001c). The inputs for the modeling calculations include groundwater compositions, surface areas, binding constants for the elements of interest, and thermodynamic data for solution species. These modeling calculations provide a basis for interpolation and extrapolation of the experimentally derived sorption coefficient data set. The effects of nonlinear sorption are approximated by capturing the effective K_d range.

The effects of groundwater composition with respect to sorption coefficients are provided in terms of probability distributions for the sorption coefficient of each element of interest among the three major rock types (devitrified, zeolitic, and vitric) found in the unsaturated zone. The influence of expected variations in water chemistry, radionuclide concentrations, and variations in rock surface properties within one of the major rock types are incorporated into these probability distributions. These distributions are specified for each radionuclide and rock type combination and are sampled in the TSPA-LA to account for the effects of natural variations in pore-water chemistry and mineral surfaces on sorption. Correlations for sampling sorption coefficient probability distributions have been derived for the elements investigated.

4.8.3 Resolution of Comment 19 (Part 5)

This FEP is now classified as included in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.28). The FEP will be added to the next revision of *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a). The NRC comment has been addressed by adding the FEP to *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a). The screening disposition was clarified by describing recent results of groundwater composition analyses and sorption experiments.

4.9 COMMENT 21

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)*. ANL-MGR-MD-000011 to address the NRC comment.

4.9.1 TSPA-SR

FEP 2.3.13.01.00, Biosphere Characteristics

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a, Section 6.2.23).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Biosphere–Included (biosphere characteristics, including plant and animal populations, microbes, current climatic conditions, and climatic conditions as a result of natural climate evolution)
- Biosphere–Excluded (climate change resulting from anthropogenic events) by regulation
- Biosphere–Excluded (forests, grasses, wetlands) because of low probability.

4.9.2 TSPA-LA

FEP 2.3.13.01.0A, Biosphere Characteristics

This FEP was addressed in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a).

Screening Decision–For the license application, the FEP was screened as follows:

- Biosphere–Included.

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

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario biosphere dose conversion factors. For the TSPA scenarios classes (nominal and seismic) and modeling case (igneous intrusion) involving groundwater as a source of radionuclides, annual doses are calculated as the product of radionuclide concentration in groundwater and biosphere dose conversion factors 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. Thus, for this exposure scenario, the biosphere model contribution to the dose assessment (i.e., biosphere dose conversion factors) can be separated from the source (i.e., radionuclide concentration in the groundwater). The biosphere dose conversion factor for a radionuclide is numerically equal to the dose for a unit activity concentration of the radionuclide in the water. To support the assessment of doses in TSPA for the scenario classes and the modeling case involving radionuclide release to the groundwater, three sets of groundwater exposure scenario biosphere dose conversion factors are generated, corresponding to present-day, monsoon, and glacial-transition climate states.

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

4.9.3 Resolution of Comment 21

This FEP is now classified as included and its screening disposition is clarified in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a). The previous screening argument for exclusion based on lack of permanent surface water is no longer applicable.

4.10 COMMENT 32

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 to address the NRC comment.

4.10.1 TSPA-SR

FEP 2.1.13.01.00, Radiolysis

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e), *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f), and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form–Excluded (miscellaneous) because of low consequence
- Waste Package–Excluded (all components of FEP not explicitly excluded based on low probability) because of low consequence
- Waste Package–Excluded (FEP 2.1.13.01.07, radiolysis of cellulose) because of low probability (not credible)
- Engineered Barrier System–Excluded because of low consequence.

4.10.2 TSPA-LA

FEP 2.1.13.01.0A, Radiolysis

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.38), *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.32), and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.77).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form–Excluded because of low consequence
- Waste Package–Excluded because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–Alpha, beta, gamma, and neutron irradiation of water leads to formation of highly reactive excited and ionized species. In pure water, the final products are hydrogen and oxidants. In addition, the oxidants formed may react with dissolved iron (+2), which will decrease the net yield of oxidants. However, the waste container will not fail, and water is not expected to contact the fuel until all of the emitters, except possibly alpha, have become significantly reduced. The effects of beta irradiation are expected to be minimal because (1) almost all beta emitters disappear due to radioactive decay after a few hundred years and (2) beta radiation is stopped in the fuel matrix or clad. Recent calculations have shown that neutron irradiation is negligible and gamma dose has been significantly reduced. Intact cladding will stop alpha particles so alpha radiolysis will not occur during the early periods of highest alpha activity. Additionally, the rate of corrosion effects of used UO_2 fuel due to alpha radiolysis, taking no credit for cladding, can be predicted (based on semiempirical methods) to have low consequence.

Water will not intrude into the waste package (i.e., the waste package will not fail) until gamma and beta emitters have decayed to low concentrations. According to Sunder and Shoesmith (1991), strong gamma and beta fields associated with the used fuel will decrease by a factor greater than 1,000 in the first few hundred years after disposal. Arguments addressing the highly improbable adverse or inconsequential impact of nitric acid and hydrogen peroxide production and other potential products of gamma radiolysis on corrosion are presented in *In-Package Chemistry for Waste Forms* (BSC 2003i, Attachment II) and *In-Package Chemistry Abstraction* (BSC 2003j, Attachment III). In this analysis, the production of nitric acid and hydrogen peroxide was increased by a factor of 10. The effect of in-package chemistry was to change the chemical compositions in the second significant figure; however, this effect is insignificant.

Sunder et al. (1997) describe an experimental strategy for determining fuel dissolution rates as a function of alpha-source strength, and they show how the evolution of corrosion behavior can be predicted as a function of the age of the fuel. The predictions presented indicate that the effects of alpha radiolysis on fuel corrosion (dissolution) will be transitory and will become minor as alpha dose rates decrease.

During the periods of highest alpha activity, it is expected that most of the commercial fuel cladding will remain intact and should substantially reduce alpha dose rates to groundwater. The stopping power of metals is at least 3 orders of magnitude greater than air; thus, clad of thickness of a few microns would stop alpha particles.

Although there is little information available in the literature on the effects of radiation on Alloy 22 (UNS N06022), data are available on the corrosion of Alloy C-4, which is compositionally similar to Alloy 22. Gamma irradiation of Alloy C-4 in aggressive $MgCl_2$ brines showed that below approximately 100 rad/hr, irradiation has no observable influence on the corrosion behavior. In this same environment, it was found that even at dose rates above 1,000 rad/hr, only a minor enhancement of film growth rates on Titanium Grade 7 was observed and passivity was not threatened. Based on these data, it is concluded that, even in aggressive $MgCl_2$ brines, the radiation levels in the repository are not high enough to result in an enhancement of corrosion processes on Alloy 22 or Titanium Grade 7. On this basis, the effects of radiolysis are excluded based on low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

4.10.3 Resolution of Comment 32

As stated in the summary disposition for this FEP, the issue of nitric acid formation from radiolysis has been examined (BSC 2003i, Attachment II; BSC 2003j). The updated screening argument relevant to comment 32 is contained in *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.38).

4.11 COMMENT 41

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 to address the NRC comment.

4.11.1 TSPA-SR

FEP 2.1.02.20.00, Pressurization from Helium Production Causes Cladding Failure

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Clad–Included.

4.11.2 TSPA-LA

FEP 2.1.02.20.0A, Internal Pressurization of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.10).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–Piron and Pelletier (2001, Section 5.3) investigated the pressurization of the fuel rods from helium production (alpha decay). They concluded that fuel (47.5 MWd/kg uranium) would produce 1,171 cm^3 at standard temperature and pressure of helium in a rod after 10,000 years, based on having all of the helium released. The values are adjusted for burnup (36 MWd/kg uranium) and temperature to be consistent with the earlier analysis reported in *Initial Cladding Condition* (CRWMS M&O 2000c, Section 6.3). The resulting values are presented in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.10). Their analysis produced a total rod pressure 30% to 50% higher than the earlier analysis. The peak pressure for the average burnup rod (44.1 MWd/kg uranium) is shown to be 13.3 MPa. The pressure would have to be significantly higher (about 33 MPa to produce the necessary stress intensity for crack propagation) for the cladding to fail from delayed hydride cracking (FEP 2.1.02.22.0A discusses hydride cracking of cladding (BSC 2004a, Section 6.12)). Even when using values provided by Piron and Pelletier (2001), the change in pressure is not significant and no cladding failure from helium production is expected.

Cladding degradation from internal pressurization of the cladding is therefore excluded from TSPA-LA.

4.11.3 Resolution of Comment 41

This FEP has been excluded on the basis of low consequence because no cladding failure from helium production due to alpha decay is anticipated. A more detailed argument describing cladding pressurization from helium production due to alpha decay is included in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.10).

4.12 COMMENT 47

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 to address the NRC comment using data relevant to the proposed repository.

4.12.1 TSPA-SR

FEP 2.1.02.17.00, Localized Corrosion (Crevice Corrosion) of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Cladding–Excluded based on low probability (credibility).

4.12.2 TSPA-LA

FEP 2.1.02.17.0A, Localized (Crevice) Corrosion of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.7).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–Yau and Webster (1987, p. 717) report:

> Of all the corrosion-resistant structural metals, zirconium and tantalum are the most resistant to crevice corrosion. In low-pH chloride solutions or chlorine gas, for example, zirconium is not subject to crevice attack.

Greene et al. (2000) and Brossia et al. (2002) performed pitting and crevice corrosion tests on Zircaloy-4. They covered temperatures from 25°C to 95°C, chloride concentrations from 0.001 to 4.0 mol/L, and pH from 2.1 to 10.7. The solutions also contained the predominant anions in the groundwater. Some of the tests had sufficiently aggressive solutions to cause pitting on exposed surfaces. Other tests had voltages applied to the sample to raise the corrosion potential above the repassivation potential and cause pitting on exposed surfaces. They report that no crevice corrosion is observed under the same environment and electrochemical conditions that promote pitting corrosion on exposed surfaces. In summary, crevice corrosion is not observed under severe conditions that promote pitting on the exposed surfaces.

More detailed information is provided by Yau (1983) showing that zirconium and Zircaloy (98% zirconium 1.5% tin) were resistant to crevice corrosion after 14 days exposed to boiling (107°C), saturated NaCl solution with the pH adjusted to 0 by the addition of HCl.

Clad Degradation-Local Corrosion of Zirconium and Its Alloys Under Repository Conditions (CRWMS M&O 2000d) shows that zirconium is not susceptible to crevice corrosion. The report discusses the crevice corrosion resistance of zirconium in various chemical solutions, summarizes seven crevice corrosion tests, and reports that crevice corrosion was not observed. The U-bend tests discussed in the report are also designed to produce crevice corrosion under the U-bend test washers. In these tests, no crevice corrosion was reported.

In conclusion, cladding degradation from localized (crevice) corrosion is excluded from TSPA-LA. Crevice corrosion of zirconium under repository in-package chemistry conditions is not expected.

4.12.3 Resolution of Comment 47

The FEP screening argument has been clarified by citing additional experimental evidence regarding crevice corrosion in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.7). The issue of corrosion in the presence of fluoride ions will be addressed in the next revision of this FEPs AMR.

4.13 COMMENT 50

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Clad Degradation Features, Events and Processes Analysis/Model Report (ANL-WIS-MD-000008) to address the NRC comment.

4.13.1 TSPA-SR

FEP 2.1.02.13.00, General Corrosion of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low probability (credibility).

4.13.2 TSPA-LA

FEP 2.1.02.13.0A, General Corrosion of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.3).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–The in-package chemistry model predicts that, in most cases, the pH remains above 4.5. These low pHs are caused by sulfur in the carbon steel rack being released and forming sulfuric acid (H_2SO_4). This period of low pH lasts for the time period when the carbon steel is corroding (see *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Figure 6.5-1) for pH profile). Yau and Webster (1987, pp. 709 to 710, Figures 5 and 7 and Table 6) review the corrosion potential for zirconium alloys in sulfuric acid. They note that zirconium alloys resist attack from H_2SO_4 at all concentrations up to 70% and at temperatures to boiling (see *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Figure 6.3-1)). A concentration of 70% H_2SO_4 represents a theoretical pH, well below anything expected in the waste package. In the range that zirconium alloys show corrosion resistance to H_2SO_4, a protective film is formed on the zirconium alloys that is predominantly cubic zirconium oxide (ZrO_2) with only traces of monoclinic phases. At higher concentrations than 70%, zirconium corrodes because loose films form that are zirconium disulfate tetrahydrate and partially zirconium hydrides. In concentrations of less than 65% H_2SO_4, zirconium can tolerate some amounts of strong oxidizing agents, such as 200 ppm Fe^{3+} and 200 ppm NO_3^-. Moreover, in 20% or less H_2SO_4, zirconium can tolerate a great amount of strong oxidizing agents.

Consequently, zirconium equipment is often used in steel pickling. Zirconium alloys are used in the chemical industry under low pH conditions. In the manufacturing of H_2SO_2, zirconium alloys are used to contain up to 65% H_2SO_4 at up to 150°C. In the manufacturing of HNO_3, zirconium alloys are used to contain the acid up to 65% concentrations and temperatures to 204°C. A pH of 1.5 (minimum in waste package with uncertainties) represents only 0.15 wt % of H_2SO_4 and is not expected to cause accelerated corrosion.

The in-package chemistry model predicts that, in most cases, the pH remains above 3.5. Under these nominal chemical conditions (pH is greater than 3.5) in the repository, general corrosion failures of the cladding are unlikely. *Waterside Corrosion of Zirconium Alloys in Nuclear Power Plants* (IAEA 1998) summarizes much of the research on zirconium corrosion. Hillner et al. (1998, p. 9) studied corrosion of Zircaloy and published a Zircaloy corrosion correlation based on Bettis Atomic Power Laboratory experiments. Bettis developed Zircaloy for naval reactors in the early 1950s and has an extensive database on Zircaloy performance, including continuous autoclave corrosion tests on some samples for 30 years. Some samples have developed oxide thickness as great as 110 μm, greater than those expected during repository corrosion. The experiments are consistent with diffusion of oxygen ions through the corrosion film being the rate-limiting phenomenon.

As alternative conceptual models for general corrosion, Hillner et al. (1998, Table 4) provide the expected corrosion for cladding after 10,000 years at 180°C using eight corrosion equations developed by others. These alternative models show that Hillner's equation is conservative and general corrosion is not expected to be significant in the repository.

In conclusion, cladding degradation from general corrosion is excluded from TSPA-LA. The small amount of corrosion that will occur during the regulatory period will not penetrate the cladding and, therefore, will not affect the release of radionuclides. Cladding failure due to general corrosion has a low consequence and is excluded from further consideration. The magnitude and time of the resulting radiological exposures to the RMEI or radionuclide releases to the accessible environment would not be significantly changed by the omission of this FEP (general corrosion of cladding) from the TSPA-LA model.

4.13.3 Resolution of Comment 50

The screening argument for FEP 2.1.02.13.0A in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.3) now provides corroborating evidence regarding the corrosion resistance of zirconium at temperatures below 250°C.

4.14 COMMENT 53

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 to address the NRC comment.

4.14.1 TSPA-SR

FEP 2.1.02.22.00, Hydride Embrittlement of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low probability.

4.14.2 TSPA-LA

FEP 2.1.02.22.0A, Hydride Cracking of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.12).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–The stresses in the cladding are not sufficient to fail the cladding at the repository temperatures, and experimental data indicate that the in-package environment and cladding stresses are not conducive to hydride cracking and embrittlement.

As the waste package internals corrode, hydrogen is generated, although little is expected to be absorbed directly by the fuel cladding because H_2 molecules do not migrate through the high-density ZrO_2 fuel cladding layer (FEP 2.1.12.03.0A (BSC 2004a, Section 6.24)). Available data on zirconium hydriding indicate that corrosion of waste package internals will not result in hydriding of fuel cladding, as long as an oxidizing environment exists in the waste package.

Cladding surface oxidation is minor at repository temperatures and hydrogen absorption will be negligible. Hydride embrittlement from galvanic corrosion of waste package contacting cladding has been excluded based on low consequence. Cladding has a thick, electrically insulating oxide layer that is produced during reactor operation. This film prevents both direct absorption of hydrogen gas in the environment and galvanic coupling to dissimilar metals. If the passive film has been mechanically removed, the unprotected cladding oxidizes within seconds and forms a passive layer if exposed to water or humid air. Therefore, cladding would undergo little hydrogen charging because the oxide layer prevents hydrogen absorption in the metal (FEP 2.1.12.03.0A (BSC 2004a, Section 6.24)).

Cladding failure by delayed hydride cracking is unlikely and has not been included in the abstraction for the TSPA-LA. Stresses and stress intensity factors are too low for crack propagation.

Cladding failure by hydride reorientation is unlikely because the maximum temperatures are too low to dissolve much hydrogen, and most rods have stresses too low for reorientation. The cladding material will maintain sufficient strength, even if hydride reorientation occurs, so that failure would not be expected.

Hydrogen axial migration will be limited at the temperatures expected during emplacement (268°C maximum). Failure of the cladding by hydrogen embrittlement is unlikely. Hydrogen absorption in the cladding from UO_2 fuel corrosion only occurs in fuel with already failed cladding. Such a reaction, if it should occur, has little consequence.

Hydrogen embrittlement results in a generally reduced resistance to fracture. In Zircaloy, hydrogen embrittlement is normally caused by precipitation of zirconium hydride. Since the hydride precipitates are quite brittle, a crack can propagate more readily by preferentially following the hydrides. Resistance to fracture (fracture toughness, K_{IC}) is a measure of resistance to crack propagation through the material. Fracture toughness is typically measured in terms of the critical stress intensity factor; that is, the stress intensity factor value that will cause growth of a crack. The stress intensity factor is proportional to the far-field stress multiplied by the square root of the crack length. Kreyns et al. (1996, Figure 5) show that for both irradiated and unirradiated material, such hydrides could decrease the fracture toughness from 42 to 8 MPa-$m^{0.5}$ as the hydrogen content increases from 0 to 4,000 ppm. The maximum stress intensity (K_I) for the statistical distribution of rods and crack sizes varies from 0.47 to 2.73 MPa-$m^{0.5}$, and, therefore, failure is not expected, even with hydride concentrations of 4,000 ppm. In the limit (100% hydride and no metal), the fracture toughness is about 1 MPa-$m^{0.5}$. The outer surface of the cladding could be fairly brittle (hydrogen content greater than 800 ppm) but much of the cladding thickness has a reasonable toughness.

In conclusion, hydride cracking and embrittlement of the cladding is excluded from the TSPA-LA on the basis of low consequence.

4.14.3 Resolution of Comment 53

An extensive, quantitative screening argument for exclusion of hydride cracking of cladding has been added to *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.12).

4.15 COMMENT 58

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 to address the NRC comment.

4.15.1 TSPA-SR

Various FEPs associated with *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c) were identified as preliminary.

4.15.2 TSPA-LA

Various FEPs associated with *Engineered Barrier System Features, Events, and Processes* (BSC 2004b) have been defined, analyzed, and screened for TSPA-LA.

4.15.3 Resolution of Comment 58

All FEPs that were considered to be preliminary for TSPA-SR have been defined, analyzed, and screened for TSPA-LA. There are no longer any preliminary FEPs associated with *Engineered Barrier System Features, Events, and Processes* (BSC 2004b).

4.16 COMMENT 67

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE has planned work to analyze the effects of thermal-hydrologic-mechanical coupled processes with regard to drainage in the pillars and flow in the vicinity of the drifts, and thermal-hydrological/thermal-hydrological-chemical/thermal-hydrological-mechanical analyses to quantify uncertainties in the thermal seepage model. In addition, THM continuum modeling will address thermal mechanical effects in rocks above and below the repository at a mountain scale in an update to the Coupled Thermal-Hydrologic-Mechanical Effects on Permeability Analysis and Model Report AMR, ANL-NBS-HS-000037. DOE will clarify the screening arguments in the FEPS in *Thermal Hydrology and Coupled Processes,* ANL-NBS-MD-000004 upon completion of this work.

4.16.1 TSPA-SR

FEP 2.2.10.05.00, Thermo-Mechanical Alteration of Rocks Above and Below the Repository

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

4.16.2 TSPA-LA

FEP 2.2.10.05.0A, Thermo-Mechanical Stresses Alter Characteristics of Rocks Above and Below the Repository

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.38) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.12).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The mountain-scale thermal-hydrologic-mechanical model assesses the magnitude and distribution of changes in hydrologic properties and analyzes the impact of such changes on the mountain-scale vertical percolation flux through the repository horizon. The result shows that a maximum thermal-hydrologic-mechanical-induced change in hydrologic properties occurs at around 1,000 years after emplacement, when the average temperature in the mountain is maximal. Near the repository level, thermal-elastic stresses tend to tighten vertical fractures to smaller apertures, leading to reduced permeability and increased capillary. At the ground surface, in a zone extending about 100 m deep, compressive stresses are completely relieved from tension. In this zone, fractures will open elastically, and fracturing or shear-slip along preexisting fractures is possible.

Using a conservative estimate of input thermal-hydrologic-mechanical properties, changes in permeability by elastic closure or opening of preexisting fractures are within a factor of 0.3 to 5, whereas calculated changes in capillary pressure are within a factor of 0.7 to 1.2. In addition, a conservative 3 order-of-magnitude increase in permeability and 1 order-of-magnitude reduction in capillary strength were imposed for the zone of possible fracturing and shear slip near the ground surface. Despite these conservative estimates of potential changes in hydrologic properties, the main conclusion of *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2004i, Sections 6.5.10 to 6.5.14) is that thermal-hydrologic-mechanical-induced changes in the mountain-scale hydrologic properties have no significant impact on the vertical percolation flux through the repository horizon. Again, these results were obtained for conservative estimates of the input thermal-hydrologic-mechanical properties, which are sufficient for bounding the possible impact of the thermal-hydrologic-mechanical processes on permeability and percolation flux on the mountain scale.

The effects of mechanical disturbance of fractures along radionuclide transport pathways are discussed in FEP 2.2.06.02.0B, Seismic Activity Changes Porosity and Permeability of Fractures (BSC 2004f, Section 6.7.7; BSC 2004e, Section 6.2.18). The conclusion is that the effects of changes to fracture aperture or spacing on radionuclide transport are expected to be negligible over a wide range of permeability variation. In this case, the disturbance is caused by thermal-mechanical effects rather than by a seismic event. The conclusions reached in FEP 2.2.06.02.0B are also applicable here because the analyses supporting the conclusions in FEP 2.2.06.02.0B are based on a general sensitivity study of how fracture properties affect radionuclide transport. Furthermore, the general effects of thermal stresses on fracture permeability due to repository heating are evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2004i, Section 6.5.12). This analysis indicates that in the zones near the repository and below the repository, the fracture permeability is either reduced or unaffected. Thus, it is conservative to not include thermal effects on fracture permeability because radionuclide transport is slower with reduced permeability. Therefore, this FEP may be excluded based on low consequence because it has no adverse effects on performance.

4.16.3 Resolution of Comment 67

The screening argument for this FEP is now based on numerical modeling of the effects of thermal loading (BSC 2003g, Section 6.5). Results of the modeling demonstrate quantitatively that thermal-hydrologic-mechanical effects have no significant impact on the vertical percolation flux through the repository horizon; therefore, the FEP can be excluded. Updated screening arguments are provided in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.38) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.12).

4.17 COMMENT J-5

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary ANL-WIS-MD-000012 to address the NRC comment.

4.17.1 TSPA-SR

FEP 2.1.09.21.00, Suspensions of Particles Larger than Colloids

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), *Waste Form Colloid-Associated Concentrations Limits: Abstraction and Summary* (CRWMS M&O 2001b), and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Waste Form Colloid–Excluded because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

4.17.2 TSPA-LA

FEP 2.1.09.21.0A, Transport of Particles Larger than Colloids in Engineered Barrier System

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.54).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–A detailed discussion on the potential role of particles larger than colloids was presented in *Waste Form Colloid-Associated Concentrations Limits: Abstraction and Summary* (CRWMS M&O 2001b, Attachment IX). If particles larger than colloids form during the degradation of waste form and waste package materials, these particles are likely to sorb radionuclides following the same principles as radionuclide sorption onto colloids. In terms of mobility, however, several differences exist between colloids and larger particles, making it unlikely that the larger particles could unfavorably affect performance. First, their large size would require relatively high-energy groundwater flow conditions to entrain (rinse) and transport the particles out of the waste package. Second, their large size makes them more susceptible to filtration.

In summary, the effects of suspensions of particles larger than colloids in the engineered barrier system have been excluded from TSPA-LA on the basis of low consequence. Omission of the effects of suspensions of particles larger than colloids will not significantly change radiological exposures or radionuclide releases because the formation of suspensions in the near field and far field environments are likely to be localized and not widespread. Furthermore, even if these suspensions were to form, it is likely that these large particles would quickly settle by gravity within a small distance, and their transport by moving water would not be extensive.

FEP 2.1.09.21.0B, Transport of Particles Larger than Colloids in the Saturated Zone

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.13).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Transport of particles larger than colloids is screened out on low consequence because (1) no radionuclide-bearing particles larger than colloids are introduced into the saturated zone from the unsaturated zone, (2) large particles will not be suspended for great distances along the flow paths given the variable vertical velocity component that would be encountered along the transport path, and (3) the highly variable size, shape, orientation, and roughness of the transporting fracture voids promote both settling and filtering. Transport of particles larger than colloids is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

FEP 2.1.09.21.0C, Transport of Particles Larger than Colloids in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.3.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Particles larger than colloids are not expected to show much mobility in the unsaturated zone because of the large gravitational settling that occurs relative to diffusive movement for such particles.

Calculation of the diffusive movement and gravitational settling velocity for a colloid (BSC 2004f, Section 6.3.4) shows that, for a colloid of diameter 0.836 µm, gravitational settling and diffusion will be roughly in balance. For particles larger than colloids (greater than 100 µm), gravitational settling will dominate particle movement. Therefore, particles larger than colloids are not mobile.

The effects of perturbed thermal-hydrologic conditions or other perturbed flow conditions (e.g., groundwater rinse) on colloid movement (or movement of particles larger than colloids) are expected to be negligible because of the limited entrainment expected. Tests with fine, cohesive sediments show that although entrainment does occur, for a wide variety of conditions this appears to be a very limited transient response. Entrainment is observed for a few days, and then the system stabilizes with no further initiation of motion, as compared with unretarded colloid transport. The limited time frame for enhanced colloid movement is negligible with respect to the time frames for waste release and transport. Therefore, this FEP may be excluded based on low consequence.

4.17.3 Resolution of Comment J-5

In order to facilitate clarification of screening arguments for the transport of particles larger than colloids in the engineered barrier system, saturated zone, and unsaturated zone, the TSPA-SR FEP 2.1.09.21.00 was divided into three separate FEPs for TSPA-LA: FEP 2.1.09.21.0A (BSC 2004b, Section 6.2.54), FEP 2.1.09.21.00B (BSC 2004e, Section 6.2.13), and FEP 2.1.09.21.00C (BSC 2004f, Section 6.3.4), respectively. *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.13) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.3.4) provide quantitative analyses to demonstrate that gravitational settling will render particles larger than colloids immobile. In the saturated zone, the calculated upward vertical component of velocity is shown to be less than the settling velocity, given measured permeabilities and gradients. *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.54) conservatively assumes that no colloid settling or filtration occurs in the engineered barrier system.

4.18 COMMENT J-16

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 to address the NRC comment.

4.18.1 TSPA-SR

FEP 1.2.07.01.00, Erosion/Denudation

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Biosphere–Included (processes that may result in significant change, such as physical weathering, chemical weathering, and mass wasting)
- Biosphere–Excluded because of low probability (glacial erosion)
- Unsaturated Zone–Excluded because of low consequence.

4.18.2 TSPA-LA

FEP 1.2.07.01.0A, Erosion/Denudation

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.4.1).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Erosion is a process that will be ongoing at Yucca Mountain over the 10,000-year performance period. The maximum erosion due to various processes (e.g., fluvial erosion, eolian erosion, chemical weathering) over a 10,000-year period is expected to be less than 10 cm, which is within the range of existing surface irregularities. DOE indicates that mass wasting, such as landslide, does not play a significant role in the present erosional regime at Yucca Mountain.

The effects of surface construction and characterization activities at the ground surface on future erosion will also be negligible because of the planned reclamation of the site ground surface. As stated in the *Reclamation Implementation Plan* (YMP 2001, Section 5.2.2.1):

> Recontouring and erosion control practices include backfilling spoil material and grading disturbed sites, so that a stable land form is created that blends with the surrounding topography. Following site decommissioning, disturbed areas will be graded such that the natural drainage pattern (predisturbance drainage) is restored. The sites will be stabilized and recontoured to blend into the natural topography of the area.

Therefore, the effects of surface erosion are negligible due to low consequence.

4.18.3 Resolution of Comment J-16

The screening argument for this FEP has been expanded to include the effects of construction and characterization activities, which addresses the NRC comment. The updated screening argument is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.4.1).

4.19 COMMENT J-18

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide clarification of the screening argument in the *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 to address the NRC comment.

4.19.1 TSPA-SR

FEP 1.3.04.00.00, Periglacial Effects

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a, Sections 6.2.3 and 6.3.1) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Biosphere–Excluded because of low probability (not credible)
- Unsaturated Zone–Excluded because of low probability (not credible).

4.19.2 TSPA-LA

FEP 1.3.04.00.0A, Periglacial Effects

This FEP was addressed in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.3) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.3.1).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low probability and low consequence
- Biosphere-Permafrost–Excluded because of low probability and low consequence.

Summary of Screening Argument–This FEP refers to climate conditions that could produce a cold but glacier-free environment. The expected return for such a climate is 200,000 years after present. Therefore, soil erosion and deposition at Yucca Mountain as a result of permafrost is not credible. Freeze and 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, 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 and, therefore, includes the effects of cooler climates. Therefore, this FEP is excluded from TSPA-LA on the basis of low consequence and low probability.

4.19.3 Resolution of Comment J-18

Per the NRC comment, freeze and thaw erosion is recognized in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f). It remains excluded in both cases due to low consequence.

5. TECHNICAL BASES FOR SCREENING ARGUMENTS (RESPONSE TO TSPAI 2.02)

This section addresses KTI Agreement TSPAI 2.02. This agreement is concerned with providing a technical basis for certain FEPs that were contained in AMRs prepared for DOE's TSPA-SR.

Wording of the agreement is as follows.

TSPAI 2.02

> Provide the technical basis for the screening argument, as summarized in Attachment 2. See Comment # 3, 4, 11, 12, 19 (Parts 1, 2, and 6), 25, 26, 29, 34, 35, 36, 37, 38, 39, 42, 43, 44, 48, 49, 51, 54, 55, 56, 57, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 78, 79, J-1, J-2, J-3, J-4, J-7, J-8, J-9, J-10, J-11, J-12, J-13, J-14, J-15, J-17, J-20, J-21, J-22, J-23, J-24, J-25, J-26, and J-27. DOE will provide the technical basis for the screening argument, as summarized in Attachment 2, for the highlighted FEPs. The technical basis will be provided in the referenced FEPs AMR and will be provided to the NRC in FY03.

For each of the NRC comments listed in the agreement, DOE and NRC agreed upon a path forward to use in addressing the comments. Responses to individual NRC comments follow.

5.1 COMMENT 3

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing DOE/NRC agreement (USFIC Subissue 5 Agreement 13). The Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 will be updated as necessary to reflect the results of this existing agreement.

5.1.1 TSPA-SR

FEP 2.2.10.03.00, Natural Geothermal Effects Saturated Zone–Geothermal Effects

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Included.

5.1.2 TSPA-LA

FEP 2.2.10.03.0A, Natural Geothermal Effects on Flow in the Saturated Zone

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.35).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Included.

Summary of Screening Disposition–Natural geothermal effects, as they influence fluid properties, are implicitly included in the saturated zone site-scale flow model. Groundwater flow is simulated in *Site-Scale Saturated Zone Flow Model* (BSC 2003k, Section 6.2) using a conservation of fluid–rock energy equation in the numerical code FEHM V 2.20 (LANL 2003). The fluid–rock energy equation is, in part, a function of permeability, density, viscosity, and temperature. For temperatures that range between 20°C and 100°C, the density of water changes by only a few percent. In contrast, the variation in water viscosity changes by a factor of 3.3 over the same temperature range. Consequently, natural geothermal effects on groundwater flow are more effectively captured by spatially varying viscosity rather than density. *Site-Scale Saturated Zone Flow Model* (BSC 2003k, Section 6.5.3.7) assigns a specified temperature to each node, which varies with depth and is based on variable temperature measurements reported by Sass et al. (1988). Permeability and viscosity are also assigned to each node. Temperatures are used to calculate nodal viscosities. Using the spatially varying viscosity, a fluid property, allows the calibration of hydraulic conductivity, a lumped fluid–rock property parameter.

Estimated hydraulic conductivity at each node is calibrated to hydraulic head measurements, while nodal viscosities and temperatures remain fixed. Hydraulic heads are, in part, manifestations of multiple processes within the system, including geothermal effects. By calibrating hydraulic conductivity to hydraulic heads and keeping spatially varying temperature and viscosity fixed, geothermal effects on flow are implicitly captured.

FEP 2.2.10.03.0B, Natural Geothermal Effects on Flow in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.37).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–Natural geothermal effects are included in the models of thermal-hydrologic processes used to describe the effects of waste heat in the repository. This gradient is primarily determined by the ground surface temperature, the water table temperature, water flux through the unsaturated zone, and the thermal conductivity from layer to layer.

The natural geothermal gradient at Yucca Mountain is explicitly included in starting conditions of the thermal-hydrologic-chemical seepage model by setting the ground surface temperature (top model boundary) and the temperature at the water table (bottom boundary) to measured values. The effect of this temperature gradient on flow is explicitly accounted for by the coupled heat–flow transport algorithms implemented into the thermal-hydrologic-chemical simulator.

Natural geothermal effects on unsaturated flow in the absence of repository thermal effects have been investigated in the models of natural thermal processes in the unsaturated zone. The natural temperature gradient is determined by the ground surface temperature, the water table temperature, and the thermal conductivity from layer to layer. The results of these models have found that the effects of the natural temperature gradient on unsaturated zone flow are insignificant.

5.1.3 Resolution of Comment 3

Per the NRC comment, KTI Agreement Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) 5.13 was completed, providing evidence from fluid inclusions regarding temperature gradients. The technical basis for this FEP has been updated in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f). This comment is addressed separately in the response to KTI Agreement Evolution of Near-Field Environment (ENFE) 2.03 (Appendix H of *Technical Basis Document No. 2: Unsaturated Zone Flow*). A revision of *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e) will include updated fluid inclusion information.

5.2 COMMENT 4

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing DOE/NRC agreements (RT Subissue 1 Agreement 5 and Subissue 2 Agreement 10). The Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 will be updated as necessary to reflect the results of these existing agreements.

5.2.1 TSPA-SR

FEP 1.2.06.00.00,Hydrothermal Activity

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, this FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded (hydrothermal activity caused by basaltic magmatism) because of low consequence
- Unsaturated Zone–Excluded (hydrothermal activity caused by silicic magmatism because of low probability).

5.2.2 TSPA-LA

FEP 1.2.06.00.0A, Hydrothermal Activity

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.7.2) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.5).

Screening Decision–For the license application, this FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Based on the geologic history and setting, the recurrence of silicic volcanism is not further considered and concern is focused on basaltic intrusion. Although basaltic magmatism could occur during the regulatory period, the effects of any related hydrothermal system would be of limited scale (FEP 1.2.04.02.0A (BSC 2004d, Section 6.2.2.2)). Due to the limited scale of effects from basaltic dikes, the potential effects of hydrothermal alteration are excluded based on low consequence.

Future igneous activity within the Crater Flat basin will typically cause minimal, highly localized basaltic dike-like intrusions with average widths on the order of 1 m. This is supported by investigations at the Grants Ridge analog sites, which indicate that basaltic intrusion produced only localized formation of volcanic glass within the contact zone. Investigations of basaltic intrusions at Paiute Ridge indicate that igneous activities altered rock properties to only a few tens of centimeters to, at most, 1 m perpendicular to an intruding dike. Associated hydrothermal activity is conditioned to these localized igneous events. It is inferred, given the lack of evidence of any past hydrothermal activity along the Crater Flat basin (BSC 2004j, Figure 3), coupled with the relatively small widths of igneous intrusions that would intersect the saturated zone flow domain, that any associated hydrothermal activity produced from future igneous activity will be minimal (localized) and of low consequence to the long term and regional saturated zone flow paths. In summary, hydrothermal activity is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

5.2.3 Resolution of Comment 4

Per the NRC comment, KTI Agreements Radionuclide Transport (RT) 1.05 and 2.10 were submitted in *Technical Basis Document No. 11: Saturated Zone Flow and Transport*, and the technical basis for this FEP will be updated in a revision to *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e).

This comment is also addressed separately in the response to KTI Agreement ENFE 2.03 (Appendix H of *Technical Basis Document No. 2: Unsaturated Zone Flow*).

5.3 COMMENT 11

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing DOE/NRC agreements (RT Subissue 2 Agreement 8 and USFIC Subissue 5 Agreement 4). The Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 will be updated as necessary to reflect the results of these existing agreements and clarify the screening argument.

5.3.1 TSPA-SR

FEP 1.3.07.01.00, Drought/Water Table Decline

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, this FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

5.3.2 TSPA-LA

FEP 1.3.07.01.0A, Water Table Decline

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.2.9) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.3.3).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The primary process affecting water table elevations is the cyclical and climatically driven infiltration through the unsaturated zone to the saturated zone. Present groundwater elevations in the Basin and Range Province (which includes the Yucca Mountain region) are reflective of current arid climatic conditions and the time-dependent decrease in infiltration (i.e., lower recharge) of the interglacial climatic interval. The interglacial climatic interval is predicted to persist for the next 400 to 600 years. After the interglacial climatic interval, warmer and wetter monsoonal climatic conditions are predicted to persist for approximately 900 to 1,400 years. It is predicted that a cooler and wetter glacial transition climatic condition will follow the brief monsoonal period and will persist for about 8,500 years.

Paleoclimate records indicate arid climatic conditions are short relative to wetter conditions. Forester et al.'s (1996, p. 52) investigations of proxy climate records indicate climatic conditions during the past 2 million years were much wetter than current climatic conditions for about 70% to 80% of the time. The analysis by Szabo et al. (1994, Figure 6) of Searles Lake deposits indicates that extreme arid conditions have only occurred twice during the past 600,000 years: once around 290,000 years ago and once between 10,000 years ago to the present. It can be inferred that the water table is now at a low point in the 150,000- to 300,000-year climate cycle and will not significantly drop below current groundwater elevations during the 10,000-year regulatory period. Therefore, water table decline is excluded based on low consequence because it has no adverse effects on performance.

5.3.3 Resolution of Comment 11

Per the NRC comment, KTI Agreements RT 2.08 and USFIC 5.04 were submitted in *Technical Basis Document No. 11: Saturated Zone Flow and Transport*, and the technical basis for this FEP will be updated in a revision to *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e).

5.4 COMMENT 12

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreement (USFIC Subissue 5 Agreement 13). The Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 will be updated to clarify the screening argument and to reflect the results of this existing agreement.

5.4.1 TSPA-SR

FEP 2.2.10.13.00, Density-Driven Groundwater Flow (Thermal) Saturated Zone–Repository Induced Thermal Effects

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d) and *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included
- Saturated Zone–Included (geothermal)
- Repository–Excluded because of low consequence.

5.4.2 TSPA-LA

FEP 2.2.10.13.0A, Repository-Induced Thermal Effects on Flow in the Saturated Zone

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.40).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Numerical modeling of the mountain-scale effects of thermal loading on the host rock due to waste emplacement is evaluated in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2003g, Section 6.5). Just above the water table, temperatures peak around 2,000 years and, depending on location within the repository footprint, locally vary between 32°C and 34°C. These elevated temperatures are, at most, only 0°C to 4°C above ambient water table temperatures beneath the repository. The model indicates that elevated temperatures decrease to within 1°C to 2°C of ambient levels at approximately 5,000 years after waste emplacement. Ambient saturated zone water temperatures at the water table along the transport path range between 30°C and 34°C. Relative to the scale of the saturated zone flow domain, this increase in water table temperatures is local and small relative to the large variability in water table temperatures along the saturated zone flow and transport path.

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

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

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

5.4.3 Resolution of Comment 12

Per the NRC comment, KTI Agreement USFIC 5.13 was submitted and is complete. The technical basis for this FEP has been updated in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e), and a revision will include results of fluid inclusion investigations.

This comment is also addressed separately in the response to KTI Agreement ENFE 2.03 (Appendix H of *Technical Basis Document No. 2: Unsaturated Zone Flow*).

5.5 COMMENT 19 (PART 1)

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE will provide a technical basis in the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)*. ANL-MGR-MD-000011 to address the NRC comment for FEP 2.3.11.04.00 (Groundwater Discharge to Surface), FEP 1.3.07.02.00 (Water Table Rise), and FEP 2.2.08.11.00 (Distribution and Release of Nuclides from the Geosphere).

5.5.1 TSPA-SR

FEP 1.3.07.02.00, Water Table Rise

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Included.

5.5.2 TSPA-LA

FEP 1.3.07.02.0A, Water Table Rise Affects Saturated Zone

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.10).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Included.

Summary of Screening Disposition–The TSPA-LA implicitly models a higher water table in the saturated zone to reflect wetter climatic conditions (resulting in an increase in time-dependent infiltration) with the use of flux multipliers. Flux multipliers are incorporated in the convolution integral method. Flux multipliers scale the base-case saturated zone radionuclide breakthrough curves, effectively modeling the impacts a higher water table would have on transport times to the 18-km boundary. Three flux multipliers are used to characterize changes in water table elevations reflective of three climatic conditions. Current climatic conditions are represented by a flux multiplier of 1.0; for a monsoonal climate, the multiplier is 2.7; and for a glacial-transition climate, the multiplier is 3.9. An upper bound estimate of saturated zone transport times to the 18-km boundary, reflective of a higher water table produced during a glacial-transition climatic condition, is conservatively bounded with the use of the 3.9 flux multiplier.

FEP 1.3.07.02.0B, Water Table Rise Affects Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–The potential for water table rise caused by climate change is included in TSPA-LA calculations using a water table rise model based on paleoclimate data. The paleoclimate data indicate that the historical water table has never risen to the level of the repository. Water table changes are implemented in the TSPA-LA by allowing the water table to change elevation instantaneously upon change in climate, concurrent with changes in infiltration (implemented by the postprocessor software WTRISE (LBNL 2003) for radionuclide transport), thus affecting the unsaturated flow and pathways in the unsaturated zone. WTRISE allows the user to specify a water table location and removes all the particles in the gridblocks below the specified water table instantaneously by setting full saturation to the submerged gridblocks (BSC 2004k, Section 6.6.3). The particles removed from the unsaturated zone gridblocks enter the saturated zone transport model. WTRISE is implemented in the TSPA-LA model. The water table for future climates is specified in *Particle Tracking Model and Abstraction of Transport Processes* (BSC 2004l, Section 6.4.9). Future climate flow fields have been generated using WTRISE for three monsoon and three glacial-transition climate flow fields (DTN: LB0312TSPA06FF.001).

5.5.3 Resolution of Comment 19 (Part 1)

This FEP has been split into FEPs 1.3.07.02.0A (saturated zone) and 1.3.07.02.0B (unsaturated zone). Per the NRC comment, this FEP will also be added to the next revision of *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a), with a technical basis for its argument.

5.6 COMMENT 19 (PART 2)

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE will provide a technical basis in Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP). ANL-MGR-MD-000011 to address the NRC comment for FEP 2.3.11.04.00 (Groundwater Discharge to Surface), FEP 1.3.07.02.00 (Water Table Rise), and FEP 2.2.08.11.00 (Distribution and Release of Nuclides from the Geosphere).

5.6.1 TSPA-SR

FEP 2.3.11.04.00, Groundwater Discharge to Surface

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

5.6.2 TSPA-LA

FEP 2.3.11.04.0A, Groundwater Discharge to Surface Outside the Reference Biosphere

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.43) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.22).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded by regulation
- Biosphere–Excluded by regulation.

Summary of Screening Argument–Reference biosphere is defined as the description of the environment inhabited by the RMEI (10 CFR 63.2). 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 of 10 CFR 63.113(b). The rule also specifies criteria that pertain to the characteristics of a reference biosphere that are required to show compliance with the postclosure standards for disposal (66 FR 55733). Similarly, the preamble to the rule states that 10 CFR 63.305 specifies characteristics of the reference biosphere to be used by DOE in its performance assessment to demonstrate compliance with the requirements specified by 10 CFR 63.113(b) and (d) (66 FR 55732, p. 55784). Since the demonstration of compliance specifies conditions of the reference biosphere, the FEPs related to any processes occurring outside the reference biosphere are implicitly excluded. Therefore, groundwater discharge to the surface outside the reference biosphere is excluded on the basis of inconsistency with the requirements of 10 CFR 63.113(b).

5.6.3 Resolution of Comment 19 (Part 2)

Per the NRC comment, this FEP was added to *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a), with a technical basis for its screening argument.

5.7 COMMENT 19 (PART 6)

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE will provide a technical basis in the Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP). ANL-MGR-MD-000011 to address the NRC comment for FEP 2.3.11.04.00 (Groundwater Discharge to Surface), FEP 1.3.07.02.00 (Water Table Rise), and FEP 2.2.08.11.00 (Distribution and Release of Nuclides from the Geosphere).

5.7.1 TSPA-SR

FEP 2.2.08.11.00, Distribution and Release of Nuclides from the Geosphere

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included.

5.7.2 TSPA-LA

FEP 2.2.08.11.0A, Groundwater Discharge to Surface within the Reference Biosphere

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.32) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.14).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Included
- Biosphere–Included.

Summary of Screening Disposition–The groundwater system in the vicinity of the hypothetical community's well system is modeled so that all the contaminants discharged at the 18-km boundary are intercepted by the community's wells. Direct discharge of groundwater to the surface via springs and unsaturated soils is bounded by the simplifying assumption of complete capture of the contaminant plume in the wells.

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

5.7.3 Resolution of Comment 19 (Part 6)

Per the NRC comment, this FEP was added to *Evaluation of Features, Events and Processes for the Biosphere Model* (BSC 2003a, Section 6.2.14), with a technical basis for its screening argument.

5.8 COMMENT 25

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP).* ANL-MGR-MD-000011.

5.8.1 TSPA-SR

FEP 2.4.07.00.00, Dwellings

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Biosphere–Included (household activities)
- Biosphere–Excluded (type of dwelling, use of local materials for construction and as a source of fuel) because of low probability
- Biosphere–Excluded (household cooling) because of low consequence
- Biosphere–Excluded (variation in location) by regulation.

5.8.2 TSPA-LA

FEP 2.4.07.00.0A, Dwellings

This FEP was addressed in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.28).

Screening Decision–For the license application, the FEP was screened as follows:

- Biosphere–Included.

Summary of Screening Disposition–The choice of dwellings is one of the attributes of a lifestyle (FEP 2.4.04.01.0A (BSC 2003a, Section 6.2.27)). Characteristics of dwellings that are included in TSPA are representative of the residents of Amargosa Valley, consistent with 10 CFR 63.312(b), which states that the lifestyle of the RMEI must be based on the people who reside in the Amargosa Valley. The location of dwellings that are included in the TSPA-LA model is consistent with the location of the RMEI, above the highest concentration of radionuclides in the plume of contamination, consistent with 10 CFR 63.312(a).

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, Table 2.4.2) indicate that the predominant housing type is a trailer or mobile home and that most residences have evaporative coolers. This information was used in selecting values for several pertinent parameters. This FEP is addressed in the air, inhalation, and external exposure submodels by including characteristics of the dwellings in the Amargosa Valley and their effects on the inhalation and external exposure pathways.

5.8.3 Resolution of Comment 25

This FEP no longer has secondary entries. Household cooling is contained in FEP 2.4.07.00.0A, which has been screened as included in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a).

5.9 COMMENT 26

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP).* ANL-MGR-MD-000011.

5.9.1 TSPA-SR

FEP 3.3.08.00.00, Radon and Radon Daughter Exposure

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Biosphere–Excluded because of low probability (not credible).

5.9.2 TSPA-LA

FEP 3.3.08.00.0A, Radon and Radon Daughter Exposure

This FEP was addressed in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.48).

Screening Decision–For the license application, the FEP was screened as follows:

- Biosphere–Included.

Summary of Screening Disposition–Radon (^{222}Rn) is a decay product of one of the primary radionuclides considered in TSPA. Human exposure to radon and radon decay products occurs through inhalation.

Exposure to radon (^{222}Rn) and radon decay products is included in the air and inhalation submodels of the groundwater and volcanic ash exposure scenarios. Concentrations of radon and radon decay products are calculated in the air submodels for the groundwater exposure scenario and volcanic ash exposure scenario. The consequences of inhalation of radon and the decay products are included in the inhalation submodels for the groundwater exposure scenario and the volcanic ash exposure scenario. The parameters supporting this FEP include radon release factor, interior wall height, house ventilation rate, fraction of ^{222}Rn from soil entering the house, ratio of ^{222}Rn concentration in air to flux density from soil, equilibrium factor for ^{222}Rn decay products, fraction of radionuclide transfer from water to air for evaporative coolers, and dose conversion factor for radon decay products.

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

5.9.3 Resolution of Comment 26

This FEP is now screened as included in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a), and the technical basis for its disposition is provided. Exposure to radon and radon decay products is now included in the air and inhalation submodels of the biosphere model.

5.10 COMMENT 29

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing agreement (CLST subissue 6 Agreement 1). DOE agreed to provide clarification of the screening argument in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002, as necessary upon completion of the agreement item.

5.10.1 TSPA-SR

FEP 2.1.06.07.00, Effects at Material Interfaces

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f) and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Package–Included (chemical effects)
- Waste Package–Excluded (hydride cracking; physical effects) because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

5.10.2 TSPA-LA

FEP 2.1.06.07.0A, Chemical Effects at Engineered Barrier System Component Interfaces

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.24).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–The basic chemical processes that occur at phase boundaries (principally liquid–solid) are included in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m). Solid–solid contact either does occur or could occur between the drip shield and the invert; between the waste package and the invert; between the pallet and the waste package and (or) drip shield; and between the waste form and any of the other engineered barrier system component materials. Since these materials are all relatively inert, no solid–solid interaction mechanisms have been identified that are significant relative to the basic seepage water induced corrosion of the engineered barrier system components.

FEP 2.1.06.07.0B, Mechanical Effects at Engineered Barrier System Component Interfaces

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.25) and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.22).

FEP Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Excluded because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–The waste package and the drip shield, as designed and emplaced, come in contact with very few other engineered barrier system components. For example, the waste package is designed to rest on a pallet, which is constructed of Alloy 22 and is designed to keep the waste package from contacting other dissimilar metals. The pallet is also designed to keep the waste package supported in a horizontal position and away from the invert and ground support under nonseismic scenarios. Similarly, the drip shields are designed to contact no other material except the Alloy 22 feet, which are attached to the bottom of the drip shields. These feet are in contact with the invert, which is covered by crushed tuff as ballast.

There is some potential for the drip shield to contact the waste package due to mechanical damage caused by rockfall. This is, however, excluded as discussed in FEP 2.1.03.07.0B, Mechanical Impact on Drip Shield (BSC 2004c, Section 6.2.14.1).

Mechanical loading at the waste package (degraded) pallet interfaces has been analyzed. The contact stresses are shown to be much less (maximum stress intensity approximately 150 MPa) than the stress threshold for initiation of stress corrosion cracking (approximately 286 MPa). On this basis, no enhanced degradation due to mechanical loading at the waste package–pallet interfaces is expected. Waste package and drip shield corrosion degradation analyses include the effects of material interfaces in the repository on thermal-hydrologic-geochemical analyses (e.g., FEP 2.1.09.09.0A (BSC 2004a, Section 6.20)). These include the effects of materials present in the emplacement drift, including waste package, drip shield, and backfill (if used), which are described in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003l) and *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003m). This treatment of mechanical effects at engineered barrier system component interfaces applies to both commercial spent nuclear fuel and codisposed waste packages.

This FEP is excluded based on low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

5.10.3 Resolution of Comment 29

This FEP has been divided into two FEPs: 2.1.06.07.0A in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.24), and 2.1.06.07.0B in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.25) and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.22.1). KTI Agreement CLST 6.01 was submitted to NRC in June 2004 (Appendix P of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*), and an updated screening argument will be contained in a revision to *Engineered Barrier System Features, Events, and Processes* (BSC 2004b).

5.11 COMMENT 34

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is covered by an existing DOE/NRC agreement (CLST Subissue 2 Agreement 8). DOE will update the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 screening argument upon completion of the agreement.

5.11.1 TSPA-SR

FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Package–Included (waste container)
- Waste Package–Excluded (drip shield) because of low consequence

5.11.2 TSPA-LA

FEP 2.1.03.02.0A, Stress Corrosion Cracking of Waste Packages

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Included.

Summary of Screening Disposition–Stress corrosion cracking of the waste package outer barrier closure weld regions is included in TSPA as part of waste package degradation analyses. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2003n, Section 8) provides input to the TSPA for waste package degradation.

As discussed in *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2003n, Section 6), the slip dissolution–film rupture model was used to assess the failure (or lack of it) of the waste package due to the stress corrosion cracking crack propagation for given manufacturing cracks and (or) cracks initiated by the combined effects of stress and environment. The threshold stress intensity factor is based on the theory that there exists a threshold value for the stress intensity factor at the crack tip below which a preexisting crack or flaw does not grow. The stress intensity factor provides a criterion for determining if a stress corrosion cracking crack will reach an arrest state or enter the propagation phase.

The application of the stress corrosion cracking models to the waste package and drip shield also requires input of weld residual stress profiles and stress intensity factor profiles along with uncertainty and variability.

Because, among other exposure condition parameters, tensile stress is required to initiate stress corrosion cracking, and the waste package closure welds are the only places under such tensile stresses, only the waste package closure welds are considered subject to stress corrosion cracking. Welds are the most susceptible to stress corrosion cracking because (1) welding can produce high tensile residual stress in the weld; (2) preexisting flaws due to fabrication and welding have much higher concentration in the weld than in the base metal; and (3) welding could result in segregation and nonequilibrium brittle phases, which could enhance material susceptibility to stress corrosion cracking. Stress corrosion cracking of the fabrication welds of the waste package outer barrier will not occur due to the resistance of Alloy 22 to stress corrosion cracking when under tensile stress and because the fabrication welds will be fully annealed before waste is loaded into the waste containers. Plastic deformation resulting from seismic events also has the potential of leading to plastic upsets and resultant sustained residual stresses that may initiate cracks and drive them through the wall. Seismic effects are discussed in FEPs 1.2.03.02.0A, Seismic Ground Motion Damages Engineered Barrier System Components (BSC 2004b, Section 6.2.8); 1.2.03.02.0B, Seismic Induced Rockfall Damages Engineered Barrier System Components (BSC 2004b, Section 6.2.9); and 1.2.03.02.0C, Seismic Induced Drift Collapse Damages Engineered Barrier System Components (BSC 2004b, Section 6.2.85).

FEP 2.1.03.02.0B, Stress Corrosion Cracking of Drip Shields

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package/Drip Shield–Excluded because of low consequence.

Summary of Screening Disposition–For the drip shields, all the fabrication welds will be fully stress-relief annealed before placement in the drifts. Therefore, drip shields are not subject to stress corrosion cracking upon emplacement. However, the drip shields are subject to stress corrosion cracking under the action of seismic-induced loading and rockfalls. Seismic effects on drip shield degradation are discussed in FEP 2.1.07.01.0A, Rockfall (BSC 2004b, Section 6.2.26), and FEP 1.2.03.02.0A, Seismic Ground Motion Damages Engineered Barrier System Components (BSC 2004b, Section 6.2.8). In the nominal case (in the absence of seismic-induced loading and rockfalls), even if stress corrosion cracking of the drip shield were to occur, cracks in passive alloys, such as Titanium Grade 7, tend to be tight (i.e., small crack opening displacement). The opposing sides of through-wall cracks will continue to corrode at very low passive corrosion rates until the gap region of the tight crack opening is plugged by corrosion products and precipitates, such as carbonate minerals. As discussed in *Stress Corrosion*

Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material (BSC 2003n, Section 6.3.7), stress corrosion cracks are sealed in a few hundred years at most when water is allowed to flow through the cracks at the expected low flow rate. When the cracks are bridged by water, the sealing process may take thousands of years, but no flow occurs since the water is held by capillary forces. Following plugging of the crack, any solution flow through the crack would be dominated by an efficiency factor determined by the ratio of solution runoff on the drip shield surface compared to through-crack flow, which, in turn, is determined by scale porosity and permeability. Because of the expected high density of the calcite deposits and lack of pressure gradient to drive water through the crack, the probability of solution flow through the crack would approach zero. Thus, the effective water flow rate through cracks in the drip shield will be extremely low and will not contribute significantly to the overall radionuclide release rate from the repository.

Therefore, since the primary role of the drip shield is to keep water from contacting the waste package, stress corrosion cracking of the drip shield does not compromise its intended design purpose. Based on the above rationale, this FEP is excluded for the drip shield due to low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

5.11.3 Resolution of Comment 34

This FEP has been divided into two FEPs, 2.1.03.02.0A (BSC 2004c, Section 6.2.4), which is screened as included, and 2.1.03.02.0B (BSC 2004c, Section 6.2.5), which is screened as excluded. The technical basis for exclusion of 2.1.03.02.0B is contained in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.5). This issue was also addressed in KTI Agreement CLST 2.08, which was submitted to NRC in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*.

5.12 COMMENT 35

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> Manufacturing defects associated with the drip shield will be addressed during the resolution of an existing agreement item for the waste package (CLST Subissue 2, Agreement 7). The FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 will be updated to reflect the results of this agreement.
>
> Mechanical integrity of the drip shield will be addressed during the resolution of an existing agreement item for the waste package (CLST Subissue 2, Agreement 6). The FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 will be updated to reflect the results of this agreement.
>
> Rockfall effects on the drip shield will be addressed during the resolution of an existing agreement item for the waste package (CLST Subissue 2, Agreement 8). The FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 will be updated to reflect the results of this agreement.
>
> The FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 will be revised to address damage from improper quality control and emplacement of the drip shield. The criteria for damage to waste package during emplacement will be addressed by administrative procedures for emplacement operations that will be developed prior to operation of the facility.

5.12.1 TSPA-SR

FEP 2.1.03.08.00, Juvenile and Early Failure of Waste Containers and Drip Shields

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Package–Included (manufacturing and welding defects in waste container degradation analysis)
- Waste Package–Excluded because of low consequence (manufacturing defects in drip shield degradation analysis); early failure of waste container and drip shield from improper quality control during the emplacement.

5.12.2 TSPA-LA

FEP 2.1.03.08.0A, Early Failure of Waste Packages

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.15).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Included.

Summary of Screening Disposition–*Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2003o) evaluates several mechanisms for early failure of the waste package. Of these mechanisms, weld flaws, improper heat treatment, improper laser peening, and improper handling of waste packages were determined to be necessary for inclusion in TSPA models.

As discussed in FEP2.1.03.02.0A, Stress Corrosion Cracking of Waste Packages (BSC 2004c, Section 6.2.4), manufacturing defects (weld flaws) on waste packages act as sites for initiation of stress corrosion cracking. Manufacturing defects are included in TSPA analysis through the stress corrosion cracking analysis of waste packages.

Early failure (due to improper heat treatment, improper laser peening, and improper handling of waste packages) is included in the waste package performance analysis. Improper heat treatment results primarily from improper stress relief annealing and the consequence of improper heat treatment is assumed to be immediate failure upon initiation of degradation processes. The consequence of improper laser peening is the introduction of unacceptable amounts of cold-work in the material and increased susceptibility to stress corrosion cracking. Improper handling of the waste packages may lead to gouges in the waste package outer surface and provide sites for stress corrosion cracks. Early failure (due to improper heat treatment, improper laser peening, and improper handling of waste packages) is included in TSPA analysis.

5.12.3 Resolution of Comment 35

KTI Agreements CLST 2.06 and 2.07 are complete. This issue was also addressed in agreement CLST 2.08, which was submitted to NRC in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*. An updated technical basis for the screening argument will be provided in a revision to *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c).

5.13 COMMENT 36

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002, to address the NRC comment.

5.13.1 TSPA-SR

FEP 2.1.09.03.00, Volume Increase of Corrosion Products

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b) and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Cladding–Included (clad unzipping due to wet oxidation of commercial spent nuclear fuel)
- Waste Form Cladding–Excluded (clad unzipping due to dry oxidation of commercial spent nuclear fuel) based on low probability
- Waste Package–Excluded because of low consequence.

5.13.2 TSPA-LA

FEP 2.1.09.03.0A, Volume Increase of Corrosion Products Impacts Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.19).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Included.

Summary of Screening Disposition–The volume increase of corrosion products causes cladding axial splitting, or unzipping, and is included in the TSPA cladding degradation abstraction. This FEP applies to failed cladding where water or moist air can interact with the fuel or cladding interior. The volume increase of corrosion products inside the cladding causes stress on the cladding and the cladding to tear open. This tearing is modeled to be instantaneous. All failed rods contain fuel pellet fragments for the full length of the fuel rod that are available for dissolution. Failed fuel rod unzipping (cladding axially splits down its length) is caused by the volume increase of corrosion products (fuel or cladding). It is based on experimental observations of two rods at Argonne National Laboratory where both rods unzipped in less than

2 years. Unzipping leaves the fuel pellets exposed to the waste package internal environment. The scientific analysis that describes the disposition in greater detail is presented in *Clad Degradation – Summary and Abstraction for LA* (BSC 2003p, Section 6.2.4).

Unzipping by dry oxidation (oxidation of UO_2 to U_3O_8) of the fuel requires low humidity and high temperature conditions. It is expected to occur in the repository if the waste package fails at closure and the fuel is exposed to the temperature transients described in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.19). If dry oxidation should occur, it also would cause rapid unzipping and is well modeled with the instant unzipping model used in TSPA-LA.

The effects of basket component degradation on external cladding integrity have been evaluated in FEP 2.1.02.24.0A, Mechanical Impact on the Cladding (BSC 2004a, Section 6.14).

FEP 2.1.09.03.0B, Volume Increase of Corrosion Products Impacts Waste Package

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.26).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Excluded because of low consequence.

Summary of Screening Argument–Analyses cited in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003l, Section 6.4.2) indicate that for chromia (Cr_2O_3) scale-forming alloys (e.g., Alloy 22 and Stainless Steel Type 316), even under very conservative assumptions, the growth of corrosion product will not exceed 93 μm after 10,000 years. This oxide layer is not thick enough to produce enough pressure to cause mechanical damage to the Alloy 22 waste package. In the current design of waste package and engineered barrier system in the emplacement drift, there is no possibility of forming such a tightly confined space so that the swelling corrosion products could cause mechanical damage to the Alloy 22 outer barrier. Therefore, waste package damage from swelling corrosion products is excluded based on low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

FEP 2.1.09.03.0C, Volume Increase of Corrosion Products Impacts Other Engineered Barrier System Components

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.45).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–This FEP represents one particular mechanism for inducing mechanical failure of the invert. Mechanical degradation of the invert is addressed in

FEP 2.1.06.05.0B, Mechanical Degradation of Invert (BSC 2004b, Section 6.2.20) and summarized below.

The carbon steel components in the invert are predicted to corrode very rapidly, within a few hundred years (BSC 2004m, Section 6.4.2.2). Thus, they are not credited for providing any structural support for the emplacement pallet.

Based on the above discussion, mechanical degradation of the invert has been screened out in FEP 2.1.06.05.0B, Mechanical Degradation of Invert (BSC 2004b, Section 6.2.20), on the basis of low consequence. Hence, invert damage as a result of corrosion products, which are a subset of mechanical degradation of the invert, can be screened out on the same basis.

5.13.3 Resolution of Comment 36

TSPA-SR FEP 2.1.09.03.00 was split into three FEPs to cover volume increase of corrosion products in cladding: FEP 2.1.09.03.0A (BSC 2004a, Section 6.19); waste packages, FEP 2.1.09.03.0B (BSC 2004c, Section 6.2.26); and other engineered barrier system components, FEP 2.1.09.03.0C (BSC 2004b, Section 6.2.45). FEP 2.1.09.03.0A was screened as included, while the remaining two FEPs are excluded. New screening arguments and technical bases are contained in the respective FEPs analysis reports.

5.14 COMMENT 37

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> Treatment of creep of the drip shield will be addressed as part of an existing agreement related to drip shield rockfall analyses (CLST Subissue 2 Agreement 8). DOE agreed to provide the technical basis for the screening argument in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002.

5.14.1 TSPA-SR

FEP 2.1.07.05.00, Creeping of Metallic Materials in the engineered barrier system

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f) and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Package–Excluded because of low consequence (all components of FEP not explicitly excluded based on low probability)
- Waste Package–Excluded (creeping of copper-FEP 2.1.07.05.01) because of low probability
- Engineered Barrier System–Excluded because of low consequence.

5.14.2 TSPA-LA

FEP 2.1.07.05.0A, Creep of Metallic Materials in the Waste Package

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.24).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Excluded because of low probability.

Summary of Screening Argument–Elevated-temperature behavior (i.e., creep deformation or creep-fracture) of nickel-based alloys is not expected at temperatures under 650°C. No directly relevant data exist for Alloy 22 in this temperature regime; however, the melting temperature of Alloy 22 is approximately 1,370°C compared to the maximum surface temperature of about 190°C. This treatment of creep of metallic materials in the waste package applies to both commercial spent nuclear fuel and codisposed waste packages. Creep of Alloy 22 at such low temperatures is not expected. Therefore, high-temperature creep has a low probability of occurrence.

External stress (e.g., by rock displacements or ground motion) may lead to the plastic deformations and mechanical damage of the waste package and subsequent leakage of radionuclides. The drip shield is designed to protect the waste package during rockfall and ground-motion events (refer to FEP 2.1.07.05.0B, Creep of Metallic Materials in the Drip Shield (BSC 2004c, Section 6.2.25)). Even if mechanical damage were to occur, creep of metallic materials in the waste package will not occur unless an external factor raises the temperature above 650°C. In view of the above rationale, this FEP is excluded based on low probability of occurrence.

FEP 2.1.07.05.0B, Creep of Metallic Materials in the Drip Shield

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.25).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Excluded because of low probability.

Summary of Screening Argument–Based on the current analyses, the maximum surface temperatures at the drip shield will be about 160°C. Literature indicates that between 200°C and 315°C (400°F and 600°F), the deformation of many titanium alloys loaded to yield point does not increase with time (ASM International 1990, p. 626). Given that creep rates decrease at lower temperatures, creep deformation will not occur to any appreciable extent under repository exposure conditions. Mechanical damage of the drip shield by rockfall is discussed in greater detail under FEP 2.1.07.01.0A, Rockfall.

In view of the above rationale, this FEP is excluded based on low probability of occurrence.

5.14.3 Resolution of Comment#37

This FEP has been split into two FEPs: 2.1.07.05.0A, Creep of Metallic Materials in the Waste Package, and 2.1.07.05.0B (BSC 2004c, Section 6.2.24), Creep of Metallic Materials in the Drip Shield (BSC 2004c, Section 6.2.25). Both remain excluded due to low probability, and screening arguments with technical bases are contained in the respective FEPs analyses report. Treatment of creep of the drip shield was also addressed by KTI Agreement CLST 2.08, which was submitted to NRC in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion.* Updates to screening arguments based on KTI results will be provided in a revision to *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c).

5.15 COMMENT 38

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 screening argument to address the NRC comment.

5.15.1 TSPA-SR

FEP 2.1.11.05.00, Differing Thermal Expansion of Repository Components

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e), *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f), and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form (Miscellaneous)–Included (thermally induced stresses in the commercial spent nuclear fuel waste form and cladding)
- Waste Form–Excluded (thermally induced stress changes for the near-field barriers and engineered barrier system) because of low consequence
- Waste Package–Excluded because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

5.15.2 TSPA-LA

FEP 2.1.11.05.0A, Thermal Expansion/Stress of In-Package Engineered Barrier System Components

This FEP was addressed in *Clad Degradation – FEPs Screening Arguments* (BSC 2004a, Section 6.22).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Clad–Excluded because of low consequence.

Summary of Screening Argument–Thermal expansion and stresses of in-package engineered barrier system components, including the waste form, are excluded from the TSPA-LA on the basis of low consequence.

The waste package and its internals are designed for thermal expansion (BSC 2004a, Appendix A, Figure A-1). The commercial spent nuclear fuel and DOE spent nuclear fuel are designed for the thermal cycles expected in reactors, which are more severe than repository conditions. As discussed in *CSNF Waste Form Degradation: Summary Abstraction* (BSC 2004n, Section 6.2.1), the in-reactor thermal cycles (principally the cycle associated with the initial power escalation) result in extensive cracking of the fuel matrix. The effects of this cracking are included in the specific surface area parameter. Glass logs crack because of the cooldown during manufacturing. The cracking that results from this cooldown is included in the defense high-level radioactive waste model surface area parameter. This cooldown (from molten glass, about 950°C) is more severe than repository conditions.

Commercial spent nuclear fuel operates at higher temperatures than expected during the postclosure period at the repository. Under normal conditions, typical cladding operates at about 320°C with fuel centerline temperatures reaching 1,800°C. Fuel is also designed to undergo anticipated operating occurrences (off-normal transients that occur during the design life) without damage. These are more severe thermal cycles than are considered for normal reactor operation or repository closure. Every time a reactor shuts down and goes to cold shutdown, the fuel is cooled to below 100°C (coolant is less than boiling). These temperature transients are more severe than repository closure. DOE spent nuclear fuel is also exposed to reactor transients more severe than the postclosure cooldown. Since the temperature transients for spent nuclear fuel from normal in-reactor operations and for defense high-level radioactive waste from normal manufacturing cooldown are more severe than the transient associated with repository closure, no further degradation (cracking) is expected from thermal expansion or stress of in-package engineered barrier system components.

In conclusion, thermal expansion and stress of in-package engineered barrier system components, including the waste form, is excluded from the TSPA-LA on the basis of low consequence. The NRC requirements in 10 CFR 63.114 (e) and (f) allow this omission because thermal expansion will not significantly change the magnitude and time of the resulting radiological exposures to the RMEI or radionuclide releases to the accessible environment.

FEP 2.1.11.07.0A, Thermal Expansion/Stress of In-Drift Engineered Barrier System Components

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.30) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.65).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Excluded because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–The coefficient of thermal expansion for Stainless Steel Type 316L (an analog for the Stainless Steel Type 316 used for the waste package inner vessel) is larger than the coefficient of thermal expansion for Alloy 22. Thus, changes in temperature could lead to contact stresses between the waste package barriers. In the calculation entitled

Waste Package Outer Barrier Stresses Due to Thermal Expansion with Various Barrier Gap Sizes (BSC 2001d), the maximum tangential stresses at the waste package outer barrier inner and outer surfaces were evaluated for several waste package types (21-PWR, 44-BWR, 12-PWR Long, 5 DHLW/DOE SNF-Short, 2-MCO/2-DHLW, and Naval SNF Long) as a function of temperature and barrier gap size (difference in radius of the two barriers evaluated at room temperature). A previous calculation in *Waste Package Barrier Stresses Due to Thermal Expansion* (BSC 2001e) using a barrier gap size of zero showed that, under thermal expansion, loading tangential stresses are significantly higher than radial stresses. The conclusion of these studies was that a barrier gap size of at least 1 mm would result in no tangential stresses due to thermal expansion. Current waste package designs require the barrier gap size to be at least 1 mm.

The *Waste Package Operation Fabrication Process Report* (Plinski 2001, Section 8.1.8) requires a loose fit between the outer barrier (Alloy 22) and the inner vessel (Stainless Steel Type 316) to accommodate the differing thermal expansion coefficients. Typical waste package designs also require large longitudinal barrier gaps (approximately 30 mm). Therefore, although thermal expansion of waste package components does occur, no significant stresses due to differing thermal expansion between the barriers develop. This FEP is excluded for the waste packages based on low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

In the current drip shield design, the drip shield connectors are designed in such a way that allows for thermal expansion with no effect on drip shield performance. The drip shield segments are interlocked with a significant amount of freedom to expand and still maintain their intended purpose. The space between the drip shield and waste package (367 mm) is large enough to accommodate deflection due to rockfall. The space needed for thermal expansion is very small by comparison. Therefore, this FEP can be excluded for the drip shields based on low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

5.15.3 Resolution of Comment 38

This FEP has been split into two FEPs: 2.1.11.05.0A, Thermal Expansion/Stress of In-Package Engineered Barrier System Components, and 2.1.11.07.0A, Thermal Expansion/Stress of In-Drift Engineered Barrier System Components. Both remain excluded due to low consequence. Updated screening arguments will be included in a revision of *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c).

5.16 COMMENT 39

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> The ability of the additional loading combinations to initiate and/or propagate preexisting cracks are being addressed in existing agreements (CLST Subissue 2 Agreements 8 and 9). DOE agreed to provide the technical basis for the screening argument in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002.

5.16.1 TSPA-SR

FEP 2.1.06.06.00, Effects and Degradation of Drip Shield

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f) and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Package–Excluded because of low consequence (damage to drip shield by rockfall, damage to drip shield by ground motion during seismic events, oxygen embrittlement)
- Waste Package–Included (physical and chemical degradation processes, effect on thermal hydrology and geochemistry included)
- Engineered Barrier System–Included.

5.16.2 TSPA-LA

FEP 2.1.06.06.0B, Oxygen Embrittlement of Drip Shields

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.21).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Excluded because of low probability.

Summary of Screening Argument–Oxygen embrittlement of titanium results from diffusion of interstitial oxygen into the metal at higher temperatures (greater than 340°C). The time to failure depends on the alloy composition, material thickness, and stress state. For the thermal-hydrologic time history files used in the TSPA analyses, the drip shield surface temperatures never exceed about 160°C, which is less than the threshold temperature for oxygen embrittlement of 340°C. Therefore, oxygen embrittlement of the titanium drip shields is excluded on the basis of low probability of occurrence under the exposure conditions in the repository.

5.16.3 Resolution of Comment 39

This FEP has been split into two FEPs: 2.1.06.06.0A, Effects of Drip Shield on Flow, and 2.1.06.06.0B, Oxygen Embrittlement of Drip Shields. Only the latter is relevant to NRC Comment 39. A quantitative basis has been added to the screening argument in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.21). This comment was also addressed by KTI Agreements CLST 2.08 and 2.09 in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*.

5.17 COMMENT 42

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreement (ENFE Subissue 2 Agreement 6, 10, and 14). The Engineered Barrier System Features, Events, and Processes. ANL-WIS-PA-000002 will be updated upon completion of these agreement items.

5.17.1 TSPA-SR

FEP 2.1.08.07.00, Pathways for Unsaturated Flow and Transport in the Waste and Engineered Barrier System

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e) and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form (Miscellaneous)–Included (pathways for unsaturated flow and transport in the waste and engineered barrier system)
- Waste Form–Excluded (preferential pathways within the waste package) because of low consequence
- Engineered Barrier System–Included.

5.17.2 TSPA-LA

FEP 2.1.08.07.0A, Unsaturated Flow in the Engineered Barrier System

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.37).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Included.

Summary of Screening Disposition–Flow within the engineered barrier system is addressed within several included FEPs as follows: FEP 2.1.08.06.0A, Capillary Effects (Wicking) in Engineered Barrier System (BSC 2004b, Section 6.2.36); FEP 2.1.08.05.0A, Flow through Invert (BSC 2004b, Section 6.2.35); and FEP 2.1.08.07.0A, Unsaturated Flow in the Engineered Barrier System (BSC 2004b, Section 6.2.37). FEP 2.1.08.09.0A, Saturated Flow in Engineered Barrier System (BSC 2004b, Section 6.2.38), is excluded.

Flow in the engineered barrier system is described in *EBS Radionuclide Transport Abstraction* (BSC 2003q, Sections 6.3 and 6.5). Hydraulic properties of engineered barrier system components and flow pathways within the engineered barrier system are discussed in detail in that report. The source of inflow to the engineered barrier system is the seepage flux that drips from the crown (roof) of the drift and imbibition flux from the unsaturated zone into the invert. This inflow can flow through the engineered barrier system along eight pathways: (1) seepage flux, (2) flux through the drip shield, (3) diversion around the drip shield, (4) flux through the waste package, (5) diversion around the waste package, (6) flux from the waste package into the invert, (7) imbibition flux from the unsaturated zone matrix to the invert, and (8) flux from the invert to the unsaturated zone fractures. These pathways are time dependent, in the sense that drip shield gaps, drip shield penetrations, and waste package penetrations will vary with time and local conditions in the repository.

The conceptual model for flow through the engineered barrier system also includes three domains: the waste form (e.g., fuel rods or defense high-level radioactive waste glass), waste package corrosion products, and the invert. Because the presence of the emplacement pallet is ignored, water and radionuclides pass directly from the waste package to the invert.

Unsaturated flow is not explicitly addressed but is implicit in the flow component of the engineered barrier system transport abstraction, in which no distinction between saturated and unsaturated flow is needed. Flow pathways that include the drip shield and waste package are modeled as quasi-steady state flows without regard to the detailed mechanisms of the flow. The calculated transport of radionuclides is bounded by fully saturated conditions, as modeled in the case of nonzero seepage flux. Under no-seep conditions, where advective transport does not occur, saturation in the waste package is calculated in the engineered barrier system transport abstraction, which impacts transport from the engineered barrier system.

Flow in the invert is determined by *Multiscale Thermohydrologic Model* (BSC 2004o), which explicitly accounts for the degree of water saturation in the invert. Wicking is not modeled explicitly as a flow mechanism in the engineered barrier system transport abstraction. However, it is implicitly accounted for in the water saturation of the invert. Water saturation in the invert is an input to the engineered barrier system transport abstraction and is provided by *Multiscale Thermohydrologic Model* (BSC 2004o). Water saturation is used in calculating the diffusion coefficient both in the waste package and in the invert, and so it impacts radionuclide transport in the engineered barrier system. Particularly in the case of no seepage flux, wicking draws water into the invert from the drift walls, providing a pathway for diffusive transport. The amount of water that flows into the engineered barrier system by capillary effects and the resulting water saturation are documented in *Multiscale Thermohydrologic Model* (BSC 2004o).

Flow in the engineered barrier system is also addressed in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m, Sections 6.6, 6.9, and 6.13). One pathway for water entering the drift is by wicking upward through the invert. The composition of water entering the drift by wicking in the invert or by crown seepage is model input to *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m). A discussion of possible incoming water compositions is included in FEP 2.1.08.06.0A.

FEP 2.1.06.06.0A, Effect of Drip Shield Flow (BSC 2004b, Section 6.2.23); FEP 2.1.06.05.0A, Mechanical Degradation of the Emplacement Pallet (i.e., waste package contacts invert) (BSC 2004b, Section 6.2.19); and FEP 2.1.08.05.0A Flow Through Invert (BSC 2004b, Section 6.2.35), are addressed separately in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m).

5.17.3 Resolution of Comment 42

KTI Agreements ENFE 2.06, 2.10, and 2.14 have been submitted to NRC in Appendices E, F, and J, respectively, of *Technical Basis Document No. 5: In-Drift Chemical Environment*. The technical basis in the screening argument for this FEP has been updated in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.37).

5.18 COMMENT 43

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreement (CLST Subissue 3 Agreement 7). DOE agreed to provide clarification of the screening argument in the Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 to address the NRC comment.

5.18.1 TSPA-SR

FEP 2.1.02.27.00, Localized Corrosion Perforation from Fluoride

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Clad–Included.

5.18.2 TSPA-LA

FEP 2.1.02.27.0A, Localized (Fluoride Enhanced) Corrosion of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.17).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–Hydrofluoric acid can contribute to an accelerated general corrosion with fluoride concentrations greater than 5 ppm and pH less than 3.18. The in-package chemistry model predicts pH values greater than 4.5, and J-13 well water contains only 2.2 ppm of fluoride. Since neither of the conditions is met, accelerated corrosion from fluoride is not expected. Even if pH dropped below 3, fluoride-enhanced localized corrosion of the cladding would not occur because the fluoride concentration would still be less than 5 ppm.

As corroborating evidence, corrosion of zirconium by fluorides is addressed in *Clad Degradation—Local Corrosion of Zirconium and Its Alloys Under Repository Conditions* (CWRMS M&O 2000d, Sections 4.1, 6.1.5, 6.2.2.3, and III.4). Zirconium resists attack by most halides, including halogen acids. The major exceptions are hydrofluoric acid and ferric chloride (localized (pitting) corrosion of cladding, FEP 2.1.02.16.0A). As shown in *Clad Degradation—Local Corrosion of Zirconium and Its Alloys Under Repository Conditions* (CWRMS M&O 2000d, Section 6.1.3), zirconium is corrosion resistant to certain fluorides when the pH is sufficiently high. Low fluoride ion concentrations (F^- ions), on the order of a few parts per million, in city water or groundwater have little effect on zirconium's excellent corrosion resistance. However, a few parts per million of hydrofluoric acid will noticeably increase zirconium's corrosion rate. Hydrofluoric acid only exists in solution at pH values below 3.18.

For accelerated corrosion to occur, the fluoride must be present as free ions (i.e., not complexed as compounds), and the pH must be low. A high insoluble fluoride concentration (in essence a low fluoride ion concentration) would not be expected to have much impact on the standard zirconium corrosion rate. *Clad Degradation—Local Corrosion of Zirconium and Its Alloys Under Repository Conditions* (CWRMS M&O 2000d, Section 4.1.1, Test 12) shows that fluoride ion concentrations of less than 5 ppm, even at pH values as low as 1, produce similar corrosion rates to those with 0 fluoride ion concentration. Thus, it is reasonable to conclude that low fluoride ion concentrations, as distinct from total fluoride content, will have limited impact on the uniform Zircaloy corrosion rate.

Repository conditions as represented by J-13 well water would not be expected to produce any significantly different corrosion rates in zirconium and its alloys than in general corrosion (FEP 2.1.02.13.0A (BSC 2004a, Section 6.3). It has been hypothesized that groundwater entering the repository may be concentrated in impurities as a result of evaporation. Of particular note is the fact that the halide content could become enriched due to the high solubility of most chlorides and fluorides. As a result, the corrosive potential of the water increases as the halide concentrations increase. However, the pH of the solution increases at the same time, and this is favorable because zirconium and its alloys are generally corrosion resistant at the higher pH values. That is, J-13 well water will not become oxidizing when the pH is so high.

In conclusion, the magnitude and time of the resulting radiological exposures to the RMEI, or radionuclide releases to the accessible environment, would not be significantly changed by the omission of this FEP (fluoride-enhanced corrosion) from the TSPA-LA model. Few, if any, rods would experience accelerated corrosion because the pH is too high (greater than 3.18) for the formation of hydrofluoric acid and the concentration of fluorine is too low (less than 5 ppm).

5.18.3 Resolution of Comment 43

The screening decision for this FEP has been changed from included to excluded. The technical basis for this decision is documented in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.17). Related information on chloride-induced localized corrosion is treated in KTI Agreement CLST 3.07 (Appendix D of *Technical Basis Document No. 7: In-Package Environment and Waste Form Degradation and Solubility*).

5.19 COMMENT 44

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreement (CLST Subissue 3 Agreement 7). DOE agreed to provide clarification of the screening argument in the Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 to address the NRC comment.

5.19.1 TSPA-SR

FEP 2.1.02.16.00, Localized Corrosion (Pitting) of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Clad–Included.

5.19.2 TSPA-LA

FEP 2.1.02.16.0A, Localized (Pitting) Corrosion of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.6).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–A zirconium-pitting model was developed to investigate the chemical conditions at which pitting occurs. Zirconium alloys are susceptible to pitting in a particularly aggressive combination of chloride (Cl^-) ions, ferric ions (Fe^{3+}), or hydrogen peroxide (H_2SO_2). In order to predict cladding failure from chloride pitting, a review of the literature for pitting rates and electrochemical data for various zirconium alloys was conducted. Based on this review of the literature, failure criteria were constructed based on an electrochemical definition of pitting as the condition at which the corrosion potential for as-polished metal exceeds repassivation potential (i.e., E_{corr} greater than E_{rp}). Corrosion potential and repassivation potential values were obtained for as-polished zirconium alloys in various solution concentrations of Cl^-, Fe^{3+}, and H_2SO_2 using measurements obtained from various experiments. The model to predict repassivation potential depends only on chloride concentration in the solution. The corrosion potential for as-polished metal (E_{corr}) was modeled by performing a regression analysis to fit experimental data with varying molar concentrations of Cl^-, Fe^{3+}, and H_2SO_2. The model describes the conditions in which pitting was observed in experiments. High concentrations of chlorides at extremely low pH (below −0.6) can lead to the general dissolution of the protective zirconium oxide film.

This model was evaluated using in-package chemistry, including the production of nitric acid and hydrogen peroxide from radiolysis (FEP 2.1.02.15.0A (BSC 2004a, Section 6.5)). Pitting is not expected because the repassivation potential exceeds the corrosion potential for as-polished metal. No pitting was predicted to occur for any conditions that were associated with Zircaloy cladding in the repository. In a sensitivity study with acid production from radiolysis increased by a factor of 10, no pitting was predicted to occur.

In conclusion, cladding degradation from localized (pitting) corrosion of the cladding is excluded from TSPA-LA. A comparison of the expected in-package chemistry to the chemical composition where pitting is observed shows that pitting is not expected. Cladding failure due to pitting has a low consequence and is excluded from further consideration.

5.19.3 Resolution of Comment 44

The screening decision for this FEP has been changed from included to excluded. The technical basis for this decision is documented in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.6). Related information on chloride-induced localized corrosion is presented in KTI Agreement CLST 3.07 (Appendix D of *Technical Basis Document No. 7: In-Package Environment and Waste Form Degradation and Solubility*).

5.20 COMMENT 48

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> Spatial variability that may affect degradation of the waste package will be addressed as part of the resolution of an existing agreement (CLST Subissue 1 Agreement 1). The scope of the agreement includes the evaluation of the range of chemical environments on the waste package. FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002.

5.20.1 TSPA-SR

FEP 2.1.01.04.00, Spatial Heterogeneity of Emplaced Waste

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form (Miscellaneous)–Excluded because of low consequence (the effect of spatial heterogeneity of the waste on repository-scale response. No secondary FEPs associated with this primary FEP).
- Waste Form–Included (heterogeneity within a waste package is implicitly included in the evaluation of in-package temperature used to determine perforation of the commercial spent nuclear fuel cladding).

5.20.2 TSPA-LA

FEP 2.1.01.03.0A, Heterogeneity of Waste Inventory

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form–Included.

Summary of Screening Disposition–As discussed in *Initial Radionuclide Inventories* (BSC 2003r), the repository waste types are quite heterogeneous in type (spent nuclear fuel versus glass) and in inventory per package. Commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste glass shipped to the repository will contain quantities of radionuclides that will vary from waste package to waste package, canister to canister, and fuel assembly to fuel assembly. The different physical, chemical, and radiological properties of the various commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste glass waste forms could result in differences in their corrosion rates. This heterogeneity is represented in TSPA-LA by sampling from distributions for radionuclide inventory (for release calculations). However, for postclosure TSPA, the only simulations that approach the regulatory dose limit in 10,000 years are those where many packages breach. With many packages breached, the heterogeneity of the inventory, while included, is of minor importance and is characterized with the uncertainty parameters for the average commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste glass radionuclide inventory in average commercial spent nuclear fuel and codisposal packages.

As discussed in *Defense HLW Glass Degradation Model* (BSC 2004p), one effect of the heterogeneity of the waste inventory is variations in the compositions of waste glasses made to immobilize specific wastes at different DOE sites. The effect of waste glass compositions on the calculated degradation rate is taken into account through the range of values of the model parameter k_E. Ranges for the values of k_E in acidic and alkaline solutions are selected based on the results of laboratory tests with glasses that provide a wide range of compositions that bounds the range of concentrations of key glass components in high-level radioactive waste glasses, such as aluminum. The glass degradation model accounts for the heterogeneity of the waste inventory through the range of parameter values. The range of glass degradation rates calculated using the glass degradation model developed in *Defense HLW Glass Degradation Model* (BSC 2004p) can be used with the average radionuclide concentrations for the entire high-level radioactive waste inventory.

FEP 2.1.01.04.0A, Repository-Scale Heterogeneity of Waste Inventory

This FEP was addressed in *Features, Events and Processes: System Level* (BSC 2004h, Section 6.2.1.7).

Screening Decision–For the license application, the FEP was screened as follows:

- System Level–Included.

Summary of Screening Disposition–At the repository scale, waste form degradation and mobilization in the TSPA-LA model is addressed using three generic waste forms: (1) commercial spent nuclear fuel, which for modeling purposes also addresses naval spent nuclear fuel, (2) DOE-owned spent nuclear fuel, and (3) DOE high-level radioactive waste glass. These three generic categories of waste will be contained and disposed in two types of waste packages: commercial spent nuclear fuel waste packages and codisposal waste packages, with the latter containing both DOE-owned spent nuclear fuel and high-level radioactive waste glass.

For scenarios in which only a few packages breach, the package-to-package heterogeneity could be important in quantifying exposure of the RMEI. For postclosure TSPA, however, these few-package scenarios are not significant to performance because only scenarios with many packages breached show calculated releases that approach the exposure limit. For multiple-package breach scenarios, package-to-package heterogeneity is directly addressed in TSPA-LA using uncertainty parameters for the average inventory within the commercial spent nuclear fuel and codisposal packages.

At the repository-scale, radionuclide dissolution and release depend more directly on infiltration than on the specific location within the repository. Accordingly, waste forms are treated as generic categories and, within the TSPA-LA model, the varying generic waste types are coupled to spatial variations in infiltration properties rather than to specific location. More specifically, the process of waste form degradation will be modeled by equations using empirical degradation rate formulas for the three different generic waste form types: commercial spent nuclear fuel, DOE-owned spent nuclear fuel, and high-level radioactive waste glass. Output will be the mass of waste form exposed versus time and the volume of water in contact with the waste form versus time, which will be used to populate several waste form cells in the model that correspond to different waste form types and seepage cases. The amount of inventory that can ultimately enter each waste form cell will be a linear function of the number of packages emplaced in each inventory, seepage, and thermal-hydrologic environment.

The potential effect of waste heterogeneity at the drift scale is addressed by including various seepage and thermal-hydrologic environments at the repository scale. Because the repository-scale heterogeneities are addressed in the above manner, this FEP is considered as explicitly included.

5.20.3 Resolution of Comment 48

This FEP was divided into two FEPs: 2.1.01.03.0A, Heterogeneity of Waste Inventory, and 2.1.01.04.0A, Repository-Scale Heterogeneity of Emplaced Waste. The TSPA disposition for this FEP is contained in *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.5), and *Features, Events and Processes: System Level* (BSC 2004h, Section 6.2.1.7). KTI Agreement CLST 1.01 was submitted to NRC in November 2003 (Appendix A of *Technical Basis Document No. 5: In-Drift Chemical Environment*).

5.21 COMMENT 49

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreement (CLST Subissue 3 Agreement 7). DOE agreed to provide clarification of the screening argument in the Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 to address the NRC comment.

5.21.1 TSPA-SR

FEP 2.1.02.15.00, Acid Corrosion of Cladding from Radiolysis

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Cladding–Included for local suppression of pH resulting in localized corrosion.

5.21.2 TSPA-LA

FEP 2.1.02.15.0A, Localized (Radiolysis Enhanced) Corrosion of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–The in-package chemistry model addressed the change of water chemistry with the inclusion of nitric acid and hydrogen peroxide production from radiolysis. In the analysis, all of the nitric acid that can be produced in a moist waste package was absorbed into the water film on the cladding surface. The radiation field was modeled as being constant at the dose at 500 years although it decreases with time.

The results of simulations show that neither the base case nor the 10× base case generation rates of HNO_3 and H_2O_2 had an impact on the in-package pH. Therefore, it may be concluded that if radiolysis only affects the chemistry via HNO_3 and H_2O_2 generation, then it will not be a significant process with regard to influencing the in-package chemistry. The radiolysis did not significantly affect the concentrations of Cl^-, Fe^{3+}, or H_2O_2 and, therefore, did not change the corrosion potential of the passive film on the zirconium alloy.

The Center for Nuclear Waste Regulatory Analysis performed a series of corrosion tests in which hydrogen peroxide was added to the ongoing test while the corrosion potential was being measured. Greene et al. (2000, Figure 8) shows two experiments where H_2O_2 was added and the corrosion potential was measured. In one test, the H_2O_2 was added two times. In the three cases where H_2O_2 was added, the effect of the hydrogen peroxide rapidly died out. In another test, a sample that was oxidized in air at 200°C was exposed to a solution of 1 mol/L NaCl. When 0.005 mol/L H_2O_2 was added, the corrosion potential increased by 0.275 V_{SCE} (volts, standard calomel electrode scale), and pitting was observed. In this experiment, the corrosion potential normally is nominally -0.07 V_{SCE}, and the repassivation potential is 0.04 V_{SCE}, so the increase in corrosion potential is significant. The concentrations of chloride and hydrogen peroxide in this experiment are many orders of magnitude higher than expected in the waste package.

Brossia et al. (2002, Figure 3) report two experiments where H_2O_2 was added to ongoing corrosion potential tests. The metal samples had oxide coatings of 1.7 μm and 3.4 μm thick. The initial solution contained 0.1 mol/L NaCl at 95°C, and 0.005 mol/L H_2O_2 was added. In both tests, the corrosion potential initially increased, but later one test showed decreasing corrosion potentials. Pitting was not observed in either experiment. Again, these concentrations are higher than expected in the in-package chemistry.

In conclusion, cladding degradation from radiolysis-enhanced corrosion is excluded from TSPA-LA. Radiolytic production of nitric acid and hydrogen peroxide was included in the in-package chemistry model and this analysis showed that radiolysis had a small effect on the chemistry. Experiments where hydrogen peroxide was added to tests show that in many cases the effect of the hydrogen peroxide quickly becomes negligible. Radiolysis by itself is not expected to damage the cladding (low consequence). Cladding failure due to radiolysis-enhanced corrosion has a low consequence, and is excluded from further consideration.

5.21.3 Resolution of Comment 49

The screening decision for this FEP has been changed from included to excluded. The technical basis for this decision is documented in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.5), where it is shown that no pH values below 3.5 are attained, despite the addition of 10 times the expected amount of radiolysis products. Related information on chloride-induced localized corrosion is presented in KTI Agreement CLST 3.07 (Appendix D of *Technical Basis Document No. 7: In-Package Environment and Waste Form Degradation and Solubility*).

5.22 COMMENT 51

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreement (CLST Subissue 3 Agreement 7). DOE agreed to provide clarification of the screening argument in the Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 to address the NRC comment. The new cladding local corrosion model will reference the In-Drift Microbial Communities AMR, ANL-EBS-MD-000038, which includes discussion of iron oxidizing bacteria. The Clad Degradation - FEPs Screening Arguments, ANL-WIS-MD-000008 AMR will be revised to be consistent with the updated Summary-Abstraction AMR.

5.22.1 TSPA-SR

FEP 2.1.02.14.00, Microbial Corrosion (MIC) of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Cladding–Included for localized effects from microbial activity.

5.22.2 TSPA-LA FEP

FEP 2.1.02.14.0A–Microbially Influenced Corrosion of Cladding

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low consequence.

Summary of Screening Argument–Two studies of microbially influenced corrosion on spent nuclear fuel have been performed. Wolfram et al. (1996, pp. iii and iv) measured microbial activity in spent nuclear fuel pools. They concluded that all spent nuclear fuel pools tested contained microbial colonies. They also performed a literature search and concluded that there was no evidence in the literature that zirconium or its alloys are susceptible to microbially influenced corrosion.

Hillner et al. (1998, p. 11) studied the corrosion of Zircaloy-clad fuels under repository conditions. They indicated that there are two major forms of microbially influenced corrosion for materials being considered for waste packages. They are sulfide attack through the action of sulfate reducing bacteria and corrosion induced by organic acids secreted from certain bacteria.

With respect to attack by sulfate reducing bacteria, Hillner et al. (1998) reference the work of McNeil and Odom (1994, p. 176), which indicates by thermodynamic calculations that sulfate reducing bacteria do not affect zirconium alloys. With respect to corrosion induced by organic acids, Hillner et al. (1998, p. 11) noted that it is most unlikely because of zirconium's tolerance of a wide range of pH values and it is unlikely that production of weak organic acids will have an adverse effect on the passivation of Zircaloy by a ZrO_2 film. Yau and Webster (1987, p. 717) also note that zirconium alloy resists a wide range of organic compounds, including acetic acid, acetic anhydride, formic acid, urea, ethylene dichloride, formaldehyde, citric acid, lactic acid, oxalic acid, tannic acid, and trichloroethylene. This supports the concept that organic solutions produced by microbially influenced corrosion are unlikely to cause significant acceleration of the corrosion of zirconium alloys.

One U.S. commercial nuclear plant spent nuclear fuel pool experienced a significant microbially influenced corrosion event that lasted for about 4 years. After an extended lay-up period, the spent nuclear fuel pool water was found to contain a significant amount of algae and bacteria. Biological agents were purged using controlled additions of chlorine and hydrogen peroxide before the pool was returned to normal operating chemistries.

The assessment revealed that the steel rack corrosion products were up to 2.5 cm thick, and they had started to engulf the individual fuel rods or flow channels of the stored assemblies in the region where the rack and plates contacted the fuel assemblies. The corrosion product had adhered to the fuel. The iron oxide was composed of FeO, Fe_2O_3, and Fe_3O_4. Ralph et al. (2002, p. 6) state:

> One fuel assembly was removed from its storage location and its channel was removed. The oxide from contact with the carbon steel rack was removed with a water lance utilizing 350 to 700 kg/cm^2 of water pressure. A camera with resolution of 0.025 mm was used to inspect the channel. The channel surface appeared uniform and smooth. No pitting, white discoloration or surface anomalies were observed.

The paper concluded that the fuel cladding was not affected through any type of corrosion. Therefore, the corrosion did not change the classification of the fuel as intact or damaged. As with the experiments by Yau (1983), the lack of pitting or stress corrosion cracking implies that the corrosion potential (E_{corr}) was not elevated to exceed E_{rp}, even with Fe_3O_4 present and adhering to the zirconium oxide film. Microbially influenced corrosion colonies could also have locally suppressed the pH but, again, no localized corrosion was observed.

In summary, microbially influenced corrosion of cladding is not expected to cause cladding failure.

5.22.3 Resolution of Comment 51

The screening decision for this FEP has been changed from included to excluded. The technical basis for this decision is documented in *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.4). Related information on chloride-induced localized corrosion is presented in

KTI Agreement CLST 3.07 (Appendix D of *Technical Basis Document No. 7: In-Package Environment and Waste Form Degradation and Solubility*).

5.23 COMMENT 54

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreements (ENFE Subissue 2 Agreement 6, 10, and 14). The Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 will be updated upon completion of these agreement items.

5.23.1 TSPA-SR

FEP 2.1.09.02.00, Interaction with Corrosion Products

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e) and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form (Miscellaneous)–Included (the effect of the presence of a rind around the fuel on the availability of water for radionuclide dissolution, the interaction between the expanding rind in the sealing of the gap and the unzipping of the cladding, and selected chemical effects in the integrated source term for each waste form)

- Waste Form–Excluded (in-package sorption FEP 2.1.09.05.00) because of low consequence (the potential effects of corrosion products on advective–diffusive transport of water and radionuclides and the potential sorptive effects from corrosion products)

- Engineered Barrier System–Included (colloids)

- Engineered Barrier System–Excluded (other than colloids) because of low consequence.

5.23.2 TSPA-LA

FEP 2.1.09.02.0A, Chemical Interaction with Corrosion Products

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.44) and *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.21).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–The model developed in *In-Package Chemistry Abstraction* (BSC 2003j) addresses in-package corrosion products and their effect on in-package chemistry. The corrosion products of the steel and aluminum alloys in the waste package and their control on the concentration of aqueous species are of primary importance in determining the pH and ionic strength of the solution. *In-Package Chemistry Abstraction* (BSC 2003j, Section 6.8) examines the effect of surface complexation of aqueous species with waste package corrosion products and provides a pH range for in-package fluids to be used in TSPA-LA. The effects of interactions of corrosion products with the in-package chemistry are implicitly included in the abstractions passed to TSPA as part of *In-Package Chemistry Abstraction* (BSC 2003j). The model parameters include pH, ionic strength, total carbonate, Eh, chloride, and fluoride.

As described in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003s), fixed and suspended colloidal corrosion products are modeled in the waste package. Suspended colloidal corrosion products are modeled in the engineered barrier system. Corrosion colloids are assumed to form and are subject to concentration and stability constraints controlled by the aqueous chemistry. The potential development of rinds on fuel and glass waste surfaces has been implicitly included in the development of the colloid model by incorporating laboratory data derived from fuel and glass waste corrosion experiments. Clogging of waste package breached zones by corrosion products, as described in *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary* (BSC 2003s, Section 6.3.1.3), is addressed in FEP 2.1.03.10.0A, Healing of Waste Packages, in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c).

The effects of corrosion product formation on in-drift water chemistry and gas composition are evaluated in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m, Sections 6.7 and 6.8). The report includes effects of corrosion products on in-drift water chemistry and gas composition as part of the modeled chemical processes and accounts for corrosion in its oxygen mass balance analysis, where in-drift gas composition calculations evaluated oxygen consumption due to corrosion of ground support materials and other committed materials. Thermal-hydrologic-chemical seepage model abstracted water compositions are reacted with the Stainless Steel Type 316L ground support at the drift wall. Corrosion products also have an impact on the potential for colloid formation. This aspect of corrosion product impact is included as part of FEP 2.1.09.17.0A, Formation of Pseudocolloids (Corrosion Products) in Engineered Barrier System (BSC 2004g, Section 6.2.29). In-package and waste form chemistry issues are specifically addressed in *Miscellaneous Waste-Form FEPs* (BSC 2004g).

5.23.3 Resolution of Comment 54

This FEP has been screened as included in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.44) and *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.21). TSPA dispositions are contained in the respective FEP analysis reports. Related information is presented in KTI Agreements ENFE 2.06, 2.10, and 2.14 (Appendices E, G, and J, respectively, of *Technical Basis Document No. 5: In-Drift Chemical Environment*).

5.24 COMMENT 55

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreements (ENFE Subissue 2 Agreement 5, 8, 11, and 12). The Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 will be updated upon completion of these agreement items.

5.24.1 TSPA-SR

FEP 2.1.09.07.00, Reaction Kinetics in Waste and Engineered Barrier System

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e) and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form (Miscellaneous)–Included (reaction kinetics in the in-package equilibrium model)
- Waste Form–Excluded (impacts of transient disequilibrium states) because of low consequence
- Engineered Barrier System–Excluded because of low consequence.

5.24.2 TSPA-LA

FEP 2.1.09.07.0A, Reaction Kinetics in Waste Package

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.24).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form–Included.

Summary of Screening Disposition–Reaction kinetics and precipitation–dissolution rates are included in the TSPA-LA in-package chemistry model abstraction. The in-package chemistry model uses kinetic reactants to represent the spent nuclear fuel and the waste package components. The kinetic rates used in the model were either linear (a fixed amount of reactant is added at each time step) or a transition-state rate law (the amount of reactant added to the system depends on chemical properties of the aqueous phase). The effect of varying the kinetics on the in-package chemistry was examined by decreasing the rates to assess the contribution to uncertainty in pH and ionic strength for inclusion in the abstractions of pH for TSPA.

The variability in the kinetics of the reactants is included in the abstractions passed to TSPA both implicitly by their use in the in-package chemistry model and explicitly via the contribution of the kinetics to output uncertainty. The effects of reaction kinetics on in-package chemistry are passed to TSPA as part of *In-Package Chemistry Abstraction* (BSC 2003j). The in-package chemistry model parameters are pH, ionic strength, total carbonate, Eh, chloride, and fluoride.

FEP 2.1.09.07.0B, Reaction Kinetics in Drifts

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.48).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Included.

Summary of Screening Disposition–The effects of reaction kinetics are implicitly included in each geochemical submodel of *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m). In reaction path geochemical modeling calculations using EQ3/6 equilibrium model of the water compositions resulting from seepage evaporation (BSC 2004m, Section 6.9) or dust deliquescence (BSC 2004m, Section 6.10), reaction kinetics are implicitly included through suppression of individual mineral phases. Individual mineral phases were suppressed if those phases are kinetically inhibited from forming under repository conditions. A list of minerals inhibited during the modeling, including justification for the decision to inhibit each mineral, is also presented in the above report (BSC 2004m, Section 6.5). The choice of mineral suppressions directly affects the modeled evolution of the in-drift waters and, hence, the water compositions that are passed to the TSPA-LA in the form of lookup tables.

In addition, the kinetics of corrosion of committed materials was examined with respect to its effect on in-drift water and atmosphere compositions. Seepage water interactions with rock bolts and Stainless Steel Type 316L mesh in the drift wall are found to be of low consequence (BSC 2004m, Section 6.8). A sensitivity analysis shows that increasing corrosion rates by an order of magnitude has no significant effect (BSC 2004m, Section 6.12). Oxygen consumption due to corrosion of ground support materials and other committed materials is evaluated using in-drift gas composition calculations (BSC 2004m, Section 6.7). Although the repository may have oxygen-depleting conditions for a short period after closure (a few hundred years) primarily due to the corrosion of mild steel, there is no long-term effect on repository atmosphere. The effects of corrosion kinetics were evaluated by reducing the corrosion rates; this resulted in a somewhat longer period of oxygen depletion but still was not significant relative to regulatory periods. For this reason, geochemical modeling was carried out assuming a partial pressure of oxygen corresponding to that of the Earth's atmosphere (about 0.2). The choice of pO_2 directly affects the modeled evolution of the in-drift waters and, hence, the water compositions that are passed to TSPA-LA in the form of lookup tables. Parameters that are extracted from the lookup tables and used by the TSPA-LA are pH, ionic strength, and total aqueous chloride and nitrogen.

As stated above, the effects of reaction kinetics are implicitly included in the geochemical submodels of *Engineered Barrier System: Physical and Chemical Environment Model* (BSC

2004m) through the selection of mineral species allowed to form. Thus, the effects are part of the chemical composition data tables used by TSPA.

5.24.3 Resolution of Comment 55

The screening decision for this FEP has been changed from mixed included/excluded to included. The TSPA disposition for this FEP is summarized in *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.24). KTI Agreements ENFE 2.08 and 2.12 are complete, while agreements ENFE 2.05 and 2.11 were submitted to NRC in November 2003 (Appendices D and H, respectively, of *Technical Basis Document No. 5: In-Drift Chemical Environment*).

5.25 COMMENT 56

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing DOE/NRC agreements (RDTME Subissue 3 Agreements 2 – 13). DOE agreed to include the analysis of floor buckling for post-closure conditions, consistent with the site-specific parameters and loading conditions used to satisfy RDTME Subissue 3, Agreements 2-13. The Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 will be revised to include this information.

5.25.1 TSPA-SR

FEP 2.1.07.06.00, Floor Buckling

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

5.25.2 TSPA-LA

FEP 2.1.07.06.0A, Floor Buckling

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.30).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–The effect of floor heave and buckling on drip shield response has been screened out of TSPA because of low consequence. Calculations documented in *Ground Control for Emplacement Drifts for SR* (BSC 2001f) demonstrated that the vertical displacement of the floor due to in situ stress and thermal response will be on the order of 10 mm. This displacement will produce only minor shifting in the drip shields and will not compromise their integrity because the overlap between adjacent drip shields is much larger, between 200 and 600 mm. The effect of floor heave on position of the waste packages is also minor. A displacement of 10 mm at one end of a 5,000-mm-long package results in an angle of inclination of less than 1°. Because of the limited vertical displacement of the floor, pallet displacement and damage to invert will also be minor. Because the magnitude of floor buckling is shown to be small relative to the depth of the invert, basin formation will not impact the waste package. The impacts of floor heave and buckling have therefore been screened out of TSPA.

5.25.3 Resolution of Comment 56

KTI Agreements Repository Design and Thermal-Mechanical Effects (RDTME) 3.02, 3.04, 3.05, 3.06, 3.08, 3.09, 3.10, 3.11, and 3.12 were submitted to NRC in June 2004 (*Technical Basis Document No. 4: Mechanical Degradation and Seismic Effects*). Agreement RDTME 3.03 was submitted to NRC in Appendix B of *Technical Basis Document No. 14: Low Probability Seismic Events*. Related information is contained in KTI Agreement RDTME 3.07. The screening argument for this FEP will be updated in a revision to *Engineered Barrier System Features, Events, and Processes* (BSC 2004b).

5.26 COMMENT 57

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 to address the NRC comment. This will include a technical basis for the use of the Waste Isolation Evaluation: Tracers, Fluids, and Materials, and Excavation Methods for Use in the Package 2C Exploratory Studies Facility Construction. BABE00000-01717-2200-00007 Rev 04.

As part of CLST Subissue 1 Agreement 1, DOE also agreed to provide additional justification on the effect of introduced materials on water chemistry in a revision to *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier* (BSC 2001g) before license application.

5.26.1 TSPA-SR

FEP 1.1.02.03.00, Undesirable Materials Left

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

5.26.2 TSPA-LA

FEP 1.1.02.03.0A, Undesirable Materials Left

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–Construction materials and fluids (e.g., diesel fuel, lubricants, coolants, battery acid, cleaning solvents) could be inadvertently left as a result of construction and preclosure operation of the repository. Materials introduced during the preclosure construction and operation phase of the repository may, if not controlled, have a significant impact on groundwater chemistry within the engineered barrier system, thereby impacting corrosion processes, radionuclide transport, and so on. A detailed assessment of such groundwater chemistry changes can be found in *Waste Isolation Evaluation: Tracers, Fluids, and Materials, and Excavation Methods for Use in the Package 2C Exploratory Studies Facility*

Construction (CRWMS M&O 1995). This document determines acceptable upper bounds on materials introduced into the repository prior to closure so that the impact of these materials has negligible consequences on repository performance. These limits will be adhered to during the preclosure phase of operation in accordance with the quality procedures developed for this phase of the operation. It is expected that strict guidelines for spill containment and cleanup will be installed so that substances that are planned to be removed from the site at or before the time of closure will not leave behind noticeable nonremovable residues. If the recommendations given on limits are adhered to, *Waste Isolation Evaluation: Tracers, Fluids, and Materials, and Excavation Methods for Use in the Package 2C Exploratory Studies Facility Construction* (CRWMS M&O 1995) states that the use of diesel powered equipment, other organic materials, and the dry chemical fire extinguishing agent are expected to have negligible impact on the repository. Thus, the presence of these substances will not have a significant effect on radiological exposures to the RMEI or radiological releases to the accessible environment.

5.26.3 Resolution of Comment 57

KTI Agreement CLST 1.01 was submitted to NRC in November 2003 (Appendix A of *Technical Basis Document No. 5: In-Drift Chemical Environment*). An updated screening argument for this FEP will be provided in a revision to *Engineered Barrier System Features, Events, and Processes* (BSC 2004b).

5.27 COMMENT 59

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by an existing DOE/NRC agreement (TEF Agreement Subissue 2 Agreement 5). The Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 will be revised upon completion of this agreement.

5.27.1 TSPA-SR

FEP 2.1.08.04.00, Cold Traps

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

5.27.2 TSPA-LA

FEP 2.1.08.04.0A, Condensation Forms on Roofs of Drifts (Drift-Scale Cold Traps)

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.33).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Included.

Summary of Screening Disposition–A condensation model described in *In-Drift Natural Convection and Condensation* (BSC 2003t) is used to predict condensation and evaporation rates along the entire length of seven selected drifts at different times (300, 1,000, 3,000, and 10,000 years). The condensation model uses single node representations of each waste package along the drifts, as well as nodes for the drip shield, invert, and drift wall. The drift-wall temperature boundary conditions for the condensation model are derived from analytical line-source solutions.

Heat transfer between the nodes (e.g., waste package to drip shield, drip shield to drift wall) is based on literature correlations for natural convection heat and mass transfer for the particular geometry. Thermal radiation is calculated based on surface-to-surface radiation and the appropriate view factors. Only heat transfer in the radial direction is considered. The effect of axial heat transfer is assumed to be small.

Sources of water are available at each waste package location at the drift wall and the top of the invert. The local vapor pressure is the saturation pressure at the calculated temperature. The rate of water evaporation is based on the local vapor pressure difference between the evaporating surface and the local gas vapor pressure and the corresponding mass transfer correlation. The rate is limited by the availability of water to the surface by capillary pumping and percolation values.

The water vapor is transported along the drift by a one-dimensional axial dispersion model using the dispersion coefficients calculated by the in-drift convection model as discussed above. These dispersion values are a function of time. The range of values for the dispersion coefficients is based on the convection model results, as presented in *In-Drift Natural Convection and Condensation* (BSC 2003t).

FEP 2.1.08.04.0B–Condensation Forms at Repository Edges (Repository-Scale Cold Traps)

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.34).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–A model for convection and condensation within the in-drift environment described in *In-Drift Natural Convection and Condensation* (BSC 2003t) provides bounding values for condensation on the drift walls. Condensation that occurs at the repository edges, while likely to occur, does not contribute to the total flow of water through the engineered barrier system and, therefore, does not influence the transport of radionuclides to the RMEI.

5.27.3 Resolution of Comment 59

This FEP has been split into two FEPs: 2.1.08.04.0A (BSC 2004b, Section 6.2.33) was screened as included, covering condensation on drift roofs, and 2.1.08.04.0B (BSC 2004b, Section 6.2.34) was screened as excluded, dealing with condensation at repository edges. An updated screening argument for FEP 2.1.08.04.0B, based on recent modeling of in-drift convection and condensation, is presented in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.34). Additional information regarding representation of the cold trap effect in models is presented in KTI Agreement TEF 2.05.

5.28 COMMENT 60

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is partially addressed by an existing DOE/NRC agreement (ENFE Subissue 2 Agreement 6). DOE agreed to provide the technical basis for the screening argument in the Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 to address the NRC comment.

5.28.1 TSPA-SR

FEP 2.1.12.01.00, Gas Generation

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e), *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b), *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form (Miscellaneous)–Excluded because of low consequence
- Unsaturated Zone–Included (effects of corrosive gases)
- Unsaturated Zone–Excluded (pressurization of the repository) because of low probability
- Engineered Barrier System–Excluded because of low consequence.

5.28.2 TSPA-LA

FEP 2.1.12.01.0A, Gas Generation (Repository Pressurization)

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.70).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–Gas may be generated in the repository by a variety of mechanisms. Waste form decay (FEP 2.1.12.02.0A (BSC 2004b, Section 6.2.71)) may result in helium gas production, waste package corrosion (FEP 2.1.12.03.0A (BSC 2004b, Section 6.2.72)) may cause hydrogen gas generation, microbial degradation may lead to the generation of gases (CO_2, CH_4, H_2S) (FEP 2.1.12.04.0A (BSC 2004b, Section 6.2.73)), and gas may be generated by radiolysis (FEP 2.1.13.01.0A (BSC 2004b, Section 6.2.77)).

For the purposes of waste-form contribution to gas generation, gas may be generated in the waste in the waste packages prior to the waste package breaching, as well as after breaching, allowing any gas to escape to the repository. Gas generation might lead to pressurization of the waste packages prior to waste package breaching. After the waste packages are breached, gas generation might lead to pressurization of the repository and affect radionuclide transport.

Because the repository is an open system, the more mobile gases, such as hydrogen and helium, will diffuse out of the repository first, followed by denser gases, such as CH_4 or H_2S (which have lower gas-diffusion rates). Thus, gas will diffuse out of the repository according to the gas density and relative gas-diffusion rate, resulting in gas compositions within the repository being relatively homogeneous. Consequently, corrosive gases will not accumulate or exacerbate degradation of waste packages and other components.

For the small amount of gas that may be produced (due to the processes listed above), gas is not expected to cause repository pressures to increase, given the repository's lithologic setting. The repository is situated in the Topopah Spring welded tuff, consisting of abundant fracture networks. In units where there are numerous fractures and fracture networks, fluid flow (both gaseous and liquid) tends to occur primarily in the fractures.

The relatively high gas saturation of the host rock within and above the repository horizon means that the host-rock gas permeability (i.e., the effective permeability) will be several orders of magnitude greater than the effective liquid permeability. An increase in liquid saturation will reduce gas permeability and increase liquid permeability. Gas flow paths that encounter perched zones (where liquid saturation approaches 100%) will be deflected at the perched zone perimeter due to the increase in liquid saturation. At unit interfaces, especially between welded and nonwelded units, the upward movement of gas will become laterally attenuated and more dispersed as it encounters the relatively larger matrix permeability and storage capacity of the nonwelded units. In the TCw unit (at depths of approximately 100 to 150 m below the surface), atmospheric pressures will promote barometric pumping of gas to the surface. This pumping will cause mixing of repository-produced gases with atmospheric gases, thus diluting gas concentrations and promoting gas migration to the mountain surface.

Therefore, gas generation (repository pressurization) is excluded from the TSPA-LA based on low consequence.

5.28.3 Resolution of Comment 60

An updated screening argument for exclusion of this FEP will be provided in a revision to *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.70. KTI Agreement ENFE 2.06 was submitted to NRC in November 2003 (Appendix E of *Technical Basis Document No. 5: In-Drift Chemical Environment*).

5.29 COMMENT 61

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the Features, Events, and Processes in the *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 to address the NRC comment.

5.29.1 TSPA-SR

FEP 2.2.10.12.00, Geosphere Dry-Out Due to Waste Heat

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included.

5.29.2 TSPA-LA

FEP 2.2.10.12.0A–Geosphere Dry-Out Due to Waste Heat

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.39).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–The coupled processes of vaporization, dryout, and resaturation are explicitly simulated with the thermal-hydrologic seepage model described in *Drift-Scale Coupled Processes (DST and TH Seepage) Models* (BSC 2004q) that feeds into the seepage abstraction. Using this model, the impact of such coupled processes on seepage is assessed for various simulation cases.

The coupled processes of vaporization, dryout, and resaturation are explicitly simulated with the thermal-hydrologic seepage model, including the formation of a dry (or nearly dry) zone around drifts, expanding and then receding through time following the pulse of heat released from the waste packages. Therefore, these effects are explicitly taken into account in the results of the thermal-hydrologic seepage model and their abstraction.

5.29.3 Resolution of Comment 61

This FEP is screened for the unsaturated zone as included for TSPA. The TSPA disposition has been updated in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section

6.1.39) to include the technical basis derived from recent coupled-process modeling. The effects of dryout on surface infiltration are discussed under FEP 2.2.10.01.0A in Section 6.8.9 of *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f).

5.30 COMMENT 62

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> TM effects on fractures will be addressed by existing agreements between DOE and NRC (RDTME Subissue 3 Agreement 20 and 21). The *FEPs in Thermal Hydrology and Coupled Processes*, ANL-NBS-MD-000004 will be revised upon completion of this work.
>
> Long term degradation of the host rock is addressed by existing agreements between DOE and NRC (RDTME Subissue 3 Agreement 11 and 19).
>
> DOE will provide an improved technical basis for this FEP by performing a postclosure drift deformation analysis that incorporates postclosure loads and rock properties using relevant information from existing agreements (RDTME Subissue 3 Agreements 2 - 13). The Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 will be revised to include this information.

5.30.1 TSPA-SR

FEP 2.2.01.02.00, Thermal and Other Waste and Engineered Barrier System-Related Changes in the Adjacent Host Rock

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Excluded (thermal-mechanical effects) because of low consequence
- Near Field Environment–Excluded (thermal-hydrologic-chemical and backfill effects) because of low probability.

5.30.2 TSPA-LA

FEP 2.2.01.02.0A, Thermally Induced Stress Changes in the Near-Field

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.80) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.3).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The results of the coupled drift-scale thermal-hydrologic-mechanical model presented in *Drift Scale THM Model* (BSC 2004r, Sections 6.5 and 6.6) shows that the impact of time-dependent thermal-hydrologic-mechanical processes will last for well over 10,000 years, but these processes have a small or moderate impact on the drift-scale thermal-hydrologic behavior, including a negligible impact on the temperature evolution and small impact on the percolation flux. These model results were obtained for a conservative estimate of input thermal-hydrologic-mechanical properties (thermal expansion coefficient and stress versus permeability function), which is sufficient for bounding the possible impact of the thermal-hydrologic-mechanical processes on permeability and percolation flux.

The thermal-hydrologic-mechanical simulations discussed in *Abstraction of Drift Seepage* (BSC 2004s, Section 6.4.4.1) suggest that temperature-induced stress changes give rise to changes in the vertical fracture permeability in the vicinity of waste emplacement drifts, in particular in the Tptpmn unit. However, these permeability changes do not result in significant changes in the flow fields. In particular, the seepage rates calculated for a permeability field including thermal-hydrologic-mechanical permeability changes were similar to, but slightly smaller than, those calculated for a permeability field representative of the initial postexcavation conditions. The simulation results from *Drift Scale THM Model* (BSC 2004r) provide reasonably accurate (slightly conservative) estimates of the expected seepage rates at long-term conditions with coupled thermal-hydrologic-mechanical property changes. Therefore, the impact of thermal-hydrologic-mechanical property changes is neglected in the seepage abstraction.

The overall effect of thermal-hydrologic-mechanical coupled processes on drift-scale radionuclide transport may also be excluded, because the primary effect of thermal-hydrologic-mechanical processes leads to enhanced seepage diversion and reduced drift seepage, reduced water saturations beneath the drift and, therefore, greater partitioning of radionuclide releases to the rock matrix. Therefore, this FEP is excluded based on low consequence because it has no adverse effects on performance.

5.30.3 Resolution of Comment 62

This FEP has been split into two FEPs: 2.2.01.02.0A and 2.2.01.02.0B. The former deals with thermally induced stress changes, and an updated screening argument, based on a recent analysis, has been developed for this FEP in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.3). FEP 2.2.01.02.0B deals with chemical changes from backfill and is excluded due to the absence of backfill. KTI Agreements RDTME 3.02, 3.04, 3.05, 3.06, 3.08, 3.09, 3.10, 3.11, and 3.12 were submitted to NRC in June 2004 with *Technical Basis Document No. 4: Mechanical Degradation and Seismic Effects*. Agreement RDTME 3.03 was submitted to NRC in Appendix B of *Technical Basis Document No. 14: Low Probability Seismic Events*. Related information is provided in KTI Agreements RDTME 3.07 and 3.20.

5.31 COMMENT 63

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 3). *FEPs in Thermal Hydrology and Coupled Processes*, ANL-NBS-MD-000004 will be revised upon completion of this work.

5.31.1 TSPA-SR

FEP 2.1.09.12.00, Rind (Altered Zone) Formation in Waste, Engineered Barrier System, and Adjacent Rock

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e), *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d), and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form (Miscellaneous)–Included (rind (altered zone) formation in the waste in evaluating cladding unzipping and water availability for radioisotope dissolution)
- Near Field Environment–Excluded (rind formation in the adjacent host-rock) because of low consequence
- Near Field Environment–Included thermal-hydrologic-chemical model
- Near Field Environment–Excluded (thermal-hydrologic model, effects on transport) because of low consequence
- Engineered Barrier System–Excluded for engineered barrier system components because of low consequence.

5.31.2 TSPA-LA

FEP 2.1.09.12.0A, Rind (Chemically Altered Zone) Forms in the Near-Field

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.1).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The thermal-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts using the thermal-hydrologic-chemical seepage model described in *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2004t). This model, which explicitly captures the effects of changes in temperature, pH, Eh, ionic strength (and other compositional variables), time dependency, precipitation–dissolution effects, and effects of resaturation, was used to examine near-field and drift seepage flow and chemistry. Changes in fracture permeabilities were found to be on the order of the natural variation in these properties, with most of the substantial effects limited to regions above and to the side of the drift within about a drift diameter. The predicted mineral precipitation reduces permeability in the affected regions and leads to a reduction in flow around the drift. Likewise, any mineralogical changes are of very limited extent below the drift, resulting in negligible effects on radionuclide sorption. Thermal-hydrologic-chemical effects on fracture characteristics have been evaluated with process models that explicitly account for fracture flow affected by thermal-hydrologic-chemical parameter alterations. It was demonstrated that the effects of these potential alterations on near-field and drift seepage flow can be neglected in the TSPA-LA, because the expected changes would lead to less seepage. Consequently, neglect of this effect is likely to result in slightly conservative model predictions for both drift seepage and radionuclide transport phenomena. Therefore, this FEP is excluded on the basis of low consequence because it has no adverse effects on performance. A discussion explaining why low consequence for specific elements of the unsaturated zone system leads to low consequence for total system performance is presented in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6).

Thermal-hydrologic-chemical effects (e.g., mineral precipitation) on fracture characteristics as they relate to near-field and drift seepage chemistry were also evaluated with the thermal-hydrologic-chemical seepage model. A discussion is provided with the related FEP 2.2.03.02.0A (BSC 2004e, Section 6.2.15).

5.31.3 Resolution of Comment 63

An updated screening argument for this FEP, based on recent thermal-hydrologic-chemical modeling, is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.1). Related information is presented in KTI Agreement ENFE 1.03 AIN-1 (Appendix F to *Technical Basis Document No. 3: Water Seeping into Drifts*). The issue of unreacted solute mass that is trapped in the dryout zone in TOUGHREACT simulations is addressed in ENFE 1.03.

5.32 COMMENT 64

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 3). The *FEPs in Thermal Hydrology and Coupled Processes*, ANL-NBS-MD-000004 will be revised upon completion of this work.

5.32.1 TSPA-SR

FEP 2.2.10.06.00, Thermo-Chemical Alteration (Solubility Speciation, Phase Changes, Precipitation/Dissolution)

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included (in-drift geochemical model that uses water chemistry and gas-phase composition from the drift-scale thermal-hydrologic-chemical model that includes thermal-chemical alteration)
- Near Field Environment–Excluded (effects in thermal-hydrologic models) because of low consequence
- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

5.32.2 TSPA-LA

FEP 2.2.10.06.0A, Thermo-Chemical Alteration in the UZ (Solubility, Speciation, Phase Changes, Precipitation/Dissolution)

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.13).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–This FEP raises some issues already addressed in FEP 2.2.08.03.0B (BSC 2004f, Section 6.8.7) and FEP 2.2.08.07.0B (BSC 2004f, Section 6.8.8). If solubility limits decrease in the geosphere compared with the waste emplacement drifts, then more radionuclides will precipitate as water flows out of the drifts. This corresponds to fewer dissolved radionuclides being available for transport into the geosphere, which is beneficial and results in no adverse effects on performance. If solubility limits increase in the geosphere compared with the waste emplacement drift, there is no effect on transport because all available radionuclides from the source at the waste emplacement drift are already aqueous species. Because the solubility is considered the same in the unsaturated zone and engineered barrier system, the effects of any reduced solubility on transport are excluded.

The effects of temperature on radionuclide sorption were evaluated in *Abstraction of Drift-Scale Coupled Processes* (BSC 2004u, Section 6.4). This evaluation focused on the radionuclides cesium, strontium, barium (a proxy for radium), cerium, europium, uranium(VI), neptunium, plutonium, and americium. The effects of temperature on sorption were found to be negligible for these radionuclides, except for strontium, neptunium, and uranium(VI). For these three radionuclides, the effects of increased temperature leads to increased sorption. Therefore, the effects of temperature on radionuclide transport can be excluded on the basis of low consequence because it has no adverse effects on performance.

The thermal-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts. This model explicitly captures the effects of changes in temperature, pH, Eh, ionic strength (and other compositional variables), time dependency, precipitation–dissolution effects, and effects of resaturation. Changes in fracture permeabilities were found to be on the order of the natural variation in these properties, with most of the substantial effects limited to regions above and to the side of the drift within about a drift diameter. The predicted mineral precipitation decreases permeability in the affected regions and leads to a reduction in flow around the drift. This is conservative for both drift seepage and radionuclide transport phenomena and, therefore, neglect of these types of permeability changes has no adverse effects on repository performance.

5.32.3 Resolution of Comment 64

An updated screening argument for this FEP, based on recent modeling and analysis results, is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.13). Related information is provided in KTI Agreement ENFE 1.03 AIN-1 (Appendix F to *Technical Basis Document No. 3: Water Seeping into Drifts*).

5.33 COMMENT 65

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> Repository wide non-uniform heating effects are the subject of existing DOE/NRC agreements (TEF Subissue 2 Agreement 5, RDTME Subissue 3 Agreement 20 and 21). The *FEPs in Thermal Hydrology and Coupled Processes*, ANL-NBS-MD-000004 will be revised upon completion of this work.
>
> THM continuum modeling will address non-uniform effects at a mountain scale. This information will be provided in the Coupled Thermal-Hydrologic-Mechanical Effects on Permeability Analysis and Model Report AMR, ANL-NBS-HS-000037.

5.33.1 TSPA-SR

FEP 2.1.11.02.00, Nonuniform Heat Distribution/Edge Effects in Repository

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included (thermal-hydrologic and thermal-hydrologic-chemical aspects)
- Near Field Environment–Excluded (thermal-mechanical effects) because of low consequence.

5.33.2 TSPA-LA

FEP 2.1.11.02.0A, Non-Uniform Heat Distribution in Engineered Barrier System

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.63).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Included.

Summary of Screening Disposition–The calculation of the repository thermal-hydrologic environment, including thermal gradients from the repository center to the edges and corners of the repository, is described in *Multiscale Thermohydrologic Model* (BSC 2004o). The impact of uneven heating and cooling is captured in that report and passed to the TSPA-LA by providing in-drift temperatures as a direct feed.

5.33.3 Resolution of Comment 65

This FEP is now screened as included, and the TSPA disposition is described in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.63). Related information is presented in KTI Agreements TEF 2.05, RDTME 3.20, and RDTME 3.21.

5.34 COMMENT 66

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> The thermal mechanical effects on rock properties are addressed by an existing DOE/NRC agreement (RDTME Subissue 3 Agreement 20 and 21). The *FEPs in Thermal Hydrology and Coupled Processes,* ANL-NBS-MD-000004 and the Features, Events, and Processes: Screening for Disruptive Events. ANL-WIS-MD-000005 will be revised upon completion of this work.

5.34.1 TSPA-SR

FEP 2.2.06.01.00, Changes in Stress (Due to Thermal, Seismic, or Tectonic Effects) Change Porosity and Permeability of Rock

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) and *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Excluded because of low consequence
- Near Field Environment–Excluded because of low consequence
- Near Field Environment–Excluded (one secondary FEP as not relevant to the project) because of low probability.

5.34.2 TSPA-LA

FEP 2.2.06.01.0A, Seismic Activity Changes Porosity and Permeability of Rock

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.9), *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.7.5), and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.16).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–A sensitivity analysis for unsaturated zone flow properties was performed and demonstrated that the consequence of seismic-induced changes in porosity or permeability in the unsaturated zone would be negligible because other factors, such as climate change, have a much larger impact on flow processes. Similarly, seismic-induced decreases or increases in matrix and fracture porosity and permeability would be of no significance to saturated zone flow characteristics because this change is encompassed within the uncertainty included in the modeling approach to flowing interval spacing.

Based on the results of sensitivity analysis of unsaturated zone flow properties, changes in fracture aperture confined to fault zones showed virtually no effect on transport behavior in the unsaturated zone. The effects of increased fracture aperture applied over the entire unsaturated zone domain are no more significant than other uncertainties related to infiltration, which are dominated by climate change effects. Effects of thermal stresses in terms of change to rock properties have been evaluated. This modeling approach is based on the assumption that stress-induced changes to rock matrix porosity and permeability are negligible compared with changes to the fracture porosity and permeability. Fracture apertures are expected to be more sensitive to mechanical strain due to the small porosity of the fracture continuum compared to the matrix porosity. Seismic sources of mechanical strain should produce analogous results.

For the saturated zone modeling approach, not all of the fractures contribute to flow, but, rather, there are flowing intervals. Horizontal anisotropy in permeability is included to represent fracture zones. The model does not explicitly address changes to fracture properties due to stress effects; however, due to conservative choices for flowing-interval spacing and uncertainties in the flow field representation, the effect of seismic-induced changes to matrix and fracture porosity and permeability would be of no significance to flow and transport characteristics of the rock.

Therefore, changes to the rock porosity or permeability due to seismic activity are excluded from TSPA-LA on the basis of low consequence.

5.34.3 Resolution of Comment 66

Updated screening arguments for this FEP, based on recent modeling results, are contained in the disruptive events, unsaturated zone, and saturated zone FEP AMRs (BSC 2004d, Section 6.2.19; BSC 2004f, Section 6.7.5; BSC 2004e, Section 6.2.16). Related information is presented in KTI Agreements RDTME 3.20 and RDTME 3.21.

5.35 COMMENT 68

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> The thermal mechanical effects on rock properties are addressed by an existing DOE/NRC agreement (RDTME Subissue 3 Agreement 20 and 21). The *FEPs in Thermal Hydrology and Coupled Processes,* ANL-NBS-MD-000004 will be revised upon completion of this work.

5.35.1 TSPA-SR

FEP 1.2.02.01.00, Fractures

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a), *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Included (for existing fracture characteristics); does not satisfy a screening criterion
- Disruptive Events–Excluded (for changes of fracture characteristics due to thermal loading, tectonic activity, or seismicity) because of low consequence to dose (preliminary)
- Near Field Environment–Included (seepage)
- Near Field Environment–Excluded (permanent effects) because of low consequence
- Saturated Zone–Included (existing fractures and uncertainty in their properties)
- Saturated Zone–Excluded (changing fracture properties) because of low consequence
- Unsaturated Zone–Included (effects of present-day fracture system)
- Unsaturated Zone–Excluded (effects of changes to the fracture system) because of low consequence.

5.35.2 TSPA-LA

FEP 1.2.02.01.0A, Fractures

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.2) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.1).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included
- Saturated Zone–Included.

Summary of Screening Disposition–This FEP on fractures is included in process models for unsaturated zone flow and transport. The unsaturated zone flow model is based on a dual-permeability concept, with fractures represented by a continuum. The fracture continuum represents the spatially averaged flow through discrete fractures. The fracture continuum interacts with the matrix continuum, which represents matrix blocks separated by fractures.

Fracture continuum properties include permeability, porosity, interface area per unit volume, van Genuchten α and *m* parameters for the saturation-capillary pressure and relative permeability functions, and an active fracture parameter. These parameters and associated range of values are presented in *UZ Flow Models and Submodels* (BSC 2004k, Section 4.1) for each unsaturated zone model layer.

The influence of fractures on radionuclide transport through the unsaturated zone is investigated through the dual permeability model. The influences of fracture characteristics on unsaturated zone flow are included through the pregenerated flow fields. Fracture aperture, porosity, and frequency affecting unsaturated zone radionuclide transport are summarized in *Particle Tracking Model and Abstraction of Transport Processes* (BSC 2004l, Section 6.5.7). Fracture porosity and frequency data will be statistically sampled during TSPA-LA multirealization runs using the distribution given in DTN: LA0311BR831371.003.

Flow processes in fractures or other channels are important for seepage abstraction because the amount of seepage is determined by the diversion capacity of the fracture flow in the drift vicinity. These flow processes are influenced by fracture characteristics such as orientation, aperture, asperity, length, connectivity, and fillings. All seepage process models that feed into seepage abstraction explicitly simulate the flow processes in fractures, using appropriate continuum properties that represent these characteristics.

This FEP is also included in TSPA-LA through the treatment of drift-scale radionuclide transport. This is captured through the fracture–matrix partitioning model for the fraction of releases from a waste emplacement drift without seepage to the fractures of the underlying rock mass. The fraction of the releases from a drift without seepage to the fractures is represented as an uncertain parameter, caused in part by uncertainty in fracture characteristics (see specifically parameters *f*, *m*, and Φ_f in *Drift-Scale Radionuclide Transport* (BSC 2004v, Table 6.4-5)). Distributions that represent the effects of this uncertainty in the fraction released to fractures are developed for use in TSPA-LA as a probabilistic parameter applied to the total radionuclide flux entering the rock from waste emplacement drifts.

Groundwater flow through fractures in the volcanic units is included in the saturated zone flow and transport model. Groundwater flow through fractures in the volcanic units is modeled in *Site-Scale Saturated Zone Flow Model* (BSC 2003k, Sections 6.3.3, 6.5.1, 7, and 8, and Figures 6.4-1 and 6.2-2) using an effective continuum approach implemented in the numerical code FEHM V 2.20 (LANL 2003).

Additionally, the characteristics of the fracture properties, such as fracture orientation, aperture size, degree of infilling, and tortuosity, are modeled through the following probabilistically modeled parameters: groundwater specific discharge, flowing interval spacing in volcanics, flowing interval porosity in the volcanic units, longitudinal dispersivity, horizontal anisotropy in the volcanic units, colloid partitioning coefficients in the volcanics, and the sorption coefficients onto colloids. The above parameters are described in *Saturated Zone Flow and Transport Model Abstraction* (BSC 2003u, Sections 6.5.2.1, 6.5.2.4, 6.5.2.5, 6.5.2.9, 6.5.2.10, 6.5.2.12, and 6.5.2.15).

5.35.3 Resolution of Comment 68

This FEP is now screened as included for both unsaturated zone (BSC 2004f, Section 6.1.2) and saturated zone (BSC 2004e, Section 6.2.1). Updated TSPA dispositions are contained in the respective FEP AMRs. The disposition relevant to this NRC comment is given in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.2). Related information is presented in KTI Agreements RDTME 3.20 and RDTME 3.21.

5.36 COMMENT 69

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> The thermal mechanical effects on rock properties are addressed by an existing DOE/NRC agreement (RDTME Subissue 3 Agreement 20 and 21). The *FEPs in Thermal Hydrology and Coupled Processes,* ANL-NBS-MD-000004 will be revised upon completion of this work.

5.36.1 TSPA-SR

FEP 2.2.01.01.00–Excavation and Construction-Related Changes in the Adjacent Host Rock

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included (initial effects on seepage)
- Near Field Environment–Excluded (permanent thermal-hydrologic-chemical and thermal-mechanical effects) because of low consequence
- Unsaturated Zone–Included (effects of stress relief and ground support on drift seepage)
- Unsaturated Zone–Excluded (changes in water chemistry) because of low consequence.

5.36.2 TSPA-LA

FEP 2.2.01.01.0A, Mechanical Effects of Excavation/Construction in the Near Field

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.9).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–Excavation effects, including mechanical effects of excavation on excavation disturbed zone fractures, near-field fractures, and seepage are taken into account in the seepage abstraction through the use of postexcavation air-permeability data and the estimation of a capillary-strength parameter determined from seepage tests. These data reflect the impact of excavation around a large opening (niche or drift). The measured postexcavation air-permeability data are supported by thermal-hydrologic-mechanical modeling results. The probability distributions for permeability and capillary strength are based on the values given in *Abstraction of Drift Seepage* (BSC 2004s, Tables 6.6-3 and 6.6-1), and thus account for such excavation effects. These distributions will be used in the TSPA-LA to calculate seepage from the seepage lookup tables, using the methodology defined in *Abstraction of Drift Seepage* (BSC 2004s, Section 6.8.1). The seepage abstraction model also captures the effects of drift collapse in terms of the larger drift profile that results.

FEP 2.2.01.01.0B, Chemical Effects of Excavation/Construction in the Near Field

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.2).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Disposition–Identified ground-support materials in the waste emplacement drifts are steel sets, pipe spacers used with steel sets, tie rods used with steel sets, and Stainless Steel Type 316L rock bolts, wire mesh, and sheets designed in accordance with ASTM standards. The principal ground support in the emplacement drifts is expected to be Stainless Steel Type 316L rock bolts and steel sheets. A model of the effects of steel ground support on aqueous chemistry was recently generated. The model considered the interaction of Bin 11 water with Stainless Steel Type 316L ground-support materials. Interaction with the abstracted Bin 11 seepage water was chosen because this is the most likely water to be present, occurring in almost 40% of the abstracted periods. In addition, this Bin 11 water is seen to occur during the relevant period for the corrosion of Stainless Steel Type 316L, in the range of approximately 500 to 5,000 years for four of the five seepage water compositions shown in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m, Tables 6.6-8 to 6.6-12). The effect of dissolving the abstracted Stainless Steel Type 316L species into Bin 11 water was found to be negligible. The Bin 11 water with and without the 5.52×10^{-5} moles of Stainless Steel Type 316L added was found to only have two differences in the water chemistries at the sixth significant figure for ionic strength and carbon total molality. Use of Bin 7 seepage water was selected as an uncertainty case and is described in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m, Section 6.12.4.1). There is effectively no change in the aqueous water chemistry caused by abstracted stainless steel corrosion and corrosion product formation in this case, as with the base-case Bin 11 seepage water.

Cementitious materials (shotcrete) are planned for use as part of the ground support for the turnouts of repository emplacement drifts. These materials can result in changes in water composition, particularly alkalinity and sulfate concentration. However, the lateral offset between such materials and waste emplacement will ensure that these materials do not affect waste emplacement drifts. The potential effect of such materials on radionuclide transport is also greatly reduced because of the mainly vertical flow patterns in the host rock. Water is expected to move in a general vertical flow pattern through the waste emplacement horizon relative to the length scale of these drifts, with some flow diversion around the drifts resulting from the capillary barrier effect. This flow pattern is consistent with the drift-scale seepage model having no-flow lateral boundary conditions. Lateral flow beneath the repository (particularly at zeolitic interfaces) may lead to some interaction between radionuclide pathways and water affected by cementitious ground support materials. However, several factors, including buffering of the alkalinity by the rock mass, carbonation of the cement by CO_2, and the generally low levels of lateral dispersion between streamlines, indicate that this should have a negligible effect on radionuclide transport. The low levels of lateral dispersion are apparent in the simulations of chloride plumes in which the plume variations between individual drifts and pillars between drifts are maintained from the repository to the water table.

Therefore, this FEP is excluded on the basis of low consequence.

5.36.3 Resolution of Comment 69

This FEP has been split into two FEPs, 2.2.01.01.0A (BSC 2004f, Section 6.1.9) and 2.2.01.01.0B (BSC 2004f, Section 6.8.2), to distinguish mechanical effects from chemical effects of excavation or construction. The former FEP is screened as included, while the latter is excluded due to low consequence. An updated disposition and screening argument is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f). Related information is provided in KTI Agreements RDTME 3.20 and RDTME 3.21.

5.37 COMMENT 70

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> The thermal mechanical effects on rock properties are addressed by an existing DOE/NRC agreement (RDTME Subissue 3 Agreement 20 and 21). The *FEPs in Thermal Hydrology and Coupled Processes,* ANL-NBS-MD-000004 will be revised upon completion of this work.

5.37.1 TSPA-SR

FEP 2.2.10.04.00, Thermo-Mechanical Alteration of Fractures near Repository

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

5.37.2 TSPA-LA

FEP 2.2.10.04.0A, Thermo-Mechanical Stresses alter Characteristics of Fractures near Repository

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.10) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.36).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The results of the coupled drift-scale thermal-hydrologic-mechanical model presented in *Drift Scale THM Model* (BSC 2004r, Sections 6.5 and 6.6) show that the impact of time-dependent, thermal-hydrologic-mechanical processes will last for well over 10,000 years, but these processes have a small or moderate impact on the drift-scale thermal-hydrologic behavior, including a negligible impact on the temperature evolution and small impact on the percolation flux. These model results were obtained for a conservative estimate of input thermal-hydrologic-mechanical properties (thermal expansion coefficient and stress versus permeability function), which is sufficient for bounding the possible impact of the thermal-hydrologic-mechanical processes on permeability and percolation flux.

The thermal-hydrologic-mechanical simulations discussed in *Abstraction of Drift Seepage* (BSC 2004s, Section 6.4.4.1) suggest that temperature-induced stress changes give rise to changes in the vertical fracture permeability in the vicinity of waste emplacement drifts, particularly in the Tptpmn unit. However, these permeability changes do not result in significant changes in the flow fields. In particular, the seepage rates calculated for a permeability field, including thermal-hydrologic-mechanical permeability changes, were similar to but slightly smaller than those calculated for a permeability field representative of the initial postexcavation conditions. The simulation results from *Drift Scale THM Model* (BSC 2004r) provide slightly conservative estimates of the expected seepage rates at long-term conditions with coupled thermal-hydrologic-mechanical property changes. Therefore, the impact of thermal-hydrologic-mechanical property changes is neglected in the seepage abstraction.

The overall effect of thermal-hydrologic-mechanical coupled processes on drift-scale radionuclide transport may also be excluded because the primary effect of thermal-hydrologic-mechanical processes leads to enhanced seepage diversion and reduced drift seepage, reduced water saturations beneath the drift, and, therefore, greater partitioning of radionuclide releases to the rock matrix. Therefore, this FEP may be excluded based on low consequence because it has no adverse effects on performance.

FEP 2.2.10.04.0B, Thermo-Mechanical Stresses Alter Characteristics of Faults near Repository

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.11) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.37).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The primary differences represented by faults, as compared with the general fractured rock mass, for flow, transport, drift seepage, and coupled processes, are the greater permeability and potential continuity of high-permeability pathways through the unsaturated zone. Thermal-mechanical effects on fault fractures may be expected to be qualitatively similar to rock-mass fractures in the sense that thermal-hydrologic-mechanical processes will lead to reductions in vertical permeabilities but increased horizontal permeability above the drift. Faults may be viewed as a specific type of heterogeneity in the fractured rock mass. From this viewpoint, *Drift Scale THM Model* (BSC 2004r, Section 6.8.5) indicates that the main effect of thermal-hydrologic-mechanical processes is on the mean permeability and that it is appropriate to apply the mean permeability changes to a seepage analysis that considers either the homogenous or heterogeneous permeability field. This is the approach presented in FEP 2.2.10.04.0A (BSC 2004f, Section 6.8.10; BSC 2004e, Section 6.2.36). Therefore, the screening arguments used in FEP 2.2.10.04.0A also apply here, and, consequently, this FEP may be excluded on the basis of low consequence.

5.37.3 Resolution of Comment 70

This FEP has been split into two FEPs: 2.2.10.04.0A (BSC 2004f, Section 6.8.10; BSC 2004e, Section 6.2.36), which deals with fractures, and 2.2.10.04.0B (BSC 2004f, Section 6.8.11; BSC 2004e, Section 6.2.37), which deals with faults. Both are screened as excluded due to low consequence, with updated screening arguments based on recent thermal-hydrologic-mechanical modeling results. Related information is presented in KTI Agreements RDTME 3.20 and RDTME 3.21.

5.38 COMMENT 78

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> Existing agreements from the Container Life and Source Term (Subissue 2 agreements 2 and 8), Repository Design and Thermal Mechanical Effects (Subissue 3 agreements 17 and 19) and Structural Deformation and Seismicity (Subissue 1 agreement 2 and Subissue 2 agreement 3) address related work. DOE agreed to provide clarification of the screening argument in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 and Features, Events, and Processes: Screening for Disruptive Events, ANL-WIS-MD-000005.

5.38.1 TSPA-SR

FEP 1.2.03.02.00, Seismic Vibration Causes Container Failure

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Excluded (for drip shield and waste package damage) because of low consequence to dose (preliminary)
- Disruptive Events–Included (for fuel rod cladding); does not satisfy a screening criterion
- Waste Package–Excluded because of low consequence.

5.38.2 TSPA-LA

FEP 1.2.03.02.0A, Seismic Ground Motion Damages Engineered Barrier System Components

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.8) and *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.3).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Vibratory ground motion associated with seismic activity has the potential to disrupt the integrity of components of the engineered barrier system. The direct effects of ground motion could lead to impaired drip shield or waste package performance, with subsequent enhanced radionuclide release. Evaluation of the effects of ground motion includes:

- Development of location-specific ground motions based on results of the probabilistic seismic hazard analysis for Yucca Mountain and ground-motion site response modeling
- Structural response calculations to determine the performance of engineered barrier system components (drip shield, waste package, fuel cladding, pallet) under various levels of ground motion loading
- Evaluation of the results of structural response calculations, using failure criteria for the drip shield, waste package, and fuel cladding, to determine the amount of surface area damaged (drip shield, waste package) or perforation (cladding)
- Abstraction of results to develop damage response surfaces relating the amount of damage to the level of ground motion. The abstraction also bounds horizontal peak ground velocity to credible values based on physical properties of the rocks at Yucca Mountain and geologic observations.

The amplitude and likelihood of a ground-motion event was determined by a probabilistic seismic hazard analysis. The probabilistic seismic hazard analysis assessed the characteristics of seismic sources and ground motion in the Yucca Mountain region, including their uncertainties. Results were expressed as hazard curves that indicate the annual probability that a given level of ground motion will be exceeded (CRWMS M&O 2000e). Estimates of peak ground velocity and corresponding ground-motion time histories were developed for the emplacement drifts, based on the results of the probabilistic seismic hazard analysis and a ground-motion site response model (BSC 2004w, Section 6). The time histories, which incorporate an appropriate range of amplitude, frequency content, and duration, serve as input to models of the dynamic behavior of the engineered barrier system for assessing mechanical disruption or damage to these systems. Ground-motion time histories were developed for annual probabilities of exceedance of 5×10^{-4}, 10^{-6}, and 10^{-7} (BSC 2004x, Section 6.3).

In addition to the seismic inputs developed for structural response calculations, an analysis also determined a bound to horizontal peak ground velocity at the emplacement drifts, based on the physical limitations of the rock, geologic observations, and ground-motion site-response results. In the probabilistic seismic hazard analysis, aleatory variability in ground-motion attenuation relations was characterized by unbounded lognormal distributions. At extremely low annual probability levels, the tails of these distributions, along with large assessed epistemic uncertainties in ground motions from large, close earthquakes, result in upper-percentile and mean ground motions that are extremely high and probably physically unrealistic. At such high ground motions, the shear strains produced in the lithophysal rock at the waste emplacement level would cause the rock to fracture and fail. Geologic studies of rock exposed in the underground excavations, however, indicate that fractures related to high levels of seismic shaking do not exist at Yucca Mountain. Thus, the extreme levels of seismic shaking required to damage the lithophysal rock have not occurred at Yucca Mountain since the rocks were deposited about 12.8 million years ago. This observation serves as the basis for a reasonable bound to the horizontal peak ground velocity values that can be achieved at Yucca Mountain. The bound is expressed as a probability distribution to incorporate uncertainty in the analysis (*Technical Basis Document No. 14: Low Probability Seismic Events*, Section 4.1.2).

The extent of mechanical disruption of engineered barriers was determined, based on estimates of how much damage may be caused by various levels of ground motion. This characterization of seismic damage is discussed in *Seismic Consequences Abstraction* (BSC 2003v). Detailed structural analyses were used to assess damage to the drip shield and waste package as a result of the site-specific vibratory ground motion. These analyses were conducted using state-of-the-art three-dimensional finite element process models and incorporated detailed structural descriptions of the waste package and drip shield, as well as site-specific ground-motion time histories. A sensitivity study was performed using ground-motion time histories as input to the models, and results of these trials were used to formulate the database used in the damage abstraction for the TSPA-LA (BSC 2003v, Section 6). Damage to these barriers is expressed in terms of damaged surface area on the drip shield, damaged surface area on the waste package, or perforation of the fuel cladding as functions of the horizontal peak ground velocity (BSC 2003v, Section 6.6.1.4).

The most likely failure mechanism from a seismic event is accelerated stress corrosion cracking in the damaged areas that exceed the residual stress threshold for Alloy 22 (the waste package outer barrier) and for Titanium Grade 7 (the drip shield). The criteria for failure are based on a residual stress threshold of between 80% and 90% of the yield strength for Alloy 22, and of 50% of the yield strength for Titanium Grade 7. No damage to engineered barrier system components is expected for vibratory ground motion with an annual exceedance probability of 5×10^{-5} (20,000-year recurrence) or higher. Cladding failure is assumed to occur with an annual probability of 1×10^{-5} (100,000-year recurrence). However, at this probability level, no damage to the drip shields is expected from rockfall or vibratory ground motion because any resulting cracks plug from groundwater-related mineral precipitates. The maximum effective area for flow into and transport out of the waste package at this probability level is less than 0.003% of its surface area. At an annual probability of 1×10^{-6} (million-year recurrence), the drip shield does not fail as a flow barrier due to rockfall or vibratory ground motion, and the maximum effective transport area through stress corrosion cracks on the waste package is less than 0.013% of its surface area. At an annual probability level of 1×10^{-7} (10-million-year recurrence), adjacent drip shields can separate and ride over each other, reducing their effective surface area by up to 50%. However, at this probability level, the waste package still provides substantial protection for the waste form, with a maximum effective surface area for flow and transport through stress corrosion cracks of less than 0.03%. These results collectively indicate that the engineered barrier system components are robust under seismic loads and will provide substantial protection of the waste form from seepage water even under severe seismic loading.

The impact of mechanical disruption on the performance of the engineered barriers is evaluated in the seismic consequence abstraction. Within the abstraction, the damage from mechanical disruption events is expressed as a damaged area for flow and transport on the surfaces of the drip shield, waste package, and cladding. The damaged areas include the combined effects of vibratory ground motion, fault displacement, and rockfall. The output from the seismic scenario class is a mathematical relationship of waste package damage (expressed as an area of stress corrosion cracks on the waste package surface) to the size of the seismic event (expressed in terms of the peak ground velocity). The damage is expressed as a mean value with a distribution around this mean to reflect uncertainty and variability in the damage level for a given value of peak ground velocity. This relationship is termed the damage response surface. Values of peak ground velocity are determined from a peak ground velocity hazard curve for the waste emplacement level and are constrained to credible values through use of a bounding peak ground velocity probability distribution. The seismic scenario is then computed within the TSPA-LA using these damage and ground-motion abstractions as input (BSC 2003v, Section 6.10).

FEP 1.2.03.02.0B–Seismic Induced Rockfall Damages Engineered Barrier System Components

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.9) and *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Because of the additional imposed stresses, seismic ground motion has the potential to dislodge blocks. This could result in additional damage to the drip shields through mechanical impact mechanisms and possibly to the waste packages (if the drip shields fail) via increased seepage through a damaged or separated drip shield and is included in the TSPA-LA.

It is anticipated that rockfall occurring within lithophysal zones will result in relatively smaller rock fragments with insufficient mass and energy to permanently deform or damage the drip shields. Therefore, damage to the drip shield from rockfall in the lithophysal units is neglected for TSPA-LA. The following discussion addresses only the potential damage to drip shields resulting from the impact of relatively large rock blocks, more likely to occur in nonlithophysal zones. The mechanical response of the drip shield to an impact by large rock blocks from the nonlithophysal unit has the potential to damage the drip shield's ability to act as a flow barrier. The abstraction for the percent failed surface area mode is included as a function of peak ground velocity. An en masse fall of rock fragments, for FEPs purposes, constitutes drift collapse. Seismic-induced drift collapse is addressed as FEP 1.2.03.02.0C in *Features, Events, and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.5) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.85).

The ground motion hazard curves developed for the probabilistic seismic hazard analysis were extended to address ground motion during the postclosure period, as documented in DTN: MO03061E9PSHA1.000. The seismic time histories were developed starting with the results of the probabilistic seismic hazard analysis and take into account the effect of the upper 300 m of rock and soil at the site (site response). The repository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, NV* (BSC 2004w). The ground motion time histories were developed for 5×10^{-4}, 10^{-6}, and 10^{-7} annual exceedance probabilities and have been used in seismic-related analyses and models to provide inputs to support postclosure analyses of damage to engineered barrier system components from seismic ground-motion, seismic-induced rockfall, and effects related to seismic-induced drift collapse.

The outputs are of particular interest because they are used by *Drift Degradation Analysis* (BSC 2004x) to determine rock block size, rockfall frequency, and drift-collapse effects related to seismic-induced ground motion, which are addressed in related FEPs. The outputs of that analysis are used to evaluate damage to engineered barrier system components from seismically induced rockfall, which is included in the seismic scenario class for TSPA-LA.

In general, vibratory ground motion can cause failure of the host rock around the emplacement drifts. The characterization of seismic damage is addressed using damage-related response surfaces and is fully discussed in *Seismic Consequences Abstraction* (BSC 2003v, Section 6.6). Damage to the drip shield from impact of individual rock blocks is determined by structural response calculations. The objective of these calculations is to determine the drip shield areas where the residual stress exceeds the threshold value (50% of yield strength) for Titanium Grade 7. The analysis evaluates damage based on six representative rock sizes impacting the drip shield from three different angles: vertically downward onto the top of the drip shield, at a 60° angle (with the horizontal) onto the transition region between the top and side of the drip shield, and horizontally into the side wall.

Vibratory ground motions also have the potential to eject large, nonlithophysal rock blocks at high velocity. Rock blocks are ejected for the 10^{-6} per year and the 10^{-7} per year ground motion levels; relatively few blocks are ejected at the 5×10^{-4} per year ground motion level. The mean damage areas for ground motions with 10^{-6} and 10^{-7} annual frequency in the nonlithophysal zone are 1.7% and 3.4%. Maximum values are 32.2% and 63.6%, respectively. Clearly, the mechanical response of the drip shield to impact by a large rock block in the nonlithophysal zone has the potential to damage the drip shield and impair its function as a flow barrier.

FEP 1.2.03.02.0C–Seismic Induced Drift Collapse Damages Engineered Barrier System Components

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.85) and *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Excluded
- Engineered Barrier System–Excluded.

Summary of Screening Argument–The potential consequences of seismic-induced drift collapse require two preceding factors: (1) that drift collapse occurs and (2) that the volume or amount of collapse is sufficient to cause structural failure of the drip shields. Drift degradation analysis, covered in the following discussion, indicates that drift collapse in the nonlithophysal unit is not of concern. However, the analysis does indicate that seismic-induced rockfall in the nonlithophysal unit may be of concern due to the rock block size.

For the 5 × 10^{-4} per year ground motion, tunnels in the lithophysal zones show no damage for higher values of rock compressive strength and exhibit only minor damage (but no collapse) at the lowest level of compressive strength. Drift degradation analysis also demonstrates that drifts in the lithophysal zones would collapse under the 10^{-6} per year (and, by inference, the larger, 10^{-7} per year) vibratory ground motions. Consequently, drift collapse in the lithophysal zones can impose a static load on the drip shield from the weight of the natural backfill that fills the drifts as a result of the collapse. The characterization of seismic damage from rockfall is addressed using damage-related response surfaces and is fully discussed in *Seismic Consequences Abstraction* (BSC 2003v, Sections 6.6.1 and 6.6.2). In the lithophysal zones, the static loads from a collapsed drift using continuum or discontinuum representations of the host rock are not expected to collapse the drip shield. Damage to the drip shield from rockfall in the lithophysal zone is excluded for TSPA-LA on this basis.

FEP 1.2.03.02.0D–Seismic Induced Drift Collapse Alters In-Drift Thermohydrology

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.86) and *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.6).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Drift collapse in the nonlithophysal unit is of no concern due to limited collapsed volume and small block size. The seepage abstraction does not change for this unit as a result of seismic impacts because rockfall does not completely fill the tunnels at the ground motions that are evaluated. An "enhancement factor" is included in the seepage abstraction model to account for limited collapse.

Ground motions with an annual frequency of 10^{-6} or less do cause collapse of emplacement drifts in the lithophysal unit. This collapse can fill the drifts with rubble, altering the hydrologic and thermal environment. Impacts on seepage are addressed by modifying the seepage flux used in TSPA-LA.

5.38.3 Resolution of Comment 78

This FEP has been divided into four FEPs: 1.2.03.02.0A, 1.2.03.02.0B, 1.2.03.02.0C, and 1.2.03.02.0D. The first three FEPs deal with damage to engineered barrier system components from ground motion, rockfall, and drift collapse, and the last FEP covers in-drift thermal-hydrology changes due to drift collapse. Only FEP 1.2.03.02.0C, Seismic Induced Drift Collapse Damages Engineered Barrier System Components, has been screened as excluded.

Updated TSPA dispositions for FEP 1.2.03.02.0A will be provided in revisions of *Features, Events and Processes: Disruptive Events* (BSC 2004d) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b). The latter document will also contain an updated screening decision and argument for FEP 1.2.03.02.0C.

KTI Agreements Structural Deformation and Seismicity (SDS) 1.02 and 2.03 are complete. Agreements RDTME 3.17 and 3.19 were submitted to NRC in June 2004 (Appendix C of *Technical Basis Document No. 4: Mechanical Degradation and Seismic Effects*). KTI Agreements CLST 2.02 and 2.08 were submitted to NRC as Appendix K to *Technical Basis Document 6: Waste Package and Drip Shield Corrosion*.

5.39 COMMENT 79

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> Existing agreements from Repository Design and Thermal Mechanical Effects agreements (Subissue 3 agreements 17 and 19) and Container Life and Source Term (subissue 2 agreements 2, 3 and 8) address related work. DOE agreed to provide clarification of the screening argument in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 and Features, Events, and Processes: Screening for Disruptive Events, ANL-WIS-MD-000005.

5.39.1 TSPA-SR

FEP 2.1.07.01.00, Rockfall (Large Block) WFClad–Rockfall

This FEP was addressed in *Clad Degradation–FEPs Screening Arguments* (CRWMS M&O 2000b), *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a), *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f), and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low probability
- Disruptive Events–Excluded because of low consequence to dose (preliminary)
- Waste Package–Excluded (drip shield) because of low consequence
- Waste Package–Excluded because of low probability
- Engineered Barrier System–Excluded because of low consequence.

5.39.2 TSPA-LA

FEP 2.1.07.01.0A, Rockfall

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.26), *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.23), and *Clad Degradation–FEPs Screening Arguments* (BSC 2004a, Section 6.1.8).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Form Cladding–Excluded because of low probability
- Waste Package–Excluded (drip shield) because of low consequence
- Waste Package–Excluded because of low probability

- Engineered Barrier System–Excluded (drip shield) because of low consequence
- Engineered Barrier System–Excluded (waste package) because of low probability.

Summary of Screening Disposition–Rockfall damage of the cladding has been excluded from the TSPA-LA on the basis of low probability of occurrence because the drip shield prevents rocks from striking the waste package and possibly damaging the cladding.

Seismic-induced rockfalls and drift degradation are not treated within this FEP. A full discussion of seismic effects is contained in FEPs 1.2.03.02.0A, Seismic Ground Motion Damages Engineered Barrier System Components (BSC 2004b, Section 6.2.8); 1.2.03.02.0B, Seismic Induced Rockfall Damages Engineered Barrier System Components (BSC 2004b, Section 6.2.9); and 1.2.03.02.0C, Seismic Induced Drift Collapse Damages Engineered Barrier System Components (BSC 2004b, Section 6.2.85).

According to *Drip Shield Structural Response to Rock Fall* (BSC 2003w, Section 6), LS-DYNA analysis shows that the deflection of the drip shield due to rockfall is not large enough to contact the waste package. The drip shield will withstand an 11.5 MT rockfall without contacting the waste package. The maximum displacement from the 11.5 MT rockfall event is 254 mm, and the minimum gap between the drip shield and waste package outer barrier is 367 mm (refer to FEP 2.1.03.07.0B, Mechanical Impact on Drip Shield (BSC 2004c, Section 6.2.14.1)). Thus, the drip shield provides adequate protection to the waste package from rockfall.

The effects of rockfall on crack initiation in the drip shield are discussed in *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2003n, Section 6.3.7). It is concluded that a crack will take a minimum of 40 years to grow through the 15-mm drip shield wall. These cracks are extremely tight and, with time, become plugged with corrosion products and other mineral precipitates (FEP 2.1.03.02.0B (BSC 2004c, Section 6.2.5)). This plugging process limits water transport through the drip shield to negligible amounts and maintains the functionality of the drip shield. Therefore, rockfall on drip shield is of low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

It is feasible that stress fractures in the host rocks and rockfall events may increase the flow of water into the repository. Given that the drip shield is capable of withstanding a rockfall event, it is reasonable to predict that the drip shield continues to divert water from falling on the waste package until the drip shield fails after 10,000 years. Therefore, increased inflow of water related to rockfall is excluded from the TSPA analysis based on low consequence to radiological exposures to the RMEI and radionuclide releases to the accessible environment.

Nominal rockfall represents static loading conditions that are characterized by in situ conditions of gravitational stresses, excavation-induced stresses, and thermally induced stresses. Nominal rockfall does not include dynamic loading caused by seismic events. *Drift Degradation Analysis* (BSC 2004x, Section 6.6.1.4) shows that threshold of drip shield damage due to vibratory ground motion or rockfall lies between 10^{-4} and 10^{-5} per year exceedance frequency. Under these conditions, there is no damage to the drip shield.

Analyses related to multiple rockfalls were conducted. In the calculation presented in that report, rock sizes of 0.1, 1, and 6 MT were considered because, as rock block size increases, the minimum distance between rock blocks also increases; therefore, these rock block sizes are adequate for their intended purpose. It was concluded that for rock sizes of 6 MT or smaller, the second rock would have to fall within 0.5 m of the first rock in order for the impact of the second rock to alter the stress and strain profile resulting from the first rock impact.

FEP 1.2.03.02.0B, Seismic Induced Rockfall Damages Engineered Barrier System Components

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.4) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.9).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Because of the additional imposed stresses, seismic ground motion has the potential to dislodge blocks. This could result in additional damage to the drip shields through mechanical impact mechanisms and possibly to the waste packages (if the drip shields fail) via increased seepage through a damaged or separated drip shield and is included in the TSPA-LA.

It is anticipated that rockfall occurring within lithophysal zones will result in relatively smaller rock fragments with insufficient mass and energy to permanently deform or damage the drip shields. Therefore, damage to the drip shield from rockfall in the lithophysal units is neglected for TSPA-LA. The following discussion addresses only the potential damage to drip shields resulting from the impact of relatively large rock blocks, more likely to occur in nonlithophysal zones. The mechanical response of the drip shield to an impact by large rock blocks from the nonlithophysal unit has the potential to damage the drip shield's ability to act as a flow barrier. The abstraction for the percent failed surface area mode is included as a function of peak ground velocity. An en masse fall of rock fragments, for FEPs purposes, constitutes drift collapse. Seismic-induced drift collapse is addressed as FEP 1.2.03.02.0C in *Features, Events, and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.5) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.85).

The ground-motion hazard curves developed for the probabilistic seismic hazard analysis were extended to address ground motion during the postclosure period, as documented in DTN: MO03061E9PSHA1.000. The seismic time histories contained in the following DTNs were developed starting with the results of the probabilistic seismic hazard analysis and take into account the effect of the upper 300 m of rock and soil at the site (site response). The repository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* (BSC 2004w). The ground motion time histories were developed for 5×10^{-4}, 10^{-6}, and 10^{-7} annual exceedance probabilities and have been used to provide inputs to support postclosure analyses of damage to engineered barrier system components from seismic ground-motion, seismic-induced rockfall, and effects related to seismic-induced drift collapse.

The outputs are of particular interest because they are used (BSC 2004x) to determine rock block size, rockfall frequency, and drift-collapse effects related to seismic-induced ground motion, which are addressed in related FEPs. The outputs of that analysis are used to evaluate damage to engineered barrier system components from seismically induced rockfall, which is included in the seismic scenario class for TSPA-LA.

In general, vibratory ground motions can cause failure of the host rock around the emplacement drifts. The characterization of seismic damage is addressed using damage-related response surfaces and is fully discussed in *Seismic Consequences Abstraction* (BSC 2003v, Section 6.6). Damage to the drip shield from impact of individual rock blocks is determined by structural response calculations. The objective of these calculations is to determine the drip shield areas where the residual stress exceeds the threshold value (50% of yield strength) for Titanium Grade 7. The analysis evaluates damage based on six representative rock sizes impacting the drip shield from three angles: vertically downward onto the top of the drip shield, at a 60° angle (with the horizontal) onto the transition region between the top and side of the drip shield, and horizontally into the side wall.

Vibratory ground motions also have the potential to eject large, nonlithophysal rock blocks at high velocity. Rock blocks are ejected for the 10^{-6} per year and the 10^{-7} per year ground motion levels; relatively few blocks are ejected at the 5×10^{-4} per year ground motion level. The mean damage areas for ground motions with 10^{-6} and 10^{-7} annual frequency in the nonlithophysal zone are 1.7% and 3.4%. Maximum values are 32.2% and 63.6%, respectively. Clearly, the mechanical response of the drip shield to impact by a large rock block in the nonlithophysal zone has the potential to damage the drip shield and impair its function as a flow barrier.

5.39.3 Resolution of Comment 79

Updated screening arguments for this FEP are contained in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.4) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.9). KTI Agreements RDTME 3.17 and 3.19 were submitted to NRC in June 2004 (Appendix C *of Technical Basis Document No. 4: Mechanical Degradation and Seismic Effects*). KTI Agreements CLST 2.02 and 2.08 were submitted to NRC as Appendix K to *Technical Basis Document 6: Waste Package and Drip Shield Corrosion*, where results of modeling potential damage to drip shields and waste packages from rockfall and seismic activity are reported. Related information is provided in KTI Agreement CLST 2.03.

5.40 COMMENT J-1

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (CLST Subissue 2 Agreement 8). FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002 will be revised upon completion of this work.

5.40.1 TSPA-SR

FEP 2.1.03.11.00, Container Form

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Waste Package–Excluded because of low consequence.

5.40.2 TSPA-LA

FEP 2.1.03.11.0A, Physical Form of Waste Package and Drip Shield

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.20).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Included.

Summary of Screening Disposition–The waste package, drip shield, and repository design are standardized for the Yucca Mountain project. While there is more than one waste package configuration expected to be used in the repository, they are all similar in their general design, fabrication methodology, and dimensions. Therefore, there will be little variation in strength, dimensions, and shape of the waste packages used in the repository. Effects of different waste forms (commercial spent nuclear fuel, DOE spent nuclear fuel, and defense high-level radioactive waste glass) on heat dissipation and physical and chemical conditions in the vicinity of the waste packages are indirectly included in the TSPA analysis through different thermal-hydrologic-geochemical responses and their impacts on corrosion processes. Waste package and drip shield degradation modes are modeled in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003l), *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003m), and *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2003x).

The physical effects of degraded waste packages and drip shields on flow and transport of radionuclides are indirectly included in the selection of the engineered barrier system flow pathways, but they do not have an explicit effect because the flow pathways are modeled without regard to the detailed mechanisms of flow (FEP 2.1.08.07.0A (BSC 2004b, Section 6.2.37)). Chemical effects of the waste package and drip shield materials are discussed in FEPs 2.1.09.01.0A, Chemical Characteristics of Water in Drifts (BSC 2004b, Section 6.2.43), and 2.1.09.02.0A, *Chemical Interactions with Corrosion Products* (BSC 2004b, Section 6.2.44).

5.40.3 Resolution of Comment J-1

This FEP is now screened as included. The TSPA disposition for this FEP is contained in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.20).

KTI Agreement CLST 2.08 was submitted to NRC in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*. This document describes results of modeling rockfall on the drip shield using the finite element program LS-DYNA. The key result relevant to Comment J-1 was that the maximum vertical displacement in the drip shield components takes place in the longitudinal stiffener during the vertical impact of the 11.5 MT rock block, which has the highest kinetic energy. The maximum displacement is 25.4 cm. The drip shield does not buckle or collapse from this impact. In addition, this maximum displacement is less than the minimum clearance (367 mm) between the inside height of the drip shield and the top of the 5-DHLW waste package. It follows that the drip shield does not contact the waste package even for an impact by the largest rock block, thereby providing a mechanical barrier against rockfall for the waste package and cladding. The 367-mm clearance between the 5-DHLW waste package and the drip shield is the smallest clearance of any of the waste packages. Other waste packages have clearances of 567 mm, 765 mm, 806 mm, and 1,132 mm.

Results of analyzing potential drip shield damage from vibratory ground motion are also reported in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion,* as well as in *Technical Basis Document No. 14: Low Probability Seismic Events.*

5.41 COMMENT J-2

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (CLST Subissue 2 Agreement 8). Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 will be revised upon completion of this work.

5.41.1 TSPA-SR

FEP 2.1.06.05.00, Degradation of Invert and Pedestal

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c, Section 6.2.19).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Engineered Barrier System–Excluded for invert because of low consequence
- Engineered Barrier System–Included for pedestal.

5.41.2 TSPA-LA

FEP 2.1.06.05.0A, Mechanical Degradation of Emplacement Pallet

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.19).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Included.

Summary of Screening Disposition–The model developed in *EBS Radionuclide Transport Abstraction* (BSC 2003q) is used to quantify the time-dependent radionuclide releases from a failed waste package and their subsequent transport through the engineered barrier system to the emplacement drift wall–unsaturated zone interface. The basic inputs to this model, referred to herein as the radionuclide transport abstraction model, consist of the drift seepage influx, the environmental conditions in the drift (temperature, relative humidity, water chemistry), and the degradation state of the engineered barrier system components. The radionuclide transport abstraction model is implemented directly into the TSPA-LA GoldSim model to compute the radionuclide release rates from the engineered barrier system.

In *EBS Radionuclide Transport Abstraction* (BSC 2003q), the emplacement pallet is conservatively modeled as failing instantaneously, resulting in contact between the waste package and the invert. Because the presence of the emplacement pallet is ignored, water and radionuclides pass directly from the waste package to the invert. This enhances the estimated rate of transport of radionuclides from the waste package, since the presence of a pallet would inhibit transport, requiring diffusion through thin water films on the surface of the pallet or potentially delaying advective transport over pallet surfaces or across the space between the waste package and the invert.

Emplacement pallet degradation processes are not analyzed; instead, the presence of a pallet is simply ignored in the flow and transport abstractions.

Analyses of failure scenarios show that pallet failure is unlikely to displace the drip shield or affect the drip shield as a flow barrier. The drip shield design includes a system of posts and mating holes that provide a mechanical connection between adjacent drip shield that is anticipated to be strong enough to hold adjacent drip shields together after failure of the emplacement pallet. If one end of the pallet were to collapse, the opposite end of the waste package could swing upward, potentially lifting and displacing the drip shield. However, calculations show that the upward swing in all waste package designs is insufficient to contact the drip shield, so this scenario will have no impact on the drip shield as a flow barrier.

Pallet failure due to waste package vibration and dislodgment is discussed in FEP 2.1.03.07.0A (BSC 2004c, Section 6.2.13), and pallet displacement from floor buckling is discussed in FEP 2.1.07.06.0A (BSC 2004b, Section 6.2.30).

FEP 2.1.06.05.0B, Mechanical Degradation of Invert

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.20).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–Consolidation of the crushed tuff could result in a slight reduction in porosity in the invert. This effect, which is expected to be small, is conservatively ignored. *EBS Radionuclide Transport Abstraction* (BSC 2003q) does not credit any retardation to flow and transport through the invert resulting from tight porosity.

Physical degradation of the invert and invert materials is excluded from the TSPA because it does not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

Invert damage due to floor buckling is discussed in FEP 2.1.07.06.0A (BSC 2004b, Section 6.2.30). Invert damage due to drift collapse is discussed in FEP 2.1.07.02.0A (BSC 2004b, Section 6.2.27).

FEP 2.1.06.05.0C, Chemical Degradation of Emplacement Pallet

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.21).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–In evaluating flow through the engineered barrier system, *EBS Radionuclide Transport Abstraction* (BSC 2003q) ignores the presence of the emplacement pallet, allowing water and radionuclides to pass directly from the waste package to the invert. Thus, any diffusion barrier (thin water film) on the pallet is not modeled.

FEP 2.1.06.05.0D, Chemical Degradation of Invert

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.22).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–The invert is composed of mild carbon steel components and crushed tuff. The carbon steel components are predicted to corrode very rapidly, within a few hundred years. Because of the high corrosion rates for carbon steel, the effects of seepage interactions with these components were screened out with respect to long-term drift chemistry. Invert materials and other committed materials are included in an evaluation of in-drift microbial communities as sources of energy and nutrients in *In-Drift Microbial Communities* (CRWMS M&O 2000f). Model results show that microbial activity is of low consequence with respect to the composition of the in-drift atmosphere. For these reasons, the chemical effects of degradation of invert materials are excluded from TSPA-LA on the basis of low consequence.

5.41.3 Resolution of Comment J-2

This FEP has been split into four FEPs: FEP 2.1.06.05.0A (BSC 2004b, Section 6.2.19), FEP 2.1.06.05.0B (BSC 2004b, Section 6.2.20), FEP 2.1.06.05.0C (BSC 2004b, Section 6.2.21), and FEP 2.1.06.05.0D (BSC 2004b, Section 6.2.22). All have been screened as excluded except FEP 2.1.06.05.0A. Updated screening arguments for these FEPs are contained in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b). The subject is also addressed by KTI Agreement CLST 2.08, which was submitted to NRC in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion.*

The concern regarding angled rock block impacts due to invert failure is addressed in the response to Comment 79 (Section 5.39 of this document), where it is concluded that the drip shield provides adequate protection to the waste package from rockfall.

5.42 COMMENT J-3

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 2 Agreements 6, 10, and 14, and RT Subissue 1 Agreement 5). Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 will be revised upon completion of this work.

5.42.1 TSPA-SR

FEP 2.1.06.01.00, Degradation of Cementitious Materials in Drift

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Engineered Barrier System–Included (drift degradation)
- Engineered Barrier System–Excluded (impact on seepage chemistry) because of low consequence.

5.42.2 TSPA-LA

FEP 2.1.06.01.0A, Chemical Effects of Rock Reinforcement and Cementitious Materials in Engineered Barrier System

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.16).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–Seepage water entering the drift may react with cement, rock bolts, and Stainless Steel Type 316L mesh in the drift wall. The impact of cement, bolt, and mesh corrosion on the chemistry of seepage entering the drift is evaluated in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m, Section 6.8), and determined to be of low consequence. Oxygen consumption due to corrosion of ground support materials and other committed materials is evaluated in the in-drift gas composition calculations in *Engineered Barrier System: Physical and Chemical Environment Model* (BSC 2004m, Section 6.7). Although the repository may be oxygen depleted for a short period after closure (a few hundred years), primarily due to the corrosion of mild steel, there is no long-term effect on repository atmosphere.

Finally, rock reinforcement materials and other introduced materials are included in an evaluation of *In-Drift Microbial Communities* (CRWMS M&O 2000f, Section 6.3.3) as sources of energy and nutrients. Model results show that microbial activity is sufficiently minor that its impact on gas generation is negligible relative to the 1 order of magnitude uncertainty on the thermal-hydrologic-chemical gas inputs. These three sensitivity analyses indicate that the chemical effects of ground support materials can be excluded on the basis of low consequence. Cementitious materials (cement grout) are not part of the repository drift design. Therefore, chemical effects from cement (grout) degradation and microbial growth on concrete are excluded.

5.42.3 Resolution of Comment J-3

An updated screening argument for the exclusion of this FEP is contained in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.16). The absence of cementitious materials in the current repository design resolves the concerns of the NRC comment. KTI Agreements ENFE 2.06, ENFE 2.10, and ENFE 2.14 were submitted to NRC in November 2003 (Appendices E, G, and J of *Technical Basis Document No. 5: In-Drift Chemical Environment*). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H to *Technical Basis Document No. 11: Saturated Zone Flow and Transport*).

5.43 COMMENT J-4

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the Engineered Barrier System Features, Events, and Processes, ANL-WIS-PA-000002 to address the NRC comment.

5.43.1 TSPA-SR

FEP 2.1.06.05.00, Degradation of Invert and Pedestal

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Engineered Barrier System–Excluded (for invert) because of low consequence
- Engineered Barrier System–Included (for pedestal).

5.43.2 TSPA-LA

FEP 2.1.06.05.0A, Mechanical Degradation of Emplacement Pallet

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.19).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Included.

Summary of Screening Disposition–The model developed in *EBS Radionuclide Transport Abstraction* (BSC 2003q) is used to quantify the time-dependent radionuclide releases from a failed waste package and their subsequent transport through the engineered barrier system to the emplacement drift wall–unsaturated zone interface. The basic inputs to this model, referred to herein as the radionuclide transport abstraction model, consist of the drift seepage influx, the environmental conditions in the drift (temperature, relative humidity, water chemistry), and the degradation state of the engineered barrier system components. The radionuclide transport abstraction model is implemented directly into the TSPA-LA GoldSim model to compute the radionuclide release rates from the engineered barrier system.

In *EBS Radionuclide Transport Abstraction* (BSC 2003q), the emplacement pallet is conservatively modeled as failing instantaneously, resulting in contact between the waste package and the invert. Because the presence of the emplacement pallet is ignored, water and radionuclides pass directly from the waste package to the invert. This enhances the estimated rate of transport of radionuclides from the waste package, since the presence of a pallet would inhibit transport, requiring diffusion through thin water films on the surface of the pallet or potentially delaying advective transport over pallet surfaces or across the space between the waste package and the invert.

Emplacement pallet degradation processes are not analyzed; instead, the presence of a pallet is simply ignored in the flow and transport abstractions.

Analyses of failure scenarios show that pallet failure is unlikely to displace the drip shield or affect the drip shield as a flow barrier. The drip shield design includes a system of posts and mating holes that provide a mechanical connection between adjacent drip shields that is anticipated to be strong enough to hold adjacent drip shields together after failure of the emplacement pallet. If one end of the pallet were to collapse, the opposite end of the waste package could swing upward, potentially lifting and displacing the drip shield. However, calculations show that the upward swing in all waste package designs is insufficient to contact the drip shield, so this scenario will have no impact on the drip shield as a flow barrier.

Pallet failure due to waste package vibration and dislodgment is discussed in FEP 2.1.03.07.0A (BSC 2004c, Section 6.2.13), and pallet displacement from floor buckling is discussed in FEP 2.1.07.06.0A (BSC 2004b, Section 6.2.30).

FEP 2.1.06.05.0B–Mechanical Degradation of Invert

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–Consolidation of the crushed tuff could result in a slight reduction in porosity in the invert. This effect, which is expected to be small, is conservatively ignored. *EBS Radionuclide Transport Abstraction* (BSC 2003q) does not credit any retardation to flow and transport through the invert resulting from tight porosity.

Physical degradation of the invert and invert materials is excluded from the TSPA because it does not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

Invert damage due to floor buckling is discussed in FEP 2.1.07.06.0A (BSC 2004b, Section 6.2.30). Invert damage due to drift collapse is discussed in FEP 2.1.07.02.0A (BSC 2004b, Section 6.2.27).

FEP 2.1.06.05.0C, Chemical Degradation of Emplacement Pallet

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.21).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–In evaluating flow through the engineered barrier system, *EBS Radionuclide Transport Abstraction* (BSC 2003q) ignores the presence of the emplacement pallet, allowing water and radionuclides to pass directly from the waste package to the invert. Thus, any diffusion barrier (thin water film) on pallet is not modeled.

FEP 2.1.06.05.0D, Chemical Degradation of Invert

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.22).

Screening Decision–For the license application, the FEP was screened as follows:

- Engineered Barrier System–Excluded because of low consequence.

Summary of Screening Argument–The invert is composed of mild carbon steel components and crushed tuff. The carbon steel components are predicted to corrode very rapidly, within a few hundred years. Because of the high corrosion rates for carbon steel, the effects of seepage interactions with these components were screened out with respect to long-term drift chemistry. Invert materials and other committed materials are included in an evaluation of in-drift microbial communities as sources of energy and nutrients in *In-Drift Microbial Communities* (CRWMS M&O 2000f). Model results show that microbial activity is of low consequence with respect to the composition of the in-drift atmosphere. For these reasons, the chemical effects of degradation of invert materials are excluded from TSPA-LA on the basis of low consequence.

5.43.3 Resolution of Comment J-4

This FEP has been split into four FEPs: FEP 2.1.06.05.0A (BSC 2004b, Section 6.2.19), FEP 2.1.06.05.0B (BSC 2004b, Section 6.2.20), FEP 2.1.06.05.0C (BSC 2004b, Section 6.2.21), and FEP 2.1.06.05.0D (BSC 2004b, Section 6.2.22). All have been screened as excluded except FEP 2.1.06.05.0A. Updated screening arguments for these FEPs are contained in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b). The subject is also addressed by KTI Agreement CLST 2.08, which was submitted to NRC in Appendix K of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*

5.44 COMMENT J-7

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, RT Subissue 1 Agreement 5, and RT Subissue 2 Agreement 10). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.44.1 TSPA-SR

FEP 2.2.08.01.00, Groundwater Chemistry/Composition in UZ and SZ SZ–Groundwater Chemistry FEPs

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Included (effects of ambient-condition geochemistry)
- Unsaturated Zone–Excluded (changes in geochemical conditions) because of low consequence.

5.44.2 TSPA-LA

FEP 2.2.08.01.0A, Chemical Characteristics of Groundwater in the SZ

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.25).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Included.

Summary of Screening Disposition–Variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater affect sorption of radionuclides onto the rock surface and colloids, which, in turn, affects the sorption coefficient, K_d, and, thus, the retardation factor, R_f, for each radionuclide. In *Site-Scale Saturated Zone Transport* (BSC 2003h, Sections 6.2 and 6.5.2.4.1), these coefficients are entered directly in the transport base-case model that describes radionuclide transport via the distribution coefficients and the retardation factors, which describe reactive transport through porous media. The effects of thermal-hydrologic-chemical and dissolved gases within the saturated zone are implicitly included in the variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater. Appropriate ranges and distributions of values for K_ds are chosen based on expert elicitation and laboratory and field studies for the sorption coefficient K_d.

Regarding the spatial and temporal dependencies of K_d, geochemical analysis indicates that current saturated zone groundwater under the repository and along the saturated zone transport path is paleoclimate recharge water. Spatial variability in the composition of the groundwater reflects, in part, temporal variability in recharge when data from Fortymile Wash are included. Uncorrected ^{14}C groundwater ages range from a few thousand years in the vicinity of Fortymile Wash to values greater than 15,000 years under portions of Yucca Mountain. Using the reasonable approach that spatial variability within the recharge domain brackets the temporal variability expected to occur at a given location within the domain, the observed variability in geochemistry among the wells in the model area brackets the temporal variations expected to occur in the water composition. Additionally, significant water table rise is evidenced to have occurred under paleoclimatic conditions. Thus, the water quality of sampled paleoclimate recharge water reflects past interactions with rock types overlying the current water table, as well as the rock types along the expected transport pathways. Consequently, the range in each radionuclide K_d and effective colloidal retardation factor bracket the temporal variations in water composition given volume and time of recharge, as well as the variability in pH, Eh, mineralogy, and the number of rock sorption sites.

FEP 2.2.08.01.0B, Chemical Characteristics of Groundwater in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.28).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Included.

Summary of Screening Disposition–Thermal-hydrologic-chemical seepage model simulations feeding the drift-scale coupled processes abstraction were run explicitly using five input water compositions spanning the range of compositions at Yucca Mountain. This variability of pore-water compositions in repository host units implicitly reflects spatial variations in rock mineralogy and infiltration rates. Therefore, the results of the thermal-hydrologic-chemical seepage model and its abstraction explicitly reflect the natural variability of pore-water compositions and implicitly reflect the natural variability of rock mineralogy.

The effects of groundwater chemical characteristics are included in the radionuclide sorption coefficients under ambient conditions. The sorption coefficient data, on which the distributions are based, are developed from laboratory experiments in which crushed rock samples from the Yucca Mountain site are contacted with groundwater (or simulated groundwater) representative of the site, which is spiked with one or more of the elements of interest. The chemistry of pore waters and perched waters in the unsaturated zone along potential flow paths to the accessible environment is discussed in *Analysis of Geochemical Data for the Unsaturated Zone* (BSC 2002c). In the unsaturated zone, two water types exist in the ambient system: perched water and pore water. Perched water is generally more dilute than pore water. The well J-13 and UE-25 p#1 waters were used in sorption experiments as end-member compositions intended to bracket the impact of water composition on sorption coefficients. Some spatial trends in water composition for the TSw and CHn hydrogeologic units have been noted. However, the uncertainty in these spatial trends and the uncertainty with respect to the effects of the bounding water compositions on sorption have led to the treatment of natural variability in water composition as uncertainty in the probability distributions sampled by TSPA-LA. Sorption experiments have been carried out as a function of time, element concentration, atmospheric composition, particle size, and temperature. In some cases, the solids remaining from sorption experiments were contacted with unspiked groundwater in desorption experiments. Experimental data were used to determine the sorption. The sorption and desorption experiments together provide information on the equilibration rates of the forward and backward sorption reactions. For elements that sorb primarily through surface complexation reactions, the experimental data are augmented with the results of modeling calculations using PHREEQC V2.3 (BSC 2001c). The inputs for the modeling calculations include groundwater compositions, surface areas, binding constants for the elements of interest, and thermodynamic data for solution species. These modeling calculations provide a basis for interpolation and extrapolation of the experimentally derived sorption coefficient data set. The effects of nonlinear sorption are approximated by capturing the effective K_d range.

The effects of groundwater composition with respect to sorption coefficients are provided in terms of probability distributions for the sorption coefficient of each element of interest among the three major rock types (devitrified, zeolitic, and vitric) found in the unsaturated zone. The influence of expected variations in water chemistry, radionuclide concentrations, and variations in rock surface properties within one of the major rock types are incorporated into these probability distributions. These distributions are specified for each radionuclide and rock type combination and are sampled in the TSPA-LA to account for the effects of natural variations in pore-water chemistry and mineral surfaces on sorption. Correlations for sampling sorption coefficient probability distributions have been derived for the elements investigated.

5.44.3 Resolution of Comment J-7

This FEP has been split into two FEPs: 2.2.08.01.0A for saturated zone and 2.2.07.01.0B for unsaturated zone. Both FEPs are now screened as included, and TSPA dispositions are contained in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.25) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.28), respectively.

KTI Agreement ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C of *Technical Basis Document No. 8: Colloids*). Agreements RT 1.05 and 2.10 were submitted to NRC in October 2003 (Appendix H of *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Related information is provided in KTI Agreement ENFE 1.04.

5.45 COMMENT J-8

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, and RT Subissue 1 Agreement 5). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.45.1 TSPA-SR

FEP 2.2.08.02.00, Radionuclide Transport Occurs in a Carrier Plume in Geosphere SZ–Radionuclide Transport in a Carrier Plume

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Excluded because of low consequence.

5.45.2 TSPA-LA

FEP 2.2.08.01.0A, Chemical Characteristics of Ground Water in the Saturated Zone

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.25).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Included.

Summary of Screening Disposition–Variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater affect sorption of radionuclides onto the rock surface and colloids, which, in turn, affects the sorption coefficient, K_d, and, thus, the retardation factor, R_f, for each radionuclide. In *Site-Scale Saturated Zone Transport* (BSC 2003h, Sections 6.2 and 6.5.2.4.1), these coefficients are entered directly in the transport base-case model that describes radionuclide transport via the distribution coefficients and the retardation factors, which describe reactive transport through porous media. The effects of thermal-hydrologic-chemical and dissolved gases within the saturated zone are implicitly included in the variations in temperature, pH, Eh, ionic strength, and major ionic concentrations in the groundwater. Appropriate ranges and distributions of values for K_ds are chosen based on the *Saturated Zone Flow and Transport Expert Elicitation Project* (CRWMS M&O 1998a, Section 3.2) and laboratory and field studies for the sorption coefficient K_d.

Regarding the spatial and temporal dependencies of K_d, geochemical analysis indicates that current saturated zone groundwater under the repository and along the saturated zone transport path is paleoclimate recharge water. Spatial variability in the composition of the groundwater reflects, in part, temporal variability in recharge when data from the Fortymile Wash are included. Uncorrected ^{14}C groundwater ages range from a few thousand years in the vicinity of the Fortymile Wash to values greater than 15,000 years under portions of Yucca Mountain. Using the reasonable approach that spatial variability within the recharge domain brackets the temporal variability expected to occur at a given location within the domain, the observed variability in geochemistry among the wells in the model area brackets the temporal variations expected to occur in the water composition.

FEP 2.2.08.01.0B, Chemical Characteristics of Groundwater in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.28).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–Thermal-hydrologic-chemical seepage model simulations feeding the drift-scale coupled processes abstraction were run explicitly using five input water compositions spanning the range of compositions at Yucca Mountain. This variability of pore-water compositions in repository host units implicitly reflects spatial variations in rock mineralogy and infiltration rates. Therefore, the results of the thermal-hydrologic-chemical seepage model and its abstraction explicitly reflect the natural variability of pore-water compositions and implicitly reflect the natural variability of rock mineralogy.

The effects of groundwater chemical characteristics are included in the radionuclide sorption coefficients under ambient conditions. The sorption coefficient data on which the distributions are based on laboratory experiments in which crushed rock samples from the Yucca Mountain site are contacted with groundwater (or simulated groundwater) representative of the site, spiked with one or more of the elements of interest. The chemistry of pore waters and perched waters in the unsaturated zone along potential flow paths to the accessible environment is discussed in *Analysis of Geochemical Data for the Unsaturated Zone* (BSC 2002c). In the unsaturated zone, two water types exist in the ambient system: perched water and pore water. Perched water is generally more dilute than pore water. The well J-13 and UE-25 p#1 waters were used in sorption experiments as end-member compositions intended to bracket the impact of water composition on sorption coefficients. Some spatial trends in water composition for the TSw and CHn hydrogeologic units have been noted. However, the uncertainty in these spatial trends and the uncertainty with respect to the effects of the bounding water compositions on sorption have led to the treatment of natural variability in water composition as uncertainty in the probability distributions sampled by TSPA-LA. Sorption experiments have been carried out as a function of time, element concentration, atmospheric composition, particle size, and temperature. In some cases, the solids remaining from sorption experiments were contacted with unspiked groundwater in desorption experiments. Experimental data were used to determine the sorption. The sorption and desorption experiments together provide information on the equilibration rates of the forward and backward sorption reactions. For elements that sorb primarily through surface complexation reactions, the experimental data are augmented with the results of modeling calculations using PHREEQC V2.3 (BSC 2001c). The inputs for the modeling calculations include groundwater compositions, surface areas, binding constants for the elements of interest, and thermodynamic data for solution species. These modeling calculations provide a basis for interpolation and extrapolation of the experimentally derived sorption coefficient data set. The effects of nonlinear sorption are approximated by capturing the effective K_d range.

The effects of groundwater composition with respect to sorption coefficients are provided in terms of probability distributions for the sorption coefficient of each element of interest among the three major rock types (devitrified, zeolitic, and vitric) found in the unsaturated zone. The influence of expected variations in water chemistry, radionuclide concentrations, and variations in rock surface properties within one of the major rock types are incorporated into these probability distributions. These distributions are specified for each radionuclide and rock type combination and are sampled in TSPA-LA to account for the effects of natural variations in pore-water chemistry and mineral surfaces on sorption. Correlations for sampling sorption coefficient probability distributions have been derived for the elements investigated.

FEP 2.2.08.03.0A, Geochemical Interactions and Evolution in the Saturated Zone

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.26).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Geochemical analysis indicates current saturated zone groundwater under the repository and along the saturated zone transport path is paleoclimate recharge water. The paleoclimate recharge water currently undergoes rock-water interactions in the unsaturated zone and saturated zone and, in the past, has mixed with waters from flow systems having different recharge waters than those indicative of current dry climatic conditions. These waters are reflective of cooler climatic conditions and cooler recharge waters 10,000 to 16,000 years old. Cooler water is able to dissolve more oxygen and thus has a higher oxidation state than warmer water (i.e., the temperature dependency of Henry's Law). Compared to recharge waters reflective of current climatic conditions, paleoclimate recharge waters have higher carbon contents and higher concentrations of dissolved CO_2 gas, which also contributes to higher oxidation states (Eh potential) and a lower pH. Lower pH values and higher CO_2 concentrations equate to waters that are more aggressive and will participate in more dissolution and subsequent precipitation along the transport path compared to groundwater originating from current climatic conditions. Consequently, resident saturated zone water chemistry currently encountered along the saturated zone transport path reflects the maximum time-dependent variability in pH and CO_2 gas concentrations. As a result, current geochemical conditions, used to derive the range in each radionuclide K_d and effective colloidal retardation factor, bracket the temporal variations in water chemistry given the volume and time of recharge, as well as the variability in pH, Eh, mineralogy, and the number of rock sorption sites. Therefore, temporal changes in water geochemistry are excluded based on low consequence.

Regional Yucca Mountain saturated zone recharge waters mainly occur through direct infiltration through the unsaturated zone and not through surface water recharge (such as lakes and perennial rivers). Consequently, temporal changes in surface water quantities are excluded based on low consequence. Since hydrothermal activity is considered to be low consequence to regional saturated zone flow and flow paths in the Yucca Mountain vicinity (FEP 1.2.06.00.0A (BSC 2004f, Section 6.7.2; BSC 2004e, Section 6.2.5)), temporal geochemical changes due to an increase in geothermal (hydrothermal) activity will not affect saturated zone geochemistry and are, therefore, excluded based on low consequence.

Detailed discussions pertaining to related FEPs in groundwater chemistry, as it effects transport and sorption, are addressed by the following FEPs: FEP 2.2.08.01.0A, chemical characteristics of groundwater in the saturated zone (BSC 2004e, Section 6.2.25); FEP 2.2.08.06.0A, complexation in the saturated zone (BSC 2004e, Section 6.2.27); FEP 2.2.08.07.0A, radionuclide solubility limits in the saturated zone (BSC 2004e, Section 6.2.28); FEP 2.2.08.09.0A, sorption in the saturated zone (BSC 2004e, Section 6.2.30); FEP 2.2.08.10.0A, colloid transport in the saturated zone (BSC 2004e, Section 6.2.31); and the following reports: *Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain, Nevada* (BSC 2004j, Section 6.7), *Saturated Zone Colloid Transport* (BSC 2003y, Section 6.2), and *Site-Scale Saturated Zone Transport* (BSC 2003h, Attachments I, II, III, and IV). All of the above reasoned arguments support the conclusion that geochemical interactions and evolution is excluded based on low consequence to radiological exposures to the RMEI.

FEP 2.2.08.03.0B, Geochemical Interactions and Evolution in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.7).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The thermal-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts using the thermal-hydrologic-chemical seepage model. This model, which explicitly captures the effects of changes in temperature, pH, Eh, ionic strength (and other compositional variables), time dependency, precipitation–dissolution effects, and effects of resaturation, was used to examine near-field and drift seepage flow and chemistry. Changes in fracture permeabilities were found to be on the order of the natural variation in these properties, with most of the substantial effects limited to regions above and to the side of the drift within about a drift diameter. The predicted mineral precipitation reduces the permeability in the affected regions and leads to a reduction in flow around the drift. This is conservative for both flow and transport phenomena and, therefore, neglect of these types of permeability changes on near-field and drift seepage flow has no adverse effects on repository performance. The effects of mineral precipitation on fracture permeability as they relate to near-field and drift seepage chemistry were also evaluated with the thermal-hydrologic-chemical seepage model. Further discussion is provided with related FEP 2.2.03.02.0A in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.11).

Two alternative conceptualizations of the modeled geochemical system were used for the model. The systems were denoted as base case and extended case and differ somewhat from one model variation to another. The extended case includes the major solid phases (minerals and glass) encountered in geologic units at Yucca Mountain, together with a range of possible reaction product minerals, CO_2 gas, and the aqueous species necessary to include these solid phases and the pore-water composition within the thermal-hydrologic-chemical model. The base case is a subset of the extended case excluding aluminum silicate minerals, which form or dissolve much less easily than minerals such as calcite or gypsum and for which thermodynamic and kinetic data are not as well established as for the other minerals. As such, the base-case system conceptualizes a geochemical system in which aluminum silicate minerals are nonreactive. The base-case system also does not include iron- and magnesium-bearing phases and aqueous species.

Compositional changes were only calculated near the drift boundary for the drift-scale thermal-hydrologic-chemical seepage model. Results from the extended and base-case models show most compositional variations returning to unperturbed conditions in 10,000 years or less. Variations in pH, a key compositional variable for sorption of some radionuclides, roughly lie within the range of variability investigated for initial pore-water compositions. Bicarbonate is found to be depressed in concentration upon water resaturation at the drift wall, as expected based on the reduced pH values for the same time period.

Results were also investigated for the Tptpll (lower lithophysal unit) model considering a range of initial pore-water compositions. In this model, five initial pore water compositions were investigated. Peak concentrations usually found at the time of rewetting in both models reflect mostly the small values of the first nonzero liquid-saturation output. In any case, elevated concentrations are predicted only for small liquid saturations that are not subject to significant fluid movement. The improved treatment of mineral precipitation at the boiling front used in the most recent thermal-hydrologic-chemical model for the Tptpll also results in the prediction of lower, more realistic aqueous silica concentrations than in earlier models. This model also predicts, upon rewetting, more rapid return to near-ambient conditions for aqueous calcium, sodium, and chlorine.

The findings indicate that, at the drift wall, most of the significant compositional variations resulting from thermal-chemical processes are limited to low-saturation conditions over time periods that are short relative to the 10,000-year performance period. Similar magnitudes of variation in chloride and pH were found in the mountain-scale thermal-hydrologic-chemical model results. The magnitudes of the variations are found to be smaller at greater distances from the drift wall. As for the drift-scale study, variations in chloride are driven mainly by evaporation and are found to return to near-ambient values upon rewetting. Variations in pH were found to lie roughly between 7 and 9, which is similar to the results for the drift-scale thermal-hydrologic-chemical model. The most persistent change in pH is a level of about 7 in the Calico Hills, but this lies within the range of pH investigated for radionuclide sorption. Therefore, the effects of these changes are excluded from TSPA-LA on the basis of low consequence.

5.45.3 Resolution of Comment J-8

FEP 2.2.08.02.00 was redundant with FEPs 2.2.08.01.00 and 2.2.08.03.00. For TSPA-LA, these FEPs are replaced by saturated zone FEPs 2.2.08.01.0A and 2.2.08.03.0A (BSC 2004e, Sections 6.2.25 and 6.2.26) and unsaturated zone FEPs 2.2.08.01.0B and 2.2.08.03.0B (BSC 2004f, Sections 6.1.28 and 6.8.7). Updated dispositions and screening arguments for these FEPs are contained in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f).

KTI Agreements ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C in *Technical Basis Document No. 8: Colloids*). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H in *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Related information is provided in KTI Agreement ENFE 1.04.

5.46 COMMENT J-9

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreements 4 and 7 and ENFE Subissue 2 Agreement 6). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.46.1 TSPA-SR

FEP 2.2.08.03.00, Geochemical Interactions in Geosphere (Dissolution, Precipitation, Weathering) and Effects on Radionuclide Transport SZ–Groundwater Chemistry FEPs

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included (changes of fracture porosity in thermal-hydrologic-chemical model)
- Near Field Environment–Excluded (changes of fracture porosity in radionuclide transport model) because of low consequence
- Saturated Zone–Included
- Unsaturated Zone–Included (effects of ambient-condition geochemistry)
- Unsaturated Zone–Excluded (changes in geochemistry due to thermal-chemical effects of the repository) because of low consequence.

5.46.2 TSPA-LA

FEP 2.2.08.03.0A, Geochemical Interactions and Evolution in the Saturated Zone

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e), Section 6.2.26).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Geochemical analysis indicates current saturated zone groundwater under the repository and along the saturated zone transport path is paleoclimate recharge water. The paleoclimate recharge water currently undergoes rock–water interactions in the unsaturated zone and saturated zone and, in the past, has mixed with waters from flow systems having different recharge waters than those indicative of current dry climatic conditions. These waters are reflective of cooler climatic conditions and cooler recharge waters 10,000 to 16,000 years old. Cooler water is able to dissolve more oxygen and, thus, has a higher oxidation state than warmer water (i.e., the temperature dependency of Henry's Law). Compared to recharge waters reflective of current climatic conditions, paleoclimate recharge waters have higher carbon contents and higher concentrations of dissolved CO_2 gas, which also contributes to higher oxidation states (Eh potential) and a lower pH. Lower pH values and higher CO_2 concentrations equate to waters that are more aggressive and will participate in more dissolution and subsequent precipitation along the transport path compared to groundwaters originating from current climatic conditions. Consequently, resident saturated zone water chemistry currently encountered along the saturated zone transport path reflects the maximum time-dependent variability in pH and CO_2 gas concentrations. As a result, current geochemical conditions used to derive the range in each radionuclide K_d and effective colloidal retardation factor, bracket the temporal variations in water chemistry, given the volume and time of recharge, as well as the variability in pH, Eh, mineralogy, and the number of rock sorption sites. Therefore, temporal changes in water geochemistry are excluded based on low consequence.

Regional Yucca Mountain saturated zone recharge waters mainly occur through direct infiltration through the unsaturated zone and not through surface water recharge (such as lakes and perennial rivers). Consequently, temporal changes in surface water quantities are excluded based on low consequence. Since hydrothermal activity is considered to be of low consequence to regional saturated zone flow and flow paths in the Yucca Mountain vicinity (FEP 1.2.06.00.0A (BSC 2004f, Section 6.7.2; BSC 2004e, Section 6.2.5)), temporal geochemical changes due to an increase in geothermal (hydrothermal) activity will not affect saturated zone geochemistry and are, therefore, excluded based on low consequence.

Detailed discussions pertaining to related FEPs in groundwater chemistry, as it effects transport and sorption, are addressed by the following FEPs: FEP 2.2.08.01.0A, chemical characteristics of groundwater in the saturated zone (BSC 2004e, Section 6.2.25); FEP 2.2.08.06.0A, complexation in the saturated zone (BSC 2004e, Section 6.2.27); FEP 2.2.08.07.0A, radionuclide solubility limits in the saturated zone (BSC 2004e, Section 6.2.28); FEP 2.2.08.09.0A, sorption in saturated zone (BSC 2004e, Section 6.2.30); FEP 2.2.08.10.0A, colloid transport in the saturated zone (BSC 2004e, Section 6.2.31); and the following reports: *Geochemical and Isotopic Constraints on Groundwater Flow Directions and Magnitudes, Mixing, and Recharge at Yucca Mountain* (BSC 2004j, Section 6.7), *Saturated Zone Colloid Transport* (BSC 2003y, Section 6.2), and *Site-Scale Saturated Zone Transport* (BSC 2003h, Attachments I, II, III, and IV). All of the above reasoned arguments support the conclusion that geochemical interactions and evolution are excluded based on low consequence to radiological exposures to the RMEI.

FEP 2.2.08.03.0B, Geochemical Interactions and Evolution in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.7).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The thermal-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts using the thermal-hydrologic-chemical seepage model. This model, which explicitly captures the effects of changes in temperature, pH, Eh, ionic strength (and other compositional variables), time dependency, precipitation–dissolution effects, and effects of resaturation, was used to examine near-field and drift seepage flow and chemistry. Changes in fracture permeabilities were found to be on the order of the natural variation in these properties, with most of the substantial effects limited to regions above and to the side of the drift within about a drift diameter. The predicted mineral precipitation reduces the permeability in the affected regions and leads to a reduction in flow around the drift. This is conservative for both flow and transport phenomena and, therefore, exclusion of these types of permeability changes on near-field and drift seepage flow has no adverse effects on repository performance. The effects of mineral precipitation on fracture permeability, as they relate to near-field and drift seepage chemistry, were also evaluated with the thermal-hydrologic-chemical seepage model. Further discussion is provided with related FEP 2.2.03.02.0A in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.11).

Two alternative conceptualizations of the modeled geochemical system were used for the model. The systems were denoted as base case and extended case and differ somewhat from one model variation to another. The extended case includes the major solid phases (minerals and glass) encountered in geologic units at Yucca Mountain, together with a range of possible reaction product minerals, CO_2 gas, and the aqueous species necessary to include these solid phases and the pore-water composition within the thermal-hydrologic-chemical model. The base case is a subset of the extended case excluding aluminum silicate minerals, which form or dissolve much less easily than minerals such as calcite or gypsum and for which thermodynamic and kinetic data are not as well established as for the other minerals. As such, the base-case system conceptualizes a geochemical system in which aluminum silicate minerals are nonreactive. The base-case system also does not include iron- and magnesium-bearing phases and aqueous species.

Compositional changes were only calculated near the drift boundary for the drift-scale thermal-hydrologic-chemical seepage model. Results from the extended and base-case models show most compositional variations returning to unperturbed conditions in 10,000 years or less. Variations in pH, a key compositional variable for sorption of some radionuclides, roughly lie within the range of variability investigated for initial pore-water compositions. Bicarbonate is found to be depressed in concentration upon water resaturation at the drift wall, as expected based on the reduced pH values for the same time period.

Results were also investigated for the Tptpll (lower lithophysal unit) model considering a range of initial pore-water compositions. In this model, five initial pore water compositions were investigated. Peak concentrations usually found at the time of rewetting in both models reflect mostly the small values of the first nonzero liquid-saturation output. In any case, elevated concentrations are predicted only for small liquid saturations that are not subject to significant fluid movement. The improved treatment of mineral precipitation at the boiling front used in the most recent thermal-hydrologic-chemical model for the Tptpll also results in the prediction of lower, more realistic aqueous silica concentrations than in earlier models. This model also predicts, upon rewetting, more rapid return to near-ambient conditions for aqueous calcium, sodium, and chlorine.

The findings indicate that, at the drift wall, most of the significant compositional variations resulting from thermal-chemical processes are limited to low-saturation conditions over time periods that are short relative to the 10,000-year performance period. Similar magnitudes of variation in chloride and pH were found in the mountain-scale thermal-hydrologic-chemical model results. The magnitudes of the variations are found to be smaller at greater distances from the drift wall. As for the drift-scale study, variations in chloride are driven mainly by evaporation and are found to return to near-ambient values upon rewetting. Variations in pH were found to lie roughly between 7 and 9, which is similar to the results for the drift-scale thermal-hydrologic-chemical model. The most persistent change in pH is a level of about 7 in the Calico Hills, but this lies within the range of pH investigated for radionuclide sorption. Therefore, the effects of these changes are excluded from TSPA-LA on the basis of low consequence.

5.46.3 Resolution of Comment J-9

This FEP was split into two FEPs: 2.2.08.03.0A (BSC 2004e, Section 6.2.26) for the saturated zone and 2.2.08.03.0B (BSC 2004f, Section 6.8.7) for the unsaturated zone, which contain updated screening arguments. KTI Agreement ENFE 2.06 was submitted to NRC in November 2003 (Appendix E of *Technical Basis Document No. 5: In-Drift Chemical Environment*). Additional information is provided in KTI Agreement ENFE 1.04.

Comment J-9 has also been addressed separately; in response to a NRC letter of March 20, 2003 (Schlueter 2003), DOE addressed KTI Agreements ENFE 1.07, ENFE 4.02, and TSPAI 2.02, Comments J-9 and J-21 in May 2004 by submitting a revision of *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2004t) to NRC.

5.47 COMMENT J-10

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, and RT Subissue 1 Agreement 5). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.47.1 TSPA-SR

FEP 2.2.08.06.00, Complexation in Geosphere

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Included (effects of ambient-condition complexation)
- Unsaturated Zone–Excluded (effects of changes to complex formation due to changes in geochemical conditions) because of low consequence.

5.47.2 TSPA-LA

FEP 2.2.08.06.0B, Complexation in the UZ

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.31).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–The effects of complexation are implicitly included in the radionuclide sorption coefficients under ambient conditions. The sorption coefficient data on which the distributions are based are obtained in laboratory experiments in which crushed rock samples from the Yucca Mountain site are contacted with groundwater (or simulated groundwater) representative of the site, spiked with one or more of the elements of interest. As such, the sorption experiments contain representative ligands responsible for complex formation, such as carbonates. Sorption experiments have been carried out as a function of time, element concentration, atmospheric composition, particle size, and temperature. In some cases, the solids remaining from sorption experiments were contacted with unspiked groundwater in desorption experiments.

The effects of organics on sorption were also investigated by Triay et al. (1997, Section IV.B). Their experiments tested the effects of organic materials (DOPA (dihydroxyphenylalanine) and NAFA (Nordic aquatic fulvic acid)) on the sorption of plutonium and neptunium on tuff materials. The results of these tests showed very little effect of the organic materials for sorption of these radionuclides in tuffs. The effects of complexation with respect to sorption coefficients are provided in terms of probability distributions for the sorption coefficient of each element of interest among the three major rock types (devitrified, zeolitic, and vitric) found in the unsaturated zone. The influence of expected variations in water chemistry, radionuclide concentrations, and variations in rock surface properties within one of the major rock types are incorporated into these probability distributions. These distributions are specified for each radionuclide and rock-type combination and are sampled in the TSPA-LA to account for the effects of natural variations in pore-water chemistry and mineral surfaces on sorption. Correlations for sampling sorption coefficient probability distributions have been derived for the elements investigated.

5.47.3 Resolution of Comment J-10

This FEP was split into two FEPs: 2.2.08.06.0A for the saturated zone and 2.2.08.06.0B for the unsaturated zone. The screening disposition relevant to this NRC comment is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.31). KTI Agreements ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C to *Technical Basis Document No. 8: Colloids*). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H to *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Related information is provided in KTI Agreement ENFE 1.04.

5.48 COMMENT J-11

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 4 Agreement 3). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.48.1 TSPA-SR

FEP 2.2.08.07.00, Radionuclide Solubility Limits in the Geosphere

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Excluded because of low consequence.

5.48.2 TSPA-LA

FEP 2.2.08.07.0A, Radionuclide Solubility Limits in the SZ

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.28).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–*Saturated Zone Flow and Transport Model Abstraction* (BSC 2003u) does not implement a solubility limit for each transported radionuclide, thus allowing the radionuclide solution concentration that is introduced into the saturated zone from the unsaturated zone to be unconstrained. If a solubility limit were to be imposed into the saturated zone model that is lower than that implemented in *Dissolved Concentration Limits of Certain Radioactive Elements* (BSC 2001h, Section 6.5), it would cause precipitates to form, pulling constituents out of the aqueous phase and reducing the maximum aqueous concentration capable of being transported downstream to the compliance boundary. Additionally, physical buildup of a solid phase onto mineral surfaces (due to precipitation, not adsorption) can reduce permeability, increase tortuosity, and clog pores, thus increasing transport times.

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

FEP 2.2.08.07.0B, Radionuclide Solubility Limits in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.8).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–If solubility limits are lower in the geosphere than in the emplacement drifts, then more radionuclides will precipitate there. This corresponds to fewer dissolved radionuclides being available for transport in the geosphere, which is beneficial and results in no adverse effects on performance. Because the solubility is assumed to be the same in the unsaturated zone as the invert, no reduction in concentration occurs at the engineered barrier system–unsaturated zone boundary. Therefore, this FEP is excluded based on low consequence.

5.48.3 Resolution of Comment J-11

This FEP was split into two FEPs: 2.2.08.07.0A for the saturated zone and 2.2.08.07.0B for the unsaturated zone. Updated screening arguments are contained in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.28) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.8), respectively. KTI Agreement ENFE 4.03 was submitted to NRC in October 2003 (Appendix C of *Technical Basis Document No. 8: Colloids*).

5.49 COMMENT J-12

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, and RT Subissue 1 Agreement 5). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.49.1 TSPA-SR

FEP 2.2.10.01.00, Repository-Induced Thermal Effects in Geosphere

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Included (thermal-chemical effects on drift seepage)
- Unsaturated Zone–Excluded (mountain-scale thermal-chemical effects) because of low consequence.

5.49.2 TSPA-LA

FEP 2.2.10.01.0A, Repository-Induced Thermal Effects on Flow in the UZ

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.9).

Screening Decision, For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Thermal-hydrologic modeling at the mountain scale has been performed using two-dimensional cross-sectional and three-dimensional dual-permeability models. During the early part of the heating period, important thermal-hydrologic processes occur near the emplacement drifts. The mountain-scale models are used to capture the thermal-hydrologic behavior at later times, when the perturbation in temperature and fracture and matrix liquid saturation extends over a much larger space domain compared to the drift-scale effects. These mountain-scale thermal-hydrologic processes include repository edge effects, large-scale enhanced water and gas flow, and potential alteration of perched-water bodies. Results from the modeling indicate that the induced flow from thermal-hydrologic processes is much smaller than changes in flow resulting from climate change at 600 and 2,000 years, which are included in the flow and transport models (FEP 1.3.01.00.0A (BSC 2004f, Section 6.1.4)). Percolation flux maps at the top of the CHn for the ambient and thermally perturbed case (at 500 years of heating) show very similar flow patterns, with the exception of reduced flow through a central portion of the waste emplacement area under the thermally perturbed case. For thermal effects on chemical processes, see FEP 2.2.08.03.0B (BSC 2004f, Section 6.8.7). For thermal effects on mechanical processes, see FEP 2.2.10.04.0A (BSC 2004f, Section 6.8.10).

This FEP is excluded from TSPA-LA based on low consequence because climate-induced changes in unsaturated zone flow overwhelm any short-term thermal impacts on unsaturated zone flow.

5.49.3 Resolution of Comment J-12

An updated screening argument, based on mountain-scale, thermal-hydrologic modeling results, is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.9). KTI Agreements ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C to *Technical Basis Document No. 8: Colloids*). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H to *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Additional information is presented in KTI Agreement ENFE 1.04.

5.50 COMMENT J-13

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, and RT Subissue 1 Agreement 5). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.50.1 TSPA-SR

FEP 2.2.10.06.00, Thermo-Chemical Alteration (Solubility Speciation, Phase Changes, Precipitation/Dissolution)

This FEP was addressed in *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 2001d), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Near Field Environment–Included (in-drift geochemical model that uses water chemistry and gas-phase composition from the drift-scale thermal-hydrologic-chemical model that includes thermal-chemical alteration)
- Near Field Environment–Excluded (effects in thermal-hydrologic models) because of low consequence
- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

5.50.2 TSPA-LA

FEP 2.2.10.06.0A, Thermo-Chemical Alteration in the UZ (Solubility, Speciation, Phase Changes, Precipitation/Dissolution)

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.13).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–This FEP raises some issues already addressed in FEP 2.2.08.03.0B (BSC 2004f, Section 6.8.7) and FEP 2.2.08.07.0B (BSC 2004f, Section 6.8.8).

If solubility limits decrease in the geosphere compared with the waste emplacement drifts, then more radionuclides will precipitate as water flows out of the drifts. This corresponds to fewer dissolved radionuclides being available for transport into the geosphere, which is beneficial and results in no adverse effects on performance. If solubility limits increase in the geosphere compared with the waste emplacement drift, there is no effect on transport because all available radionuclides from the source at the waste emplacement drift are already aqueous species. Because the solubility is considered the same in the unsaturated zone and the engineered barrier system, the effects on any reduced solubility on transport are excluded.

The effects of temperature on radionuclide sorption were evaluated in *Abstraction of Drift-Scale Coupled Processes* (BSC 2004u, Section 6.4). This evaluation focused on the radionuclides cesium, strontium, barium (a proxy for radium), cerium, europium, uranium(VI), neptunium, plutonium, and americium. The effects of temperature on sorption were found to be negligible for these radionuclides, except for strontium, neptunium, and uranium(VI). For these three radionuclides, the effects of increased temperature leads to increased sorption. Therefore, the effects of temperature on radionuclide transport can be excluded on the basis of low consequence because it has no adverse effects on performance.

The thermal-chemical interactions that will occur in the repository environment have been studied with respect to effects on the seepage water entering the waste emplacement drifts. This model explicitly captures the effects of changes in temperature, pH, Eh, ionic strength (and other compositional variables), time dependency, precipitation–dissolution effects, and effects of resaturation. Changes in fracture permeabilities were found to be on the order of the natural variation in these properties, with most of the substantial effects limited to regions above and to the side of the drift within about a drift diameter. The predicted mineral precipitation decreases permeability in the affected regions and leads to a reduction in flow around the drift. This is conservative for both drift seepage and radionuclide transport phenomena, and, therefore, neglect of these types of permeability changes has no adverse effects on repository performance.

Results of drift-scale thermal-hydrologic-chemical modeling indicate that, at the drift wall, most of the significant compositional variations resulting from thermal-chemical processes are limited to low-saturation conditions over time periods that are short relative to the 10,000-year performance period. Similar magnitudes of variation in chloride and pH were found in the mountain-scale thermal-hydrologic-chemical model results. The magnitudes of the variations are found to be smaller at greater distances from the drift wall. As for the drift-scale study, variations in chloride are driven mainly by evaporation and are found to return to near-ambient values upon rewetting. Variations in pH were found to lie roughly between 7 and 9, which is similar to the results for the drift-scale thermal-hydrologic-chemical model. The most persistent change in pH is a level of about 7 in the Calico Hills, but this lies within the range of pH investigated for radionuclide sorption. Therefore, the effects of these changes are excluded from TSPA-LA on the basis of low consequence.

5.50.3 Resolution of Comment J-13

An updated screening argument and technical basis for this FEP is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.3). KTI Agreements ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C to *Technical*

Basis Document No. 8: Colloids). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H to *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Additional information is presented in KTI Agreement ENFE 1.04.

This comment referred to an unverified assumption regarding the extrapolation of near-field results to the far field. This assumption was no longer required in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f), because of the availability of both drift-scale and mountain-scale thermal-hydrologic-mechanical model results.

5.51 COMMENT J-14

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, and RT Subissue 1 Agreement 5). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.
>
> DOE also stated that alteration of vitric rock has not been addressed and will need to be included in the overall thermal-hydrological-chemical analyses.

5.51.1 TSPA-SR

FEP 2.2.10.07.00, Thermo-Chemical Alteration of the Calico Hills Unit SZ–Repository Induced Thermal Effects

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

5.51.2 TSPA-LA

FEP 2.2.10.07.0A, Thermo-Chemical Alteration of the Calico Hills Unit

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.14).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Model results show that significant glass alteration is found in the CHn at locations where temperatures by thermal heating exceed approximately 50°C. Much of the reaction has taken place by 3,000 years, with the alteration rate decreasing strongly as temperatures decline in the rocks below the repository. The extent of glass alteration is limited to the strongly heated regions directly below the repository drifts, with few effects elsewhere. The dominant phases formed by volcanic glass reactions with aqueous fluids are zeolites, potassium feldspar, and albite. Differences in radionuclide sorption between vitric and zeolitic rock are generally found to have either greater sorption on zeolitic rock (e.g., americium and uranium) or little difference in sorption (e.g., neptunium and plutonium). Therefore, the effects of mineral alteration from glass to zeolites on radionuclide sorption are expected to be either negligible or will have no adverse effect on repository performance.

The basal vitrophyre of the TSw and the underlying vitric units and glass-rich zeolitic units all contain abundant clinoptilolite, which (in the model simulations) breaks down at elevated temperatures to form predominantly stellerite. Although stellerite is common in fractures in the devitrified tuffs in the TSw, it is not typical as an alteration product of glass in the vitric units. It is likely that the fixed composition of clinoptilolite used in the thermodynamic database limits its ability to form preferentially to stellerite under the changing calcium, sodium, and potassium concentrations in the aqueous fluid, thus reducing its relative stability to stellerite, potassium feldspar, and albite at elevated temperatures. At near-ambient temperatures, clinoptilolite is stable in the simulation and actually precipitates preferentially in the glass-rich layers. This trend is consistent with the observed mineral assemblage, although the 1% reacted in 7,000 years is probably greater than that actually formed in this short period of time.

Changes in porosity and, hence, permeability are related to the net effects of volume changes taking place via mineral dissolution–precipitation. Mineral precipitation takes place through several different mechanisms, and, therefore, the distribution in the changes in hydrologic properties is related to the spatial distributions of the various processes. In the CHn, there is a modest increase in porosity of about 1%, owing primarily to the reaction of clinoptilolite and glass to feldspars and stellerite. As a consequence of the small fracture porosity changes, the fracture permeability does not show a significant reduction. Permeability changes in the matrix of the CHn vitric and zeolitic units are minor because of the initially high porosity of these rocks. Therefore, the porosity and permeability values in the matrix are essentially the same as the initial values. Consequently, this FEP is excluded on the basis of low consequence.

5.51.3 Resolution of Comment J-14

An updated screening argument and technical basis for this FEP is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.14). KTI Agreements ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C to *Technical Basis Document No. 8: Colloids*). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H to *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Additional information is provided in KTI Agreement ENFE 1.04.

This comment referred to an unverified assumption regarding the extrapolation of near-field results to the far field. This assumption was no longer required in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f), because of the availability of both drift-scale and mountain-scale thermal-hydrologic-mechanical model results.

5.52 COMMENT J-15

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, and RT Subissue 1 Agreement 5). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.52.1 TSPA-SR

FEP 2.2.10.09.00, Thermo-Chemical Alteration of the Topopah Spring Basal Vitrophyre

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

5.52.2 TSPA-LA

FEP 2.2.10.09.0A, Thermo-Chemical Alteration of the Topopah Spring Basal Vitrophyre

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.15).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Model results show that, due to repository heating of the rock matrix, after 1,000 years over 5% of the volcanic glass in the basal vitrophyre of the TSw has reacted and by 7,000 years it has dissolved up to nearly 20% by volume. The dominant phases formed by volcanic glass reactions with aqueous fluids are zeolites, potassium feldspar, and albite. At locations beneath waste emplacement drifts, the principle precipitate is zeolite (stellerite). Differences in radionuclide sorption between vitric and zeolitic rock are generally found to have either greater sorption on zeolitic rock (e.g., americium and uranium) or little difference in sorption (e.g., neptunium and plutonium). Therefore, the effects of mineral alteration from glass to zeolites on radionuclide sorption are expected either to be negligible or to have no adverse effects.

The basal vitrophyre of the TSw and the underlying vitric units and glass-rich zeolitic units all contain abundant clinoptilolite, which (in the model simulations) breaks down at elevated temperatures to form predominantly stellerite. Although stellerite is common in fractures in the devitrified tuffs in the TSw, it is not typical as an alteration product of glass in the vitric units. It is likely that the fixed composition of clinoptilolite used in the thermodynamic database limits its ability to form preferentially to stellerite under the changing calcium, sodium, and potassium concentrations in the aqueous fluid, thus reducing its relative stability to stellerite, potassium feldspar, and albite at elevated temperatures. At near-ambient temperatures, clinoptilolite is stable in the simulation and actually precipitates preferentially in the glass-rich layers. This trend is consistent with the observed mineral assemblage, although the 1% reacted in 7,000 years is probably greater than that actually formed in this short period of time.

Changes in porosity and, hence, permeability are related to the net effects of volume changes taking place via mineral dissolution–precipitation. Mineral precipitation takes place through several different mechanisms, and, therefore, the distribution in the changes in hydrologic properties is related to the spatial distributions of the various processes. As in the CHn, there is a modest increase in porosity in the TSw basal vitrophyre owing primarily to the reaction of clinoptilolite and glass to feldspars and stellerite. As a consequence of the small fracture porosity changes, the fracture permeability does not show a significant reduction. Permeability changes in the matrix are minor because of the initially high porosity of the vitric TSw vitrophyre rocks. Therefore, the porosity and permeability values in the matrix are essentially the same as the initial values. Consequently, this FEP is excluded on the basis of low consequence.

5.52.3 Resolution of Comment J-15

An updated screening argument and technical basis for this FEP is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.15). KTI Agreements ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C to *Technical Basis Document No. 8: Colloids*). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H to *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Additional information is provided in KTI Agreement ENFE 1.04.

This comment referred to an unverified assumption regarding the extrapolation of near-field results to the far field. This assumption was no longer required in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f), because of the availability of both drift-scale and mountain-scale thermal-hydrologic-mechanical model results.

5.53 COMMENT J-17

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 screening argument to address the NRC comment.

5.53.1 TSPA-SR

FEP 1.2.10.02.00, Hydrologic Response to Igneous Activity

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Excluded because of low consequence to dose (preliminary)
- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

5.53.2 TSPA-LA

FEP 1.2.10.02.0A, Hydrologic Response to Igneous Activity

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.8), *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.7.4), and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.8).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Igneous intrusion into the repository (i.e., igneous activity) could potentially alter the hydrologic characteristics of the site and, thereby, affect flow-and-transport characteristics and release to the accessible environment and exposure. However, the orientation of the dikes and the limited scale of a few meters indicate that the hydrologic response would be of low consequence.

The anisotropic transmissivity in the saturated zone observed in the Yucca Mountain region has a maximum principal transmissivity direction of approximately N15°E, which is consistent with the fault and fracture orientation, and a corroborative analysis by Ferrill et al. (1999, p. 1), which indicates N30°E. Based on the PVHA results, future dikes also most likely will trend in a north-to-northeast direction, although this may be altered by the presence of existing faults or localized changes in the stress field with the orientation being perpendicular to the least compressive stress. A north-to-northeast trend parallels or subparallels the faults and fractures active in the present-day in situ stress field. Dike features, such as the platy texture and welded surfaces that could affect the permeability, will presumably parallel the dike orientation and be aligned in a north-to-northeast orientation.

This parallel to subparallel orientation of dikes and maximum principal transmissivity, coupled with the expected limited affected volume of material around the dikes, indicates that dikes, even if differing in permeability, will not significantly affect groundwater flow patterns at the mountain scale. By way of corroboration, an early analysis of the effect of a dike on flow in the saturated zone was conducted and documented. The corroborative analysis suggested that there would be negligible impact for a dike oriented north-to northeast. The analysis included a variety of dike lengths and locations respective to the repository area. Additionally, the occurrence of such a change is conditional on a low probability event of an igneous intrusion.

With regard to geochemical changes and based on the study of natural-analog sites, for shallow, small-volume basaltic intrusions, the chemical and mineralogical studies of host tuffs indicate that alteration is limited to within a few tens of meters of the intrusion. More particularly, from a study of the Paiute Ridge analog site, there is no indication for extensive hydrothermal circulation and alteration, brecciation and deformation related to magmatic intrusion, and vapor-phase recrystallization during the magmatic intrusions into the vitric and zeolitized tuffs. The analog studies show that alteration is quite limited, typically only found within 5 to 10 m of intrusions. At the Paiute Ridge site, low-temperature secondary minerals persist near the contact with intrusions. This suggests that little destruction of sorptive minerals is expected. Given the limited area of alteration and the consequent change of rock properties around the intrusion, the effect of alteration is minimal, and alteration does not provide a mechanism to significantly change the dose. Therefore, this FEP is excluded from the TSPA-LA based on low consequence.

With regard to postintrusion in-drift conditions, the TSPA-LA addresses conditions through the assumption that the permeability of any contact metamorphic aureole surrounding the intruded drifts is as great as that of the bulk host rock. The basalt is assumed to fracture during cooling so that it, too, provides no barrier to flow. After postintrusive magma cooling and reversion to normal in-drift environmental conditions, the seepage water is expected to flow through the contact metamorphic aureole and react first with the basalt in the intruded emplacement drifts, resulting in basalt-equilibrated seepage water. The geochemical interaction of seepage water with the basalt and the resulting hydrochemistry are simulated using the EQ6 model.

As corroborative information, for a dike initially intruding into the saturated zone, Rojstaczer (1991) indicates a rise in the water table of a few tens of meters. Also of a corroborative nature and based on initial work with highly simplified systems used to represent Yucca Mountain, the horizontal distance over which an intrusion affects convective air flow is always less than 2.5 km, and the dike or sill particles representing magmatic volatiles never travel more than approximately 500 m horizontally. Consequently, the development of hydrothermal systems from igneous activity is excluded from TSPA-LA based on low consequence due to the limited size respective to the repository footprint.

The potential for igneous activity (primarily via eruption or effusive flow) to change surface topography and subsequently affect drainage and infiltration is possible, albeit at the same or slightly lower probability than for an eruptive event. The net effect could, hypothetically, result in temporary damming of a drainage intersected by a dike at the surface, or from the sloughing of ash materials from hill slopes. While possible, the steep topographic gradients at Yucca Mountain above the repository, the increased sedimentation rate associated with ash redistribution in comparison to unaffected areas as discussed for FEP 1.2.04.07.0C (Ash redistribution via soil and sediment transport), and the limited extent of effusive flow from small-scale volcanoes such as Lathrop Wells, would tend to limit the consequences of any such topographic changes. The net result through time would likely resemble something akin to Lathrop Wells Cone, wherein drainage patterns readjust and re-equilibrate to match the change in conditions, resulting in relocation of the drainage rather than any significant ponding or increased infiltration effects.

In summary, the parallel orientation of dikes and the direction of maximum transmissivity, coupled with the expected, limited affected-volume of the saturated zone and the generally low probability of an igneous intrusion, indicates that dikes, even if differing in permeability from the host rock, will not significantly affect groundwater-flow patterns or water levels. Because there would be no significant change to the flow system, hydrologic response to igneous activity does not provide a mechanism for significantly changing dose. Given the limited area of alteration and the consequent change of rock properties around the intrusion, the effect of alteration would be minimal, and alteration would not provide a mechanism to significantly change the dose. Furthermore, the development of hydrothermal systems from igneous activity is excluded from the TSPA-LA based on low consequence due to the limited size and minimal rise in the water table respective to the repository footprint. Consequently, hydrologic response to igneous activity is excluded from the TSPA-LA based on low consequence.

5.53.3 Resolution of Comment J-17

Updated screening arguments and technical bases for exclusion of this FEP are contained in *Features, Events and Processes: Disruptive Events* (BSC 2004d), *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f). The latter contains the screening argument relevant to this NRC comment.

5.54 COMMENT J-20

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (USFIC Subissue 4 Agreement 4). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.54.1 TSPA-SR

FEP 2.2.07.05.00, Flow and Transport in the UZ from Episodic Infiltration

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

5.54.2 TSPA-LA

FEP 2.2.07.05.0A, Flow and Transport in the UZ from Episodic Infiltration

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The process that drives infiltration in the unsaturated zone is precipitation, which is clearly episodic in nature. Studies of episodic infiltration and percolation have found, however, that matrix-dominated flow in the PTn damps out the transient nature of the percolation so that unsaturated zone flow below the PTn is essentially steady. Furthermore, the PTn overlies the entire repository block. This damping of transient flow is due to capillary forces and high matrix permeability in the PTn that lead to matrix imbibition of water from fractures to the matrix. Therefore, this FEP is excluded on the basis that the unsaturated zone flow is steady at the repository and along radionuclide transport pathways. Very small amounts of fracture flow do appear to penetrate as fast pathways through fault zones between the ground surface and the repository elevation, as evidenced by high ^{36}Cl concentrations in samples taken from the Exploratory Studies Facility. Higher concentrations of this isotope found in the Exploratory Studies Facility can only be explained through surface deposition of ^{36}Cl from nuclear weapons testing and subsequent aqueous transport to certain Exploratory Studies Facility sampling locations in a period of approximately 50 years. The flow responsible for rapid transport could occur either as steady flow or as episodic transient flow. In either case, the key to fast transport through the PTn is for solute to move through fractures and bypass transport through the rock matrix. However, the flow and transport models indicate that the quantity of water and dissolved constituents that do penetrate the PTn as a result of fast pathways (generally less than 1% of the total infiltration) is negligible with respect to repository performance.

5.54.3 Resolution of Comment J-20

This comment was addressed with KTI Agreement USFIC 4.04 in Appendix I of *Technical Basis Document No. 2: Unsaturated Zone Flow*. An updated screening argument will be provided in a revision to *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f).

5.55 COMMENT J-21

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreements 5 and 7, and ENFE Subissue 4 Agreement 3). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.55.1 TSPA-SR

FEP 2.2.11.02.00, Gas Pressure Effects

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b) and *Engineered Barrier System Features, Events, and Processes* (CRWMS M&O 2001c).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence (not credible)
- Engineered Barrier System–Excluded because of low consequence.

5.55.2 TSPA-LA

FEP 2.2.11.02.0A, Gas Effects in the UZ

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.6.2).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–In the Yucca Mountain unsaturated zone, the buildup of any significant gas pressure is very unlikely because of the permeable fracture pathways. Furthermore, sealing of fractures due to precipitation in the thermally perturbed repository environment has a negligible effect on hydrogeologic properties of the fractures relative to gas pressure effects. This can be seen by comparing the gas-phase pressures in fractures for thermal-hydrologic calculations (no mineral precipitation) with those for thermal-hydrologic-chemical calculations (mineral precipitation included). This argument is valid regardless of the specific potential sources of gas generation (e.g., degradation of repository components or microbial degradation of organic matter). Therefore, the FEP is excluded on the basis of low consequence.

5.55.3 Resolution of Comment J-21

An updated screening argument, based on recent thermal-hydrologic and thermal-hydrologic-chemical modeling, is contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f). KTI Agreement ENFE 1.05 was submitted to NRC in November 2003 (Appendix B to *Technical Basis Document No. 5: In-Drift Chemical Environment*). ENFE 1.07 was submitted to NRC in May 2004. ENFE 4.03 was submitted to NRC in October 2003 (Appendix C to *Technical Basis Document No. 8: Colloids*).

Comment J-21 has also been addressed separately; in response to a NRC letter of March 20, 2003 (Schlueter 2003), DOE addressed KTI Agreements ENFE 1.07, ENFE 4.02, and TSPAI 2.02, Comments J-9 and J-21 in May 2004 by submitting a revision to *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2004t) to NRC.

5.56 COMMENT J-22

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 1 Agreement 4, ENFE Subissue 4 Agreements 3 and 4, and RT Subissue 1 Agreement 5). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.56.1 TSPA-SR

FEP 1.2.04.02.00, Igneous Activity Causes Changes to Rock Properties

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Excluded because of low consequence to dose (preliminary)
- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence.

5.56.2 TSPA-LA

FEP 1.2.04.02.0A, Igneous Activity Changes Rock Properties

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.2), *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.7.1), and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.3).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Excluded because of low consequence
- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–With regard to extreme changes in hydrologic properties, sills and dikes initially intrude into the country rock as molten material and then cool. Cooling joints are formed, and resulting permeabilities may be greater than, equivalent to, or less than the surrounding country rock. However, the scale of these effects is limited to a few meters around the dike and changes in properties are, therefore, of low consequence.

An appropriate analog for understanding the components of a volcanic event is the Paiute Ridge intrusive–extrusive center on the northeastern margin of the Nevada Test Site. Carter Krogh and

Valentine (1996, pp. 7 and 8) described the margins of the Paiute Ridge dike complex and the interaction of dikes and faults.

Their observations suggest that zones of change in rock properties (i.e., formation of vitrophyres and (or) various degrees of welding of the host rock) are limited to between a few tens of centimeters to, at most, a meter perpendicular to the dike. Other features, such as the platy texture along the dike margins and vesicles in the welded tuff, are oriented parallel to the dike margins. This suggests that the primary direction of increased or decreased permeability (if any) is parallel with the dike margins. The description also indicates the interaction of faults and dikes and alludes to the segmented, discontinuous, en echelon structures observed for the dike complex.

The anisotropic transmissivity in the saturated zone observed in the Yucca Mountain region has a maximum principal transmissivity direction of approximately N15°E, which is consistent with the fault and fracture orientation and a corroborative analysis by Ferrill et al. (1999, p. 1), which indicates N30°E. Based on the PVHA results, future dikes most likely will trend in a north-to-northeast orientation, although this may be altered by the presence of existing faults or localized changes in the stress field with the orientation being perpendicular to the least compressive stress. A north-to-northeast orientation parallels or subparallels the faults, and fractures active in the present-day in situ stress field. Dike features, such as the platy texture and welded surfaces that could affect the permeability, will presumably parallel the dike orientation and be aligned in a north-to-northeast orientation.

This parallel to subparallel orientation of dikes and maximum principal transmissivity, coupled with the expected limited affected volume of material around the dikes, indicates that dikes, even if differing in permeability, will not significantly affect groundwater flow patterns at the mountain scale. By way of corroboration, an early analysis of the effect of a dike on flow in the saturated zone was conducted. The corroborative analysis suggested that there would be negligible impact for a dike oriented north to northeast. The analysis included a variety of dike lengths and locations respective to the repository area. Additionally, the occurrence of such a change is conditional on a low probability event of an igneous intrusion.

With regard to extreme changes in mineralogy, it is possible that the thermal and geochemical influence of igneous activity could affect the rock mineralogy surrounding the igneous intrusion. However, igneous intrusions at natural-analog sites are generally confined to relatively thin zones of rock ranging from a few to a few hundred meters. In particular, natural-analog studies at the Nevada Test Site show that alteration is limited to a zone less than 10 m away from the intrusion–host rock contact. Based on natural-analog sites, there is no indication for extensive hydrothermal circulation and alteration, brecciation and deformation related to magmatic intrusion, and vapor phase recrystallization during the magmatic intrusion into the vitric and zeolitized tuffs. Because the alteration zone around dikes is limited to the immediate proximity of the dike, then, at the scale of the repository, changes in mineralogy are of low consequence.

In summary, each potential effect described in the FEP description has been evaluated based on site data or natural analogs. The subparallel orientation of dikes to transmissivity, coupled with the expected limited affected volume, indicates that dikes, even if differing in permeability, will not significantly affect groundwater flow patterns. Because the joints on the dike margin are near vertical, it would seem that the formation of a significant perched water zone is problematic.

Furthermore, natural-analog studies show that alteration is limited to a zone less than 10 m away from the contact at the Nevada Test Site natural-analog sites. Consequently, changes in rock properties due to igneous activity do not provide a mechanism to significantly affect exposure or release of radionuclides to the accessible environment. Therefore, the FEP is excluded from the TSPA-LA based on low consequence.

5.56.3 Resolution of Comment J-22

An updated screening argument and technical basis is contained in *Features, Events, and Processes: Disruptive Events* (BSC 2004d), *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004e), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f). KTI Agreements ENFE 4.03 and 4.04 were submitted to NRC in October 2003 (Appendices A and C to *Technical Basis Document No. 8: Colloids*). Agreement RT 1.05 was submitted to NRC in October 2003 (Appendix H to *Technical Basis Document No. 11: Saturated Zone Flow and Transport*). Additional information is provided in KTI Agreement ENFE 1.04.

The issue of the potential for larger-scale intrusive events is addressed in more detail in C*haracterize Framework for Igneous Activity at Yucca Mountain*, *Nevada* (BSC 2003b, Section 6.3.2), where results of the *Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada* (CRWMS M&O 1996), including the derivation of a probability distribution for aggregate dike length, are described.

5.57 COMMENT J-23

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (ENFE Subissue 2 Agreement 3). *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 will be revised upon completion of this work.

5.57.1 TSPA-SR

FEP 1.2.06.00.00, Hydrothermal Activity

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence
- Unsaturated Zone–Excluded (hydrothermal activity caused by basaltic magmatism) because of low consequence
- Unsaturated Zone–Excluded (hydrothermal activity caused by silicic magmatism) because of low probability.

5.57.2 TSPA-LA

FEP 1.2.06.00.0A, Hydrothermal Activity

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.7.2) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence
- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–Based on the geologic history and setting, the recurrence of silicic volcanism is not further considered, and concern is focused on basaltic intrusion. Although basaltic magmatism could occur during the regulatory period, the effects of any related hydrothermal system would be of limited scale, as described in FEP 1.2.04.02.0A (BSC 2004d, Section 6.2.2.2) where the effects of basaltic magmatism are addressed. Due to the limited scale of effects from basaltic dikes, the potential effects of hydrothermal alteration are excluded based on low consequence.

Future igneous activity within the Crater Flat basin will typically cause minimal, highly localized basaltic dike-like intrusions with average widths on the order of 1 m. This is supported by investigations at the Grants Ridge analog sites, which indicate that basaltic intrusion produced only localized formation of volcanic glass within the contact zone. Investigations of basaltic intrusions at Paiute Ridge suggest that igneous activities altered rock properties to only a few tens of centimeters to, at most, 1 m perpendicular to an intruding dike. Associated hydrothermal activity is conditioned to these localized igneous events. It is inferred, given the lack of evidence of any past hydrothermal activity along the Crater Flat Basin, coupled with the relatively small widths of igneous intrusions that would intersect the saturated zone flow domain, that any associated hydrothermal activity produced from future igneous activity will be minimal (localized) and of low consequence to the long-term and regional saturated zone flow paths. In summary, hydrothermal activity is excluded based on low consequence because it will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

5.57.3 Resolution of Comment J-23

A separate response to this NRC comment has been submitted to NRC with the response to KTI Agreement ENFE 2.03 in Appendix H of *Technical Basis Document No. 2: Unsaturated Zone Flow*. An updated screening argument and technical basis relevant to this comment will be provided in a revision to *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f).

5.58 COMMENT J-24

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to provide the technical basis for the screening argument in the Features, Events, and Processes in SZ Flow and Transport, ANL-NBS-MD-000002 screening argument to address the NRC comment.

5.58.1 TSPA-SR

FEP 1.2.04.07.00, Ashfall

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) and *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Included (for ash cloud and surface deposition); does not satisfy a screening criterion
- Disruptive Events–Excluded (pyroclastic flow) because of low consequence to dose (preliminary)
- Saturated Zone–Excluded because of low consequence.

5.58.2 TSPA-LA

FEP 1.2.04.07.0A, Ashfall

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.6) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.1).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Biosphere–Included.

Summary of Screening Disposition–The TSPA-LA approach for addressing igneous intrusion includes consideration of exposure from an ash-fall event.

Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003b, Table 22) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3×10^{-8} (see Assumption 5.1 of *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 5)). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003c; BSC

2003d). Additionally, the lateral extent of ash fall is sufficient to reach the location of the RMEI, so the FEP has been included.

The two igneous events (with individual probabilities and consequences) being modeled by the TSPA-LA are: (1) an igneous intrusion groundwater transport modeling case featuring the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to the repository level where it intersects drifts, and (2) a volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. The potential consequence of the second event (volcanic eruption modeling case) is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the RMEI. The conceptual model for the eruptive process is discussed under FEP 1.2.04.06.0A (BSC 2004d, Section 6.2.2.5), Eruptive Conduit to Surface Intersects Repository. *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003e, Section 6) provides the technical basis for inclusion of the FEP in TSPA-LA. The properties of basaltic eruptions, based on the observed characteristics of past basaltic eruptions in the Yucca Mountain region and other analogous eruptions, and results of field investigations dealing with physical volcanology and with ash and tephra redistribution (including the conceptual models for eruptive processes and for ash and tephra redistribution) are used to develop parameter value distributions appropriate for analysis of the consequences of volcanic eruptions through a repository at Yucca Mountain.

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

FEP 1.2.04.07.0B, Ash Redistribution in Groundwater

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–If a volcanic eruption were to occur within the repository entraining radioactive waste, contaminated radionuclide-bearing ash deposited on the surface could leach and be transported through the unsaturated zone and saturated zone to the compliance point. Assuming that the contents of six commercial spent nuclear fuel waste packages are entrained in the volcanic eruption (which is the median number of packages brought to the surface by a single volcanic eruption intersecting one drift) and that all of the waste is uniformly distributed in the ash blanket on the ground surface, the resulting estimated conditional dose rate is 20.5 mrem/yr. The resulting probability-weighted dose rate due to leaching of radionuclides from contaminated ash is less than 3×10^{-3} mrem/yr. In addition, the conservative assumption is made that all radionuclides derived from the volcanic ash blanket are captured in the hypothetical pumping wells of the RMEI. This is consistent with the TSPA nominal class scenario model, in which radionuclide contamination of groundwater in the saturated zone is assumed to be completely captured in the groundwater usage of the hypothetical future farming community. This is significantly less than the probability-weighted doses resulting from other igneous pathways during this period. The effects of nonuniform distribution of the ash blanket are addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4, Supplemental Discussion). The effects of ash fall on saturated zone transport are excluded on the basis of low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

FEP 1.2.04.07.0C, Ash Redistribution via Soil and Sediment Transport

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.7).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included.

Summary of Screening Disposition–The TSPA-LA includes consideration of exposure from redistributed ash.

Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003b, Table 22) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3×10^{-8} (see Assumption 5.1 of *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 5). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003c; BSC 2003d). Additionally, the lateral extent of ash fall from such an event and subsequent ash redistribution are sufficient to reach the location of the RMEI, so the FEP has been included.

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. The TSPA-LA model, using ASHPLUME V2.0, estimates radionuclide concentrations in contaminated ash falling at the location of the RMEI. The TSPA-LA approach for calculating exposure through the use of volcanic-specific biosphere dose conversion factors is further outlined in *Total System Performance Assessment—License Application Method and Approach* (BSC 2002b, Section 8.1.2).

This hypothetical direct deposition of ash and waste in the vicinity of the RMEI presumably represents the greatest degree of exposure from an eruptive process. Other mechanisms (e.g., eolian or fluvial processes) allow for mixing and dilution of the ash and waste through distance and with time. Presumably, a volume of transported sediment with a highly diluted ash component would have less impact on the RMEI than would primary ash fall that fell directly on or nearby the RMEI. Accordingly, the worst-case conceptual model would be one in which winds blow the initial eruption column south from the repository toward the RMEI. This is the only conceptual model in which ash would directly fall on the RMEI without additional dilution.

To assess the degree to which redistribution and mixing processes (primarily fluvial processes) might affect the percent of ash and waste in reworked and transported sediment and its contribution to exposure, a study was performed using the ash deposits and tephra sheet of the Lathrop Wells Cone and ^{137}Cs studies in the Fortymile Wash alluvial fan. The results of these studies are documented in *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* (BSC 2003e, Section 6.5) and *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003f). Both reports include the results of field investigations and present the conceptual and technical basis for the ash redistribution model implemented within TSPA-LA. The technical basis for the TSPA ash redistribution model is supported by geomorphic data and analyses.

5.58.3 Resolution of Comment J-24

This FEP has been split into three FEPs: FEP 1.2.04.07.0A, Ashfall, in disruptive events (BSC 2004d, Section 6.2.2.6) and biosphere (BSC 2003a, Section 6.2.1); FEP 1.2.04.07.0B, Ash Redistribution in Groundwater, in saturated zone (BSC 2004e, Section 6.2.4); and FEP 1.2.04.07.0C, Ash Redistribution Via Soil and Sediment Transport, in disruptive events (BSC 2004d, Section 6.2.2.7). All of these FEPs are screened as included, and TSPA dispositions are contained in the cited AMRs.

5.59 COMMENT J-25

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (SDS Subissue 1 Agreement 2) and an NRC letter dated August 3, 2001. Features, Events, and Processes: Screening for Disruptive Events, ANL-WIS-MD-000005 will be revised upon completion of this work.

5.59.1 TSPA-SR

FEP 1.2.02.02.00, Faulting

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Included (for existing fault characteristics) does not satisfy a screening criterion
- Disruptive Events–Excluded (for changes of fault characteristics) because of low consequence to dose (preliminary)
- Disruptive Events–Excluded (for formation of new faults) because of low probability
- Saturated Zone–Included (uncertainty in the existing hydrologic properties of the system)
- Saturated Zone–Excluded because of low consequence (changes to existing hydrologic properties due to additional movement along existing faults)
- Saturated Zone–Excluded because of low consequence (changes to existing hydrologic properties due to new faults)
- Unsaturated Zone–Included (effects of present-day faults)
- Unsaturated Zone–Excluded (effects of changes in fault properties) because of low consequence
- Unsaturated Zone–Excluded (effects of new faults) because of low consequence.

5.59.2 TSPA-LA

FEP 1.2.02.02.0A, Faults

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.3) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.2).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included
- Saturated Zone–Included

Summary of Screening Disposition–Major displacement, dip-slip, strike-slip, and detachment faults within the model domain are explicitly discretized in the mountain-scale unsaturated zone flow and transport models. These faults are represented in the unsaturated zone model grid as vertical or inclined discrete zones 30 m wide and include existing displacements that affect the relative geometry of the hydrogeologic model units. Specific hydrogeologic properties are assigned to the fault zones. Fault properties (matrix and fracture parameters) are in DTN: LB02092DSSCFPR.002 and *UZ Flow Models and Submodels* (BSC 2004k, Table 4.1-1).

The influence of faults on radionuclide transport is implicitly included through the use of dual permeability model, the use of pregenerated flow fields that includes the faults in the three-dimensional model and the characteristics of fractures within the faults. In TSPA-LA runs, the influence of faults is included through the use of fault properties and the pregenerated flow fields under different climate conditions.

Geologic features and hydrostratigraphic units are explicitly included in the saturated zone flow and transport model abstraction in a configuration that accounts for the effects of existing faults, based on the hydrogeologic framework model. As discussed in site-scale saturated zone flow model, the hydrogeologic framework model represents faults and other hydrogeologic features (e.g., zones of hydrothermal alteration) that affect saturated zone flow. Model configuration of these discrete features accounts for fault dip, strike, slip, and detachment.

5.59.3 Resolution of Comment J-25

This FEP has now been screened as included for both unsaturated zone and saturated zone, and TSPA dispositions are contained in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.3) and *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.2). The issue of using mean values versus median values for fault displacements and ground motions was addressed in the DOE response to KTI Agreements SDS 1.02 and 2.03. These agreements received a status of "Complete" from NRC.

5.60 COMMENT J-26

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (SDS Subissue 1 Agreement 2) and an NRC letter dated August 3, 2001. Features, Events, and Processes: Screening for Disruptive Events, ANL-WIS-MD-000005 will be revised upon completion of this work.

5.60.1 TSPA-SR

FEP 1.2.02.03.00, Fault Movement Shears Waste Container

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Excluded because of low probability
- Waste Package–Excluded because of low probability.

5.60.2 TSPA-LA

FEP 1.2.02.03.0A, Fault Displacement Damages Engineered Barrier System Components

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.2) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.7).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Faulting is considered to be a potentially disruptive process with effects that include sudden relative rock–soil displacements across a fault surface (i.e., fault displacement). These effects are potentially relevant to the integrity of the repository and are included in the TSPA-LA. Ground motions associated seismic activity are addressed in FEPs 1.2.03.02.0A, 1.2.03.02.0B, 1.2.03.02.0C, and 1.2.03.02.0D.

Consequences, and the manner of inclusion, are addressed in *Seismic Consequence Abstraction* (BSC 2003v, Sections 6.8.5 and 6.10). The following technical basis for inclusion involves a comparison of the fault displacement occurring with a 10^{-8} annual frequency to various elements of the repository design (i.e., waste package to drift-wall spacing and setback requirements). The potential for fault displacement damage from intrablock faults and features likely to exist within the repository are explicitly included in the TSPA-LA.

The use of setbacks is a project requirement for Type I block-bounding faults. The potential displacements from the block-bounding faults are implicitly included because the repository design that is being used as the basis for the TSPA-LA includes setback requirements, and the repository design is part of the technical basis used to evaluate the repository performance.

In the case of the Bow Ridge Fault, the north-to-northeast trending faults located east of the Ghost Dance Fault do not intersect the repository footprint and are located sufficiently distant from the repository so that setback requirements are inherently satisfied, and explicit consideration within the TSPA-LA is not required. This also applies to the intrablock Ghost Dance Fault located east of the repository because it does not intersect the waste emplacement area. In the case of the Solitario Canyon Fault, specific setback requirements have been instituted as part of the design documentation.

The intrablock faults are mapped features that intersect the repository footprint area. They include, but are not limited to, the Drill Hole Wash Fault, the Ghost Dance Fault, the Sundance Fault, an unnamed fault west of Dune Wash, and the Midway Fault. Because of the orientation and location of the Drill Hole Wash Fault, the estimated displacements are used as an analog for possible displacement along the additional intrablock Pagany Wash Fault and Sever Wash Fault, which transect the northeast portion of the repository footprint. At a 10^{-8} annual-exceedance probability, the 85th fractile and mean fault displacements for intrablock faults are, with one exception, less than or equal to 2 m. The exception is for the mean fault displacement of the Drill Hole Wash Fault, which is approximately 2.5 m.

The evaluation of potential damage due to fault displacement near fault zones is further evaluated and included in the TSPA-LA analysis. In general, the expected number of damaged waste packages on four secondary faults is evaluated for displacements corresponding to a range of annual exceedance frequencies, based on the mean hazard curves for the Sundance Fault, the Drill Hole Wash Fault, the Pagany Wash Fault, and the Sever Wash Fault. The evaluation considers the clearances between various types of waste packages and the drip shield and the expected numbers of waste packages that lie on these four faults. Furthermore, the potential for defense high-level radioactive waste packages to be placed where existing, previously unknown features exist is also incorporated into the analysis on a probabilistic basis. Damage to the waste package is sampled from a uniform distribution with a lower bound of no damage and an upper bound given by the area of the waste package lid. The uniform distribution is a simple approximation to the upper and lower damage bounds in lieu of detailed structural response calculations. The upper bound is a reasonable estimate for a severely crimped waste package that loses its lid due to welds holding the lid in place cracking. The lower bound is a reasonable estimate for a waste package that is minimally damaged, either because fault displacement slightly exceeds the available clearance or because the package shear occurs at the opposite end of the waste package from the lid.

5.60.3 Resolution of Comment J-26

This FEP has been screened as included for disruptive events and engineered barrier system, and TSPA dispositions are contained in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.2) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.7). The specific concerns of this NRC comment are addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) examines fault displacement magnitudes and setback distances. Related KTI Agreement SDS 1.02 is complete.

5.61 COMMENT J-27

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> This issue is addressed by existing agreements between DOE and NRC (SDS Subissue 2 Agreement 1) and an NRC letter dated August 3, 2001. Features, Events, and Processes: Screening for Disruptive Events, ANL-WIS-MD-000005 will be revised upon completion of this work.

5.61.1 TSPA-SR

FEP 1.2.03.01.00, Seismic Activity

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Excluded (for indirect effects: fault growth, new faults, changes in rock stress, disruption of drifts) because of low consequence

- Disruptive Events–Excluded because of low consequence to dose (preliminary) (for direct breaching of drip shield, emplacement pallet, and waste package)

- Disruptive Events–Included; does not satisfy screening criteria (for fuel rod cladding damage).

5.61.2 TSPA-LA

Not applicable.

5.61.3 Resolution of Comment J-27

FEP 1.2.03.01.00, Seismic Activity, has been deleted due to redundancy with the following FEPs:

- 1.2.03.02.0A: Seismic ground motion damages EBS components
- 1.2.03.02.0B: Seismic induced rockfall damages EBS components
- 1.2.03.02.0C: Seismic induced drift collapse damages EBS components
- 1.2.03.02.0D: Seismic induced drift collapse alters in-drift thermohydrology
- 1.2.03.03.0A: Seismicity associated with igneous activity.

The issue raised in the NRC comment regarding the Probabilistic Seismic Hazard Assessment Expert Elicitation was addressed in KTI Agreement SDS 2.01 AIN-1, which was submitted to the NRC in Appendix C of *Technical Basis Document No. 14: Low Probability Seismic Events.*

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6. ADDED FEPS (RESPONSE TO TSPAI 2.03)

This section addresses KTI Agreement TSPAI 2.03. This agreement is concerned with adding certain FEPs to the list that was prepared for DOE's TSPA-SR.

Wording of the agreements is as follows.

TSPAI 2.03

> Add the FEPs highlighted in Attachment 2 to the appropriate FEPs AMRs. See Comment 19 (Part 7 and 8), 20, and J-6. DOE will add the FEPs highlighted in Attachment 2 to the appropriate FEPs AMRs. The FEPs will be added to the appropriate FEPs AMRs and the AMRs will be provided to the NRC in FY03.

Responses to individual NRC comments follow.

6.1 COMMENT 19 (PART 7)

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE will add links to the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP).* ANL-MGR-MD-000011 for FEP 3.1.01.01.00 (Radioactive Decay and Ingrowth), and FEP 1.2.04.07.00 (Ashfall).

6.1.1 TSPA-SR

FEP 3.1.01.01.00, Radioactive Decay and Ingrowth

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2001e), *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision-For the site recommendation, the FEP was screened as follows:

- Waste Form—Included (miscellaneous)
- Saturated Zone—Included
- Unsaturated Zone—Included.

6.1.2 TSPA-LA

FEP 3.1.01.01.0A, Radioactive Decay and Ingrowth

This FEP was addressed in *Miscellaneous Waste-Form FEPs* (BSC 2004g, Section 6.2.41), *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.44), *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.44), and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.34).

Screening Decision—For the license application, the FEP was screened as follows:

- Waste Form—Included
- Unsaturated Zone—Included
- Saturated Zone—Included
- Biosphere—Included.

Summary of Screening Argument–Radioactive decay and in-growth were considered in the selection of isotopes of importance to TSPA-LA and are included as standard features of the GoldSim code. Once the isotopes most important to dose were identified, the parents of these isotopes were examined to determine if decay and in-growth could significantly affect the amount of the important isotopes during the regulatory period. Seven parent isotopes were identified whose decay significantly increased the amount of their progeny:

- ^{245}Cm decays to ^{241}Pu decays to ^{241}Am
- ^{235}U decays to ^{231}Pa
- ^{230}Th decays to ^{226}Ra
- ^{232}Th decays to ^{228}Ra
- ^{236}U decays to ^{232}Th
- ^{242}Pu decays to ^{238}U.

These seven isotopes were added to the list of isotopes to be tracked in the TSPA-LA GoldSim model. During execution, the GoldSim model automatically calculates decay and in-growth of the included isotopes within the waste package and drift modeling cells.

6.1.3 Resolution of Comment 19 (Part 7)

Per the NRC comment, FEP 3.1.01.01.0A was added to *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a).

6.2 COMMENT 19 (PART 8)

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE will add links to the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP).* ANL-MGR-MD-000011 for FEP 3.1.01.01.00 (Radioactive Decay and Ingrowth), and FEP 1.2.04.07.00 (Ashfall).

6.2.1 TSPA–SR

FEP 1.2.04.07.00, Ashfall

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) and *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision—For site recommendation, the FEP was screened as follows:

- Disruptive Events—Included; does not satisfy a screening criterion (for ash cloud and surface deposition)
- Disruptive Events—Excluded because of low consequence to dose (for pyroclastic flow)
- Saturated Zone—Excluded because of low consequence.

6.2.2 TSPA-LA

FEP 1.2.04.07.0A, Ashfall

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.6) and *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.1).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Biosphere–Included.

Summary of Screening Disposition–The TSPA-LA approach for addressing igneous intrusion includes consideration of exposure from an ash-fall event.

Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003b, Table 22) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3×10^{-8} (see Assumption 5.1 of *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 5). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003c; BSC 2003d).

Additionally, the lateral extent of ash fall is sufficient to reach the location of the RMEI, so the FEP has been included.

The two igneous events (with individual probabilities and consequences) being modeled by the TSPA-LA are: (1) an igneous intrusion groundwater transport modeling case featuring the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to the repository level where it intersects drifts, and (2) a volcanic eruption modeling case featuring the development of a volcano within the repository footprint with one or more conduits that intersect waste packages. The potential consequence of the second event (volcanic eruption modeling case) is that waste packages entrained within a conduit may be breached, releasing radionuclides in an erupting ash plume where they can be dispersed downwind to the RMEI. The conceptual model for the eruptive process is discussed under FEP 1.2.04.06.0A (BSC 2004d, Section 6.2.2.5), Eruptive Conduit to Surface Intersects Repository. *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003e, Section 6) provides the technical basis for inclusion of the FEP in the TSPA-LA. The properties of basaltic eruptions, based on the observed characteristics of past basaltic eruptions in the Yucca Mountain region and other analogous eruptions, and results of field investigations dealing with physical volcanology and with ash and tephra redistribution and (including the conceptual models for eruptive processes and for ash and tephra redistribution) are used to develop parameter value distributions appropriate for analysis of the consequences of volcanic eruptions through a repository at Yucca Mountain.

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

FEP 1.2.04.07.0B, Ash Redistribution in Groundwater

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–If a volcanic eruption were to occur within the repository entraining radioactive waste, contaminated radionuclide-bearing ash deposited on the surface could leach and be transported through the unsaturated zone and saturated zone to the compliance point. Assuming that the contents of six commercial spent nuclear fuel waste packages are entrained in the volcanic eruption (which is the median number of packages brought to the surface by a single volcanic eruption intersecting one drift) and that all of the waste is uniformly distributed in the ash blanket on the ground surface, the resulting estimated conditional dose rate is 20.5 mrem/yr. The resulting probability-weighted dose rate due to leaching of radionuclides from contaminated ash is less than 3×10^{-3} mrem/yr. In addition, the conservative assumption is made that all radionuclides derived from the volcanic ash blanket are captured in the hypothetical pumping wells of the RMEI. This is consistent with the TSPA nominal class scenario model, in which radionuclide contamination of groundwater in the saturated zone is assumed to be completely captured in the groundwater usage of the hypothetical future farming community. This is significantly less than the probability-weighted doses resulting from other igneous pathways during this period. The effects of nonuniform distribution of the ash blanket are addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.4, Supplemental Discussion). The effects of ash fall on saturated zone transport are excluded on the basis of low consequence because they will not significantly change radiological exposures to the RMEI or radionuclide releases to the accessible environment.

FEP 1.2.04.07.0C, Ash Redistribution via Soil and Sediment Transport

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.2.7).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included.

Summary of Screening Disposition–The TSPA-LA includes consideration of exposure from redistributed ash.

Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003b, Table 22) indicates that the annualized frequency of one or more eruptive centers with the repository footprint is 1.3×10^{-8} (see Assumption 5.1 of *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 5)). This is based on the repository footprint presented in 800-IED-EBS0-00402-000-00B and 800-IED-EBS0-00401-000-00C (BSC 2003c; BSC 2003d). Additionally, the lateral extent of ash fall from such an event and subsequent ash redistribution are sufficient to reach the location of the RMEI, so the FEP has been included.

For the volcanic eruption modeling case, the TSPA-LA assumes 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. The TSPA-LA model, using ASHPLUME V2.0, estimates radionuclide concentrations in contaminated ash falling at the location of the RMEI. The TSPA-LA approach for calculating exposure through the use of volcanic-specific biosphere dose conversion factors is further outlined in *Total System Performance Assessment-License Application Method and Approach* (BSC 2002b, Section 8.1.2).

This hypothetical direct deposition of ash and waste in the vicinity of the RMEI presumably represents the greatest degree of exposure from an eruptive process. Other mechanisms (e.g., eolian or fluvial processes) allow for mixing and dilution of the ash and waste through distance and with time. Presumably, a volume of transported sediment with a highly diluted ash component would have less impact on the RMEI than would primary ash fall that fell directly on, or nearby, the RMEI. Accordingly, the worst-case conceptual model would be one in which winds blow the initial eruption column south from the repository toward the RMEI. This is the only conceptual model in which ash would directly fall on the RMEI without additional dilution.

To assess the degree to which redistribution and mixing processes (primarily fluvial processes) might affect the percent of ash and waste in reworked and transported sediment and its contribution to exposure, a study was performed using the ash deposits and tephra sheet of the Lathrop Wells Cone and ^{137}Cs studies in the Fortymile Wash alluvial fan. The results of these studies are documented in *Characterize Eruptive Processes at Yucca Mountain*, *Nevada* (BSC 2003e, Section 6.5) and *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2003f). Both reports include the results of field investigations and present the conceptual and technical basis for the ash redistribution model implemented within TSPA-LA. The technical basis for the TSPA ash redistribution model is supported by geomorphic data and analyses.

6.2.3 Resolution of Comment 19 (Part 8)

This FEP was added to *Evaluation of the Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a). It has been split into FEPs 1.2.04.07.0A, Ashfall; 1.2.04.07.0B, Ash Redistribution in Groundwater; and 1.2.04.07.0C, Ash Redistribution via Soil and Sediment Transport.

6.3 COMMENT 20

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE will add this FEP to the *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP).* ANL-MGR-MD-000011 and present the DOE discussion in the screening argument.

6.3.1 TSPA-SR

FEP 2.2.08.07.00, Radionuclide Solubility Limits in the Geosphere

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a) and *Features, Events, and Processes in UZ Flow and Transport* (BSC 2001b).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included
- Unsaturated Zone–Excluded because of low consequence.

6.3.2 TSPA-LA

FEP 2.2.08.07.0A, Radionuclide Solubility Limits in the SZ

This FEP was addressed in *Features, Events and Processes in SZ Flow and Transport* (BSC 2004e, Section 6.2.28).

Screening Decision–For the license application, the FEP was screened as follows:

- Saturated Zone–Excluded because of low consequence.

Summary of Screening Argument–The saturated zone flow and transport model abstraction does not implement a solubility limit for each transported radionuclide, thus allowing the radionuclide solution concentration that is introduced into the saturated zone from the unsaturated zone to be unconstrained. The rationale supporting this position is as follows. If a solubility limit were to be imposed into the saturated zone model that is lower than that implemented in *Dissolved Concentration Limits of Radioactive Elements* (BSC 2001h, Section 6.5), it would cause precipitates to form, pulling constituents out of the aqueous phase and reducing the maximum aqueous concentration capable of being transported downstream to the compliance boundary. Additionally, physical buildup of a solid phase onto mineral surfaces (due to precipitation, not adsorption) can reduce permeability, increase tortuosity, and clog pores, thus increasing transport times.

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

FEP 2.2.08.07.0B, Radionuclide Solubility Limits in the UZ

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.8.8).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Excluded because of low consequence.

Summary of Screening Argument–If solubility limits are lower in the geosphere than in the emplacement drifts, then more radionuclides will precipitate there. This corresponds to fewer dissolved radionuclides being available for transport in the geosphere, which is beneficial and results in no adverse effects on performance. Because the solubility is assumed to be the same in the unsaturated zone as the invert, no reduction in concentration occurs at the engineered barrier system–unsaturated zone boundary. Therefore, this FEP is excluded based on low consequence.

6.3.3 Resolution of Comment 20

This FEP has been split into two new FEPs: 2.2.08.07.0A for the saturated zone and 2.2.08.07.0B for the unsaturated zone. Per the NRC comment, this FEP will also be incorporated into the next revision of *Evaluation of the Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a).

6.4 COMMENT J-6

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE will add this FEP to the *Features, Events, and Processes in UZ Flow and Transport*, ANL-NBS-MD-000001 and present the DOE discussion in the screening argument.

6.4.1 TSPA-SR

FEP 2.2.07.15.00, Advection and Dispersion

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Saturated Zone–Included.

6.4.2 TSPA-LA

FEP 2.2.07.15.0A, Advection and Dispersion in the Saturated Zone

This FEP was addressed in *Features, Events, and Processes in SZ Flow and Transport* (CRWMS M&O 2001a), Section 6.2.22).

Screening Decision–For license application, the FEP was screened as follows:

- Saturated Zone–Included.

Summary of Screening Disposition–Advection and longitudinal dispersion of dissolved radionuclides are explicitly included in the conceptual and mathematical models for TSPA-LA. The numerical code implements dispersion tensor and random walk particle tracking method. The flow field and the dispersion tensor input to this model depend on the nature of the geologic material and the scale of the model.

FEP 2.2.08.15.0B, Advection and Dispersion in the Unsaturated Zone

This FEP was addressed in *Features, Events, and Processes in UZ Flow and Transport* (BSC 2004f, Section 6.1.2.3).

Screening Decision–For the license application, the FEP was screened as follows:

- Unsaturated Zone–Included.

Summary of Screening Disposition–Radionuclide transport through the unsaturated zone by advection is simulated using the residence time transfer function. Dispersion is incorporated into the residence time transfer function algorithm through the use of a transfer function based on an analytical solution to the advection–dispersion. In TSPA–LA runs, advection and dispersion are implicitly included through the use of FEHM residence time transfer function model and pregenerated flow fields.

This FEP is also included in TSPA-LA through the treatment of drift-scale radionuclide transport. This is captured through the fracture–matrix partitioning model for the fraction of releases from a waste emplacement drift without seepage to the fractures of the underlying rock mass. Advective transport in fractures and matrix, based on flow as computed in the unsaturated zone flow model, is included as part of the model for radionuclide transport from the waste emplacement drift to the rock. Diffusive transport in fractures is also included, but hydrodynamic dispersion is not considered. The fraction of the releases from a drift without seepage to the fractures is represented as an uncertain parameter, caused in part by uncertainty in fracture and matrix flow. Distributions that represent the effects of this uncertainty in the fraction released to fractures are developed for use in TSPA-LA as a probabilistic parameter applied to the total radionuclide flux entering the rock from waste emplacement drifts.

6.4.3 Resolution of Comment J-6

This FEP has been added to the unsaturated zone FEPs. The original FEP was split into FEP 2.2.07.15.0A for the saturated zone and FEP 2.2.07.15.0B for the unsaturated zone.

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7. CLARIFICATION OF FEP DESCRIPTIONS (RESPONSE TO TSPAI 2.04)

This section addresses KTI Agreement TSPAI 2.04. This agreement is concerned with clarification of certain FEPs that were prepared for DOE's TSPA-SR. At the time the TSPA-SR was prepared, FEPs were categorized as primary or secondary. These categories have since been discarded, and FEPs are now considered to be at the same level.

Wording of the agreements is as follows.

TSPAI 2.04

> Provide a clarification of the description of the primary FEP. See Comments 24, 31, and 33. DOE will clarify the description of the primary FEPs, as summarized in Attachment 2, for the highlighted FEPs. The clarifications will be provided in the referenced FEPs AMR and will be provided to the NRC in FY03.

Responses to individual NRC comments follow.

7.1 COMMENT 24

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to clarify the description of the primary FEP in the Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP) ANL-MGR-MD-000011.

7.1.1 TSPA-SR

FEP 2.3.13.02.00, Biosphere Transport

This FEP was addressed in *Evaluation of the Applicability of Biosphere-Related Features, Events, and Processes (FEP)* (BSC 2001a).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Biosphere–Included (radionuclide transport and transfer through and between biosphere compartments).

7.1.2 TSPA-LA

FEP 2.3.13.02.0A, Radionuclide Alteration during Biosphere Transport

This FEP was addressed in *Evaluation of Features, Events, and Processes (FEP) for the Biosphere Model* (BSC 2003a, Section 6.2.24).

Screening Decision–For the license application, the FEP was screened as follows:

- Biosphere–Included.

Summary of Screening Disposition–The biosphere model is constructed around the radionuclide transfer interaction matrix, 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 $^{14}CO_2$ and from the surface water (fish ponds) to the air, the plant uptake of carbon dioxide from the air, and release of gaseous species during operation of evaporative coolers. This FEP is also implicitly addressed through the use of steady-state radionuclide-specific and crop-type-specific soil-to-plant transfer factors and steady-state radionuclide-specific and animal-product-specific transfer factors in the plant and animal submodels, respectively, as identified in *Biosphere Model Report* (BSC 2003z, Sections 6.4 and 6.5).

This FEP is dispositioned in the biosphere component of the TSPA model through the use of groundwater exposure scenario biosphere dose conversion factors that are direct inputs to the

TSPA nominal scenario, seismic scenario, and igneous intrusion case. Annual doses are calculated as the product of radionuclide concentration in groundwater and biosphere dose conversion factors. There are three sets of biosphere dose conversion factors for the groundwater exposure scenario corresponding to the present-day, monsoon, and glacial-transition climates.

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

7.1.3 Resolution of Comment 24

There are no longer secondary entries associated with FEPs. This FEP has been redefined as radionuclide alteration during biosphere transport. The revised Yucca Mountain Project (YMP) FEP description of this FEP is:

> 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.

Other issues related to biosphere transport have been moved to the following FEPs:

- 2.3.02.03.0A, Soil and Sediment Transport in the Biosphere (BSC 2003a, Section 6.2.17)
- 2.3.04.01.0A, Surface Water Transport and Mixing (BSC 2003a, Section 6.2.18)
- 2.3.09.01.0A, Animal Borrowing/Intrusion (BSC 2003a, Section 6.2.20)
- 2.4.09.01.0B, Agricultural Land Use and Irrigation (BSC 2003a, Section 6.2.31)
- 3.2.10.00.0A, Atmospheric Transport of Contaminants (BSC 2003a, Section 6.2.35).

7.2 COMMENT 31

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to clarify the description of the primary FEP in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002.

7.2.1 TSPA-SR

FEP 1.2.03.02.00, Seismic Vibration Causes Container Failure

This FEP was addressed in *Features, Events, and Processes: Disruptive Events* (CRWMS M&O 2000a) and *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f).

Screening Decision–For site recommendation, the FEP was screened as follows:

- Disruptive Events–Excluded (for drip shield and waste package damage) because of low consequence to dose (preliminary)

- Fuel-Rod Cladding–Included; does not satisfy a screening criterion

- Waste Package–Excluded because of low consequence.

7.2.2 TSPA-LA

FEP 1.2.03.02.0A, Seismic Ground Motion Damages Engineered Barrier System Components

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.3) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.8).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Vibratory ground motion associated with seismic activity has the potential to disrupt the integrity of components of the engineered barrier system. The direct effects of ground motion could lead to impaired drip shield or waste package performance, with subsequent enhanced radionuclide release. Evaluation of the effects of ground motion includes:

- Development of location-specific ground motions based on results of the probabilistic seismic hazard analysis for Yucca Mountain and ground motion site response modeling
- Structural response calculations to determine the performance of engineered barrier system components (drip shield, waste package, fuel cladding, pallet) under various levels of ground-motion loading
- Evaluation of the results of structural response calculations using failure criteria for the drip shield, waste package, and fuel cladding to determine the amount of surface area damaged (drip shield, waste package) or perforation (cladding)
- Abstraction of results to develop damage response surfaces relating the amount of damage to the level of ground motion. The abstraction also bounds horizontal peak ground velocity to credible values based on physical properties of the rocks at Yucca Mountain and geologic observations.

The amplitude and likelihood of a ground-motion event was determined by a probabilistic seismic hazard analysis. The probabilistic seismic hazard analysis assessed the characteristics of seismic sources and ground motion in the Yucca Mountain region, including their uncertainties. Results were expressed as hazard curves that indicate the annual probability that a given level of ground motion will be exceeded (CRWMS M&O 2000e). Estimates of peak ground velocity and corresponding ground-motion time histories were developed for the emplacement drifts based on the results of the probabilistic seismic hazard analysis and a ground-motion site response model (BSC 2004w, Section 6). The time histories, which incorporate an appropriate range of amplitude, frequency content, and duration, serve as input to models of the dynamic behavior of the engineered barrier system for assessing mechanical disruption or damage to these systems. Ground motion time histories were developed for annual probabilities of exceedance of 5×10^{-4}, 10^{-6}, and 10^{-7} (BSC 2004w, Section 6.3).

In addition to the seismic inputs developed for structural response calculations, an analysis also determined a bound to horizontal peak ground velocity at the emplacement drifts based on the physical limitations of the rock, geologic observations, and ground-motion site-response results. In the probabilistic seismic hazard analysis, aleatory variability in ground motion attenuation relations was characterized by unbounded lognormal distributions. At extremely low annual probability levels, the tails of these distributions, along with large assessed epistemic uncertainties in ground motions from large, close earthquakes, result in upper percentile and mean ground motions that are extremely high and probably physically unrealistic. At such high ground motions, the shear strains produced in the lithophysal rock at the waste emplacement level would cause the rock to fracture and fail. Geologic studies of rock exposed in the underground excavations, however, indicate that fractures related to high levels of seismic shaking do not exist at Yucca Mountain. Thus, the extreme levels of seismic shaking required to damage the lithophysal rock have not occurred at Yucca Mountain since the rocks were deposited about 12.8 million years ago. This observation serves as the basis for a reasonable bound to the horizontal peak ground velocity values that can be achieved at Yucca Mountain. The bound is expressed as a probability distribution to incorporate uncertainty in the analysis (*Technical Basis Document No. 14: Low Probability Seismic Events*, Section 4.1.2).

The extent of mechanical disruption of engineered barriers was determined based on estimates of how much damage may be caused by various levels of ground motion. This characterization of seismic damage is discussed in *Seismic Consequences Abstraction* (BSC 2003v). Detailed structural analyses were used to assess damage to the drip shield and waste package as a result of the site-specific vibratory ground motion. These analyses were conducted using state-of-the-art three-dimensional finite element process models and incorporated detailed structural descriptions of the waste package and drip shield, as well as site-specific ground motion time histories. A sensitivity study was performed using ground-motion time histories as input to the models, and results of these trials were used to formulate the database used in the damage abstraction for TSPA-LA (BSC 2003v, Section 6). Damage to these barriers is expressed in terms of damaged surface area on the drip shield, damaged surface area on the waste package, or perforation of the fuel cladding as functions of the horizontal peak ground velocity (BSC 2003v, Section 6.6.1.4).

The most likely failure mechanism from a seismic event is accelerated stress corrosion cracking in the damaged areas that exceed the residual stress threshold for Alloy 22 (the waste package outer barrier) and for Titanium Grade 7 (the drip shield). The criteria for failure are based on a residual stress threshold of between 80% and 90% of the yield strength for Alloy 22 and of 50% of the yield strength for Titanium Grade 7. No damage to engineered barrier system components is expected for vibratory ground motion with an annual exceedance probability of 5×10^{-5} (20,000-year recurrence) or higher. Cladding failure is assumed to occur with an annual probability of 1×10^{-5} (100,000-year recurrence). However, at this probability level, no damage to the drip shields is expected from rockfall or vibratory ground motion because any resulting cracks plug from groundwater-related mineral precipitates. The maximum effective area for flow into and transport out of the waste package at this probability level is less than 0.003% of its surface area. At an annual probability of 1×10^{-6} (million-year recurrence), the drip shield does not fail as a flow barrier due to rockfall or vibratory ground motion, and the maximum effective transport area through stress corrosion cracks on the waste package is less than 0.013% of its surface area. At an annual probability level of 1×10^{-7} (10-million-year recurrence), adjacent drip shields can separate and ride over each other, reducing their effective surface area by up to 50%. However, at this probability level, the waste package still provides substantial protection for the waste form, with a maximum effective surface area for flow and transport through stress corrosion cracks of less than 0.03%. These results collectively indicate that the engineered barrier system components are robust under seismic loads and will provide substantial protection of the waste form from seepage water even under severe seismic loading.

The impact of mechanical disruption on the performance of the engineered barriers is evaluated in the seismic consequence abstraction. Within the abstraction, the damage from mechanical disruption events is expressed as a damaged area for flow and transport on the surfaces of the drip shield, waste package, and cladding. The damaged areas include the combined effects of vibratory ground motion, fault displacement, and rockfall. The output from the seismic scenario class is a mathematical relationship of waste package damage (expressed as an area of stress corrosion cracks on the waste package surface) to the size of the seismic event (expressed in terms of the peak ground velocity). The damage is expressed as a mean value with a distribution around this mean to reflect uncertainty and variability in the damage level for a given value of peak ground velocity. This relationship is termed the damage response surface. Values of peak ground velocity are determined from a peak ground velocity hazard curve for the waste emplacement level and are constrained to credible values through use of a bounding peak ground velocity probability distribution. The seismic scenario is then computed within the TSPA-LA using these damage and ground motion abstractions as input (BSC 2003v, Section 6.10).

FEP 1.2.03.02.0B, Seismic Induced Rockfall Damages Engineered Barrier System Components

This FEP was addressed in *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.4) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.9).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Because of the additional imposed stresses, seismic ground motion has the potential to dislodge blocks. This could result in additional damage to the drip shields through mechanical impact mechanisms and possibly to the waste packages (if the drip shields fail) via increased seepage through a damaged or separated drip shield and is included in the TSPA-LA.

It is anticipated that rockfall occurring within lithophysal zones will result in relatively smaller rock fragments with insufficient mass and energy to permanently deform or damage the drip shields. Therefore, damage to the drip shield from rockfall in the lithophysal units is neglected for TSPA-LA. The following discussion addresses only the potential damage to drip shields resulting from the impact of relatively large rock blocks, more likely to occur in nonlithophysal zones. The mechanical response of the drip shield to an impact by large rock blocks from the nonlithophysal unit has the potential to damage the drip shield's ability to act as a flow barrier. The abstraction for the percent failed surface area mode is included as a function of peak ground velocity. An en masse fall of rock fragments, for FEPs purposes, constitutes drift collapse. Seismic-induced drift collapse is addressed as FEP 1.2.03.02.0C in *Features, Events, and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.5) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.85).

The ground motion hazard curves developed for the probabilistic seismic hazard analysis (CRWMS M&O 1998b) were extended to address ground motion during the postclosure period, as documented in DTN: MO03061E9PSHA1.000. The seismic time histories contained in the following DTNs were developed starting with the results of the probabilistic seismic hazard analysis and take into account the effect of the upper 300 m of rock and soil at the site (site response). The repository-level inputs for postclosure seismic evaluations are presented in *Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, Nevada* (BSC 2004w). The ground-motion time histories were developed for 5×10^{-4}, 10^{-6}, and 10^{-7} annual exceedance probabilities (BSC 2004d) and have been used in seismic-related analyses and models to provide inputs to support postclosure analyses of damage to engineered barrier system components from seismic ground-motion, seismic-induced rockfall, and effects related to seismic-induced drift collapse.

The outputs are of particular interest because they are used by *Drift Degradation Analysis* (BSC 2004x) to determine rock block size, rockfall frequency, and drift-collapse effects related to seismic-induced ground motion, which are addressed in related FEPs. The outputs of that analysis are used to evaluate damage to engineered barrier system components from seismically induced rockfall, which is included in the seismic scenario class for TSPA-LA.

In general, vibratory ground motions can cause failure of the host rock around the emplacement drifts. The characterization of seismic damage is addressed using damage-related response surfaces and is fully discussed in *Seismic Consequences Abstraction* (BSC 2003v, Section 6.6). Damage to the drip shield from impact of individual rock blocks is determined by structural response calculations. The objective of these calculations is to determine the drip shield areas where the residual stress exceeds the threshold value (50% of yield strength) for Titanium Grade 7. The analysis evaluates damage based on six representative rock sizes impacting the drip shield from three angles: vertically downward onto the top of the drip shield; at a 60° angle (with the horizontal) onto the transition region between the top and side of the drip shield; and horizontally into the side wall.

Vibratory ground motions also have the potential to eject large, nonlithophysal rock blocks at high velocity. Rock blocks are ejected for the 10^{-6} per year and the 10^{-7} per year ground motion levels; relatively few blocks are ejected at the 5×10^{-4} per year ground motion level. The mean damage areas for ground motions with 10^{-6} and 10^{-7} annual frequency in the nonlithophysal are 1.7% and 3.4%. Maximum values are 32.2% and 63.6%, respectively. Clearly, the mechanical response of the drip shield to impact by a large rock block in the nonlithophysal zone has the potential to damage the drip shield and impair its function as a flow barrier.

FEP 1.2.03.02.0C–Seismic Induced Drift Collapse Damages Engineered Barrier System Components

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.85) and *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.5).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive Events–Excluded
- Engineered Barrier System–Excluded.

Summary of Screening Argument–The potential consequences of seismic-induced drift collapse require two preceding factors: that drift collapse occurs and that the volume or amount of collapse is sufficient to cause structural failure of the drip shields. Drift degradation analysis covered in the following discussion indicates that drift collapse in the nonlithophysal unit is not of concern. However, the analysis does indicate that seismic-induced rockfall in the nonlithophysal unit may be of concern due to the rock block size. The analysis also demonstrates that drifts in the lithophysal zones would collapse under the 10^{-6} per year (and, by inference, the larger, 10^{-7} per year) vibratory ground motions.

However, the analysis does indicate that seismic-induced rockfall in the nonlithophysal unit may be of concern due to the rock block size. Seismic-induced rockfall damage is addressed as a separate FEP.

For the 5×10^{-4} per year ground motion, tunnels in the lithophysal zones show no damage for higher values of rock compressive strength and exhibit only minor damage (but no collapse) at the lowest level of compressive strength. Drift degradation analysis also demonstrates that drifts in the lithophysal zones would collapse under the 10^{-6} per year (and, by inference, the larger, 10^{-7} per year) vibratory ground motions. Consequently, drift collapse in the lithophysal zones can impose a static load on the drip shield from the weight of the natural backfill that fills the drifts as a result of the collapse. The characterization of seismic damage from rockfall is addressed using damage-related response surfaces and is fully discussed in *Seismic Consequence Abstraction* (BSC 2003v, Sections 6.6.1 and 6.6.2). In the lithophysal zones, the static loads from a collapsed drift using continuum or discontinuum representations of the host rock are not expected to collapse the drip shield. Damage to the drip shield from rockfall in the lithophysal zone is neglected for TSPA-LA on this basis.

FEP 1.2.03.02.0D–Seismic Induced Drift Collapse Alters In-Drift Thermohydrology

This FEP was addressed in *Engineered Barrier System Features, Events, and Processes* (BSC 2004b, Section 6.2.86) and *Features, Events and Processes: Disruptive Events* (BSC 2004d, Section 6.2.1.6).

Screening Decision–For the license application, the FEP was screened as follows:

- Disruptive events–Included
- Engineered Barrier System–Included.

Summary of Screening Disposition–Drift collapse in the nonlithophysal unit is of no concern due to limited collapsed volume and small block size. The seepage abstraction does not change for this unit as a result of seismic impacts because rockfall does not completely fill the tunnels at the ground motions that are evaluated. An enhancement factor is included in the seepage abstraction model to account for limited collapse.

Ground motions with an annual frequency of 10^{-6} or less do cause collapse of emplacement drifts in the lithophysal unit. This collapse can fill the drifts with rubble, altering the hydrologic and thermal environment. Impacts on seepage are addressed by modifying the seepage flux used in TSPA-LA.

7.2.3 Resolution of Comment 31

This FEP has been divided into four FEPs: 1.2.03.02.0A, 1.2.03.02.0B, 1.2.03.02.0C, and 1.2.03.02.0D. The first three FEPs deal with damage to engineered barrier system components from ground motion, rockfall, and drift collapse, and the last FEP covers in-drift thermal-hydrology changes due to drift collapse. Only FEP 1.2.03.02.0C, Seismic Induced Drift Collapse Damages Engineered Barrier System Components, has been screened as excluded.

The current YMP FEP descriptions of these FEPs are as follows:

- 1.2.03.02.0A: Seismic activity causes repeated vibration of the EBS components (drip shield, waste package, pallet, and invert). This could result in severe disruption of the drip shields and waste packages through vibration damage or contact between EBS components. Such damage mechanisms could lead to degraded performance.

- 1.2.03.02.0B: Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced rockfall that could impact drip shields, waste packages, or other EBS components.

- 1.2.03.02.0C: Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse that could impact drip shields, waste packages, or other EBS components. Possible effects include both dynamic and static loading.

- 1.2.03.02.0D: Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse and/or rubble infill throughout part or all of the drifts. Drift collapse could impact flow pathways within the EBS, mechanisms for water contact with EBS components, and thermal properties within the EBS.

Updated TSPA dispositions for FEP 1.2.03.02.0A will be contained in the next revisions of *Features, Events and Processes: Disruptive Events* (BSC 2004d) and *Engineered Barrier System Features, Events, and Processes* (BSC 2004b). The latter document will also contain an updated screening decision and argument for FEP 1.2.03.02.0C.

KTI Agreements SDS 1.02 and 2.03 are complete. Agreements RDTME 3.17 and 3.19 were submitted to NRC in June 2004 (Appendix C of *Technical Basis Document No. 4: Mechanical Degradation and Seismic Effects*). KTI Agreements CLST 2.02 and 208 were submitted to NRC as Appendix K to *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*.

7.3 COMMENT 33

Based on discussions between the NRC and the DOE regarding the TSPA-SR FEPs screening position, agreement was reached regarding the path forward for resolution of the comment (Reamer 2001b). The wording of the subject agreement is as follows:

> DOE agreed to clarify the description of the primary FEP in the FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation, ANL-EBS-PA-000002.

7.3.1 TSPA-SR

Specific FEPs were not identified in this comment. The comment refers to primary FEPs identified in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (CRWMS M&O 2001f).

7.3.2 TSPA-LA

FEP 2.1.03.01.0A, General Corrosion of Waste Packages

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.2).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Included.

Summary of Screening Disposition–General corrosion is included in waste package degradation analysis. This includes the effects of corrosive gases. Because general corrosion is likely to be operative for most of the repository operation period, it is one of the key corrosion processes that could lead to degradation and failure of waste packages in the repository. General corrosion due to dry-air oxidation, aqueous corrosion, microbially influenced corrosion, and aging and phase instability of the waste package outer barrier are discussed in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (BSC 2003l).

It was concluded in *General Corrosion and Localized Corrosion of the Waste Package Outer Barrier* (BSC 2003l, Section 6.4.2) that, although dry air oxidation occurs, it results in a negligible amount of barrier thinning over repository timescales (only approximately 93 μm, even if the waste package outer barrier were exposed for 10,000 years at 350°C). Therefore, dry oxidation does not need to be considered in TSPA analyses.

Details of the general corrosion rate distributions used for the Alloy 22 waste package outer barrier are given in *General Corrosion and Localized Corrosion of the Waste Package Outer Barrier* (BSC 2003l).

Additional aqueous corrosion processes are addressed in other FEPs: FEP 2.1.03.03.0A, Localized Corrosion of Waste Packages (BSC 2004c, Section 6.2.6); FEP 2.1.03.02.0A, Stress Corrosion Cracking (SCC) of Waste Packages (BSC 2004c, Section 6.2.4); FEP 2.1.03.04.0A, Hydrogen Induced Cracking (HIC) of Waste Packages (BSC 2004c, Section 6.2.8); and FEP 2.1.03.05.0A, Microbially Influenced Corrosion (MIC) of Waste Packages (BSC 2004c, Section 6.2.10).

FEP 2.1.03.01.0B, General Corrosion of Drip Shields

This FEP was addressed in *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation* (BSC 2004c, Section 6.2.3).

Screening Decision–For the license application, the FEP was screened as follows:

- Waste Package–Included.

Summary of Screening Disposition–General corrosion is included in drip shield degradation analysis. This includes the effects of corrosive gases. General corrosion due to dry-air oxidation, humid-air and aqueous general corrosion, microbially influenced corrosion, and aging and phase instability of the Titanium Grade 7 drip shield are discussed in *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003m).

It was concluded in *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003m, Section 8.2) that although dry-air oxidation occurs, it results in a negligible amount of barrier thinning over repository timescales (only approximately 2,129 nm, even if the drip shield were exposed for 10,000 years at 200°C). Therefore, dry oxidation does not need to be considered in the TSPA analyses.

Penetration rates for general corrosion are provided in *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003m) and are used in TSPA analyses. Both humid-air and aqueous corrosion processes are considered part of general corrosion (BSC 2003m, Sections 6.1 and 6.3).

Additional aqueous corrosion processes are addressed in other FEPs: FEP 2.1.03.03.0B, Localized Corrosion of Drip Shields (BSC 2004c, Section 6.2.7); FEP 2.1.03.02.0B, Stress Corrosion Cracking (SCC) of Drip Shields (BSC 2004c, Section 6.2.5); FEP 2.1.03.04.0B, Hydride Cracking of Drip Shields (BSC 2004c, Section 6.2.9); and FEP 2.1.03.05.0B, Microbially Influenced Corrosion (MIC) of Drip Shields (BSC 2004c, Section 6.2.11). These processes are described in *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2003m), *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2003n), and *Hydrogen Induced Cracking of Drip Shield* (BSC 2003aa). As discussed in FEP 2.1.03.05.0B, Microbially Influenced Corrosion of Drip Shields, the drip shield is considered to be immune to microbially influenced corrosion. Also, as discussed in FEP 2.1.11.06.0B, Thermal Sensitization of Drip Shields, aging and phase instability has no effect on drip shield degradation processes.

7.3.3 Resolution of Comment 33

The project has reviewed the results reported by Barkatt and Gorman (2000) and has concluded that the testing conditions used were not relevant to Yucca Mountain. However, existing KTI Agreements CLST 1.01, CLST 1.10, and CLST 6.01 are intended to evaluate the effects of introduced materials on water chemistry and deleterious trace element concentrations on the corrosion behavior of titanium, similar to the electrochemically based studies on Alloy 22. Agreement CLST 1.01 was submitted to NRC in Appendix A of *Technical Basis Document No. 5: In-Drift Chemical Environment*. Agreements CLST 1.10 and CLST 6.01 were submitted to NRC in Appendices O and P of *Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion*.

In addition, the following FEPs deal with trace metals:

- 2.1.03.01.0A, General Corrosion of Waste Packages (BSC 2004c, Section 6.2.2). YMP FEP Description: General corrosion may contribute to waste package failure.

- 2.1.03.01.0B, General Corrosion of Drip Shields (BSC 2004c, Section 6.2.3). YMP FEP Description: General corrosion may contribute to drip shield failure.

- 2.1.03.03.0A, Localized Corrosion of Waste Packages (BSC 2004c, Section 6.2.6). YMP FEP Description: Localized corrosion (pitting or crevice corrosion) could enhance degradation of the waste packages.

- 2.1.03.03.0B, Localized Corrosion of Drip Shields (BSC 2004c, Section 6.2.7). YMP FEP Description: Localized corrosion (pitting or crevice corrosion) could enhance degradation of the drip shields.

- 2.1.03.02.0A, Stress Corrosion Cracking (SCC) of Waste Packages (BSC 2004c, Section 6.2.4). YMP FEP Description: At specific locations where waste packages become wet and are stressed, stress corrosion cracking ensues. The possibility of stress corrosion cracking under dry conditions or due to thermal stresses is also addressed as part of this FEP.

- 2.1.03.02.0B, Stress Corrosion Cracking (SCC) of Drip Shields (BSC 2004c, Section 6.2.5). YMP FEP Description: At specific locations where drip shields become wet and are stressed, stress corrosion cracking ensues. The possibility of stress corrosion cracking under dry conditions or due to thermal stresses is also addressed as part of this FEP.

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8. CONCLUSIONS

This report has addressed each of the NRC comments specified in KTI Agreements TSPAI 2.01, TSPAI 2.02, TSPAI 2.03, TSPAI 2.04, and TSPAI 2.07. Clarifications, technical bases, and additions to FEPs have been documented (as described in Section 1), as agreed. This report identifies the locations of this documentation and summarizes the information pertinent to the KTI Agreements.

The information in this report is responsive to agreements TSPAI 2.01, TSPAI 2.02, TSPAI 2.03, TSPAI 2.04, and TSPAI 2.07 made between DOE and NRC. This report contains the information that DOE considers necessary for NRC review for closure of these agreements.

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