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

1. QA: QA

2. ☒ Analysis — Check all that apply

Type of Analysis	☐	Engineering
	☒	Performance Assessment
	☐	Scientific
Intended Use of Analysis	☐	Input to Calculation
	☐	Input to another Analysis or Model
	☒	Input to Technical Document
	☐	Input to other Technical Products

Describe use: To Discuss Near Field Environment FEPs in TSPA

3. ☐ Model — Check all that apply

Type of Model	☐	Conceptual Model
	☐	Mathematical Model
	☐	Process Model
	☐	Abstraction Model
	☐	System Model
Intended Use of Model	☐	Input to Calculation
	☐	Input to another Model or Analysis
	☐	Input to Technical Document
	☐	Input to other Technical Products

Describe use:

4. Title:
Features, Events, and Processes in Thermal Hydrology and Coupled Processes

5. Document Identifier (including Rev. No. and Change No., if applicable):
ANL-NBS-MD-000004 Rev 00

6. Total Attachments:
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7. Attachment Numbers - No. of Pages in Each:
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		Printed Name	Signature	Date
8.	Originators	Nicholas D. Francis	SIGNATURE ON FILE	5/2/00
		Michael T. Itamura	SIGNATURE ON FILE	5/2/00
9.	Checker	Noreen Baker	SIGNATURE ON FILE	5/2/00
10.	Lead/Supervisor	Nicholas D. Francis	SIGNATURE ON FILE	5/3/00
11.	Responsible Manager	Clifford K. Ho	SIGNATURE ON FILE	5/3/2000

12. Remarks:

Nicholas Francis is responsible for the THC FEPs
Michael T. Itamura is responsible the other FEPs

Per Section 5.5.6 of AP-3.10Q, the responsible manager has determined that the subject AMR is not subject to AP-2.14Q review because the analysis does not affect a discipline or area other than the originating organization (Performance Assessment). The originators of this AMR worked closely with the originators of the process level models that are references in this AMR. The downstream user of the information resulting from this AMR is Performance Assessment (PA), which is also the originating organization of this work. However, it was determined that this analysis does not directly affect other organizations other than the originating organization. Therefore, no formal AP-2.14Q reviews were requested or determined to be necessary.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

Complete Only Applicable Items

2. Analysis or Model Title:

Features, Events, and Processes in Thermal Hydrology and Coupled Processes

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

ANL-NBS-MD-000004 Rev 00

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

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TABLES

ACRONYMS

AMR	Analysis Modeling Report
CRWMS	Civilian Radioactive Waste Management System
CSNF	Commercial Spent Nuclear Fuel
DDT	Discrete heat source, Drift-scale, Thermal-conduction model
DOE	United States Department of Energy
DSNF	Defense Spent Nuclear Fuel
DST	Drift Scale Test
EBS	Engineered Barrier System
EDZ	Excavation Disturbed Zone
ENFE	Evolution of the Near Field Environment
EPA	United States Environmental Protection Agency
FEPs	Features, Events, and Processes
HLW	High-Level Waste
IRSR	Integration Issue Resolution Status Report
LADS	License Application Design Selection
LDTH	Line-load, Discrete heat source, Thermal-Hydrologic model
M&O	Management & Operating (Contractor)
MSTHM	Multi-Scale Thermal-Hydrologic Methodology
NEA	Nuclear Energy Agency of the Organization for Economic Co-Operation and Development
NFE	Near-Field Environment
NRC	U.S. Nuclear Regulatory Commission
OECD	Organization for Economic Co-Operation and Development
OCRWM	Office of Civilian Radioactive Waste Management
PMR	Process Modeling Report
PTn	Paintbrush Tuff, non-welded
QARD	Quality Assurance Requirements and Description
SDT	Smeared heat source, Drift-scale, Thermal-conduction model
SMT	Smeared heat source, Mountain-scale, Thermal-conduction model
SZ	Saturated Zone
TBV	To-be Verified
TEF	Thermal Effects on Flow
TH	Thermal-Hydrologic
THC	Thermal-Hydrologic-Chemical
THMC	Thermal-Hydrologic-Mechanical-Chemical
TM	Thermal-Mechanical
TSPA	Total System Performance Assessment
TSPA-SR	Total System Performance Assessment Site Recommendation
UZ	Unsaturated Zone
UZFT	Unsaturated Zone Flow and Transport

ACRONYMS (Continued)

YMP	Yucca Mountain Project
WF	Waste Form
WIPP	Waste Isolation Pilot Plant
WP	Waste Package

1. PURPOSE

Under the provisions of the U.S. Department of Energy's (DOE) *Revised Interim Guidance Pending Issuance of New U. S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999,) for Yucca Mountain, Nevada* (Dyer 1999), herein referred to as DOE's interim guidance, the DOE must provide a reasonable assurance that the regulatory-specified performance objectives for the Yucca Mountain project can be achieved for a 10,000-year post-closure period. This assurance must be demonstrated in the form of a performance assessment that: (1) identifies the features, events, and processes (FEPs) that might affect the performance of the geologic repository; (2) examines the effects of such FEPs on the performance of the geologic repository; and (3) estimates the expected annual dose to a specified nearby population group. The performance assessment must also provide the technical basis for inclusion or exclusion of specific FEPs.

Although the NRC has not defined or used the term "scenario" in the pertinent regulations, the Yucca Mountain Total System Performance Assessment (TSPA) has chosen to satisfy the above-stated performance assessment requirements by adopting a scenario development process. This decision was made based on the Yucca Mountain TSPA adopting a definition of "scenario" as not being limited to a single, deterministic future of the system, but rather as a set of similar futures that share common FEPs. The DOE has chosen to adopt a scenario development process based on the methodology developed by Cranwell et al. (1990) for the NRC. The first step of this process is the identification of FEPs potentially relevant to the performance of the Yucca Mountain repository; the second step includes the screening of each FEP.

The primary purpose of this Analysis/Model Report (AMR) is to identify and document the analysis, screening decision, and TSPA disposition or screening argument for each of the 26 FEPs that have been identified as Near Field Environment (NFE) FEPs (described in Section 1.1). The screening decisions and associated TSPA disposition or screening argument will be catalogued separately in a project-specific FEPs database for the subject FEPs (see Section 1.4). This AMR and the database are being used to document information related to the FEPs screening decisions and associated screening argument and to assist reviewers during the license review process.

1.1 SCOPE

This AMR has been prepared to satisfy the FEP screening documentation requirements in the Work Scope/Objectives/Tasks section of the development plan entitled *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 1999a). The NFE is treated in Total System Performance Assessment - Site Recommendation (TSPA-SR) as being equivalent to the thermal hydrologic and coupled processes in the unsaturated zone repository host rock. The thermal environment inside of the drift is considered in the Engineered Barrier System (EBS).

The current FEPs list consists of 1786 entries (as described in Section 1.2). The FEPs have been classified as Primary and Secondary FEPs (as described in Section 1.2) and have been assigned to various Process Model Reports (PMRs). The assignments were based on the nature of the FEPs so that the analysis and resolution for screening decisions reside with the subject-matter experts in the relevant disciplines. The resolution of the 26 NFE FEPs is documented in this AMR and the resolution of other FEPs are documented in other FEP AMRs prepared by the responsible PMR groups. Several relevant FEPs do not fit neatly into the existing PMR structure. Criticality is an example, and it is treated in FEP assignments as if it were a separate PMR. Some FEPs were best assigned to the TSPA itself (i.e., system-level FEPs), rather than to its component models.

This AMR addresses the 26 Primary FEPs that have been identified as NFE FEPs. These FEPs represent the key features, events and processes of the NFE that influence other aspects of the repository. The 26 Primary NFE FEPs addressed in this AMR are provided in Table 1.

Table 1. Primary NFE FEPs

FEP Name – Yucca Mountain Project (YMP) FEP #
Excavation/Construction – YMP 1.1.02.00.00
Effects of pre-closure ventilation – YMP 1.1.02.02.00
Fractures – YMP 1.2.02.01.00
Increased unsaturated water flux at the repository – YMP 2.1.08.01.00
Enhanced influx (Philip's drips) – YMP 2.1.08.02.00
Repository dry-out due to waste heat – YMP 2.1.08.03.00
Desaturation/dewatering of the repository – YMP 2.1.08.10.00
Resaturation of the repository – YMP 2.1.08.11.00
Properties of the potential carrier plume in the waste and EBS – YMP 2.1.09.01.00
Rind (altered zone) formation in waste, EBS, and adjacent rock. – YMP 2.1.09.12.00
Heat output/temperature in waste and EBS – YMP 2.1.11.01.00
Nonuniform heat distribution/edge effects in repository – YMP 2.1.11.02.00
Excavation and construction-related changes in the adjacent host rock – YMP 2.2.01.01.00
Thermal and other waste and EBS-related changes in the adjacent host rock – YMP 2.2.01.02.00
Changes in fluid saturations in the excavation disturbed zone (EDZ) – YMP 2.2.01.03.00
Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock – YMP 2.2.06.01.00
Condensation zone forms around drifts – YMP 2.2.07.10.00
Return flow from condensation cap/resaturation of dry-out zone – YMP 2.2.07.11.00
Geochemical interactions in geosphere (dissolution, precipitation, weathering and effects on radionuclide transport) – YMP 2.2.08.03.00
Redissolution of precipitates directs more corrosive fluids to container – YMP 2.2.08.04.00

Table 1. Primary NFE FEPs (Continued)

Thermo-mechanical alteration of fractures near repository – YMP 2.2.10.04.00
Thermo-mechanical alteration of rocks above and below the repository – YMP 2.2.10.05.00
Thermo-chemical alteration (solubility speciation, phase changes, precipitation/dissolution) – YMP 2.2.10.06.00
Two-phase buoyant flow/heatpipes – YMP 2.2.10.10.00
Geosphere dry-out due to waste heat – YMP 2.2.10.12.00
Density-driven groundwater flow (thermal) – YMP 2.2.10.13.00

1.2 FEPs IDENTIFICATION

For the YMP TSPA, a scenario is a defined subset of the set of all possible futures of the disposal system that contains futures resulting from a specific combination of features, events, and processes. The first step of the scenario development process is the identification of FEPs potentially relevant to the performance of the Yucca Mountain repository. The most current list of FEPs is contained in the YMP FEPs database. A comprehensive discussion of the origin of these FEPs, their organization, and their assignment to the various PMRs is provided in the documentation accompanying the database (CRWMS M&O 1999b). A brief summary of that discussion follows.

The initial set of FEPs was created for the Yucca Mountain TSPA by combining lists of FEPs previously identified as relevant to the YMP with a draft FEP list compiled by the Nuclear Energy Agency (NEA) of the Organization for Economic Co-Operation and Development (OECD) (SAM 1997). The NEA list is maintained as an electronic FEP database and is the most comprehensive list available internationally. The list currently contains 1261 FEPs from Canadian, Swiss, and Swedish spent-fuel programs, intermediate and low-level waste programs of the U.K., and the US Waste Isolation Pilot Plant (WIPP) program. An additional 292 FEPs have been identified from YMP literature and site studies, and 82 FEPs have been identified during YMP project staff workshops. These FEPs are organized under 151 categories, based on NEA category headings, resulting in a total of 1786 entries. Consistent with the diverse backgrounds of the programs contributing FEPs lists, FEPs have been identified by a variety of methods, including expert judgement, informal elicitation, event tree analysis, stakeholder review, and regulatory stipulation. All potentially relevant FEPs have been included, regardless of origin. This approach has led to considerable redundancy in the FEP list, because the same FEPs are frequently identified by multiple sources, but it also ensures that a comprehensive review of narrowly defined FEPs will be performed. The FEPs list is considered open and will continue to grow as additional FEPs are identified.

There is no uniquely correct level of detail at which to define scenarios or FEPs. Decisions regarding the appropriate level of resolution for the analysis are made based on consideration of the importance of the scenario in its effect on overall performance and the resolution desired in the results. The number and breadth of scenarios depend on the resolution at which the FEPs have been defined: coarsely defined FEPs result in fewer, broad scenarios, whereas narrowly defined FEPs result in many narrow scenarios. For efficiency, both FEPs and scenarios should be aggregated at the coarsest level at which a technically sound argument can be made that is adequate for the purposes of the analysis.

Consequently, each FEP has been identified as either a Primary or Secondary FEP. Primary FEPs are those FEPs for which the project proposes to develop detailed screening arguments. The classification and description of Primary FEPs strives to capture the essence of all the Secondary FEPs that map to the primary. For example, the Primary FEP "Two-phase buoyant flow/heat pipes" can be used appropriately to resolve multiple and redundant Secondary FEPs that address the evolution and continuation of a heat pipe. By working to the Primary FEP description, the subject matter experts assigned to the Primary FEP address all relevant Secondary FEPs, and arguments for Secondary FEPs can be rolled into the Primary FEP analysis. Secondary FEPs are either FEPs that are completely redundant or that can be aggregated into a single Primary FEP.

To perform the screening and analysis, the FEPs have been assigned based on the PMR structure so that the analysis, screening decision, and TSPA disposition reside with the subject matter experts in the relevant disciplines. The TSPA recognizes that FEPs have the potential to affect multiple facets of the project, may be relevant to more than one PMR, or may not fit neatly within the PMR structure. For example, many FEPs affect unsaturated zone flow and transport (UZFT), the EBS, waste form (WF), and the NFE. Rather than create multiple separate FEPs, the FEPs have been assigned, as applicable, to one or more process modeling groups, which are responsible for the AMRs.

At least two approaches have been used to resolve overlap and interface problems of multiple assigned FEPs. FEP owners from different process modeling groups may decide that only one PMR will address all aspects of the FEP, including those relevant to other PMRs. Alternatively, FEP owners may each address only those aspects of the FEP relevant to their area. In either case, the FEP AMR produced by each process modeling group lists the FEP and summarizes the screening result, citing the appropriate work in related AMRs as needed.

This AMR addresses the 26 FEPs that have been identified as Primary NFE FEPs, as discussed in *YMP FEP Database Rev 00C* (CRWMS M&O 1999b). In those cases where the FEP is relevant to other PMRs, the relevance of the FEP to the NFE is discussed herein. Overlap with other PMRs' FEPs occurs for the following PMRs: Unsaturated Zone, Saturated Zone, Engineered Barrier System, Waste Form, and Disruptive Events. It should be noted that in a few cases such a FEP has been designated as "excluded" from the TSPA relative to the NFE. It is important to note, however, that such a designation of "exclude" for the NFE does not mean that the FEP is necessarily "excluded" relative to another PMR.

1.3 FEPs SCREENING AND ANALYSIS PROCESS

As described in Section 1.2, the first step in the scenario development process was the identification and analysis of FEPs. The second step in the scenario development process includes the screening of each FEP. Each FEP is screened for inclusion or exclusion in the TSPA against three criteria, which are stated as regulatory requirements in NRC's proposed rule 10 CFR Part 63 (64 FR 8640) and in the U.S. Environmental Protection Agency's (EPA) proposed rule 40 CFR Part 197 (64 FR 46976). The screening criteria are discussed in more detail in Section 4.2 and are summarized here. FEPs are excluded from the TSPA only if:

- They are specifically ruled out by regulation, are contrary to the stated regulatory assumptions, or are in conflict with statements made in background information regarding intent or directions of the regulations.

- They can be shown to have a probability of occurrence less than 10^{-4} in 10^{4} years.

- Their occurrence can be shown to have no significant effect on the overall performance of the system.

The regulatory screening criteria contained in DOE's interim guidance (Dyer 1999) and in the proposed 40 CFR Part 197 (64 FR 46976) are relevant to many of the FEPs. FEPs that are contrary to DOE's interim guidance, or specific proposed regulations, regulatory assumptions, or regulatory intent are excluded from further consideration. Examples include: the explicit exclusion of consideration of all but a stylized scenario to address treatment of human intrusion (10 CFR §63.113(d)), assumptions about the critical group to be considered in the dose assessment (10 CFR §63.115), and the intent that the consideration of "the human intruders" be excluded from the human intrusion assessment (64 FR 8640, Section XI, Human Intrusion).

Probability estimates used in the FEPs screening process may be based on technical analysis of the past frequency of similar events (such as igneous and seismic events) or, in some cases, on expert elicitation. Probability arguments, in general, require including some information about the magnitude of the event in its definition. Probability arguments are also sensitive to the spatial and temporal scales at which FEPs are defined. For example, the definition of the probability of a seismic event depends on the magnitude of the event. Probability arguments are therefore made at reasonably coarse scales.

Consequence-based screening arguments can be established in a variety of ways. Various methods include TSPA sensitivity analyses, modeling studies outside of the TSPA, or reasoned arguments based on literature research. For example, consequences of many geomorphic processes such as erosion and sedimentation can be evaluated by considering bounding rates reported in geologic literature. More complicated processes, such as igneous activity, require detailed analyses conducted specifically for the Yucca Mountain Project. Low-consequence arguments are often made by demonstrating that a particular FEP has no effect on the distribution of an intermediate performance measure in the TSPA. For example, by demonstrating that including a particular WF has no effect on the concentrations of radionuclides transported from the repository in the aqueous phase, it is also demonstrated that including this waste form in the inventory would not compromise compliance with the performance objectives. Explicit modeling of the characteristics of this waste form could therefore be excluded from the TSPA.

Using the type of arguments discussed above, each FEP identified as relevant to the NFE was reviewed against the three exclusion criteria. Those that were determined to meet one of the three criteria were designated as “excluded” from further consideration within the TSPA. Those that did not meet one of these criteria must, by definition, be “included.”

1.4 ORGANIZATION OF FEP DATABASE

Under a separate scope, the TSPA team is constructing an electronic database to assist project reviewers during the license review process. Each FEP has been entered as a separate record in the database. Fields within each record provide a unique identification number, a description of the FEP, the origin of the FEP, identification as a Primary or Secondary FEP for the purposes of the TSPA, and mapping to related FEPs and to the assigned PMRs. Fields also provide summaries of the screening arguments with references to supporting documentation and AMRs, and, for all retained FEPs, statements of the disposition of the FEP within the TSPA modeling system. The AMRs, however, contain the detailed arguments and description of the disposition of the subject FEPs.

Alphanumeric identifiers (called the “NEA category”) previously used have been retained in the database for traceability purposes. Each FEP has also been assigned a unique YMP FEP database number, based on the NEA categories. The database number is the primary method for identifying FEPs, and consists of an eight-digit number of the form x.y.zz.pp.qq. The general structure of the database is reflected in the first two digits (x.y) as shown below:

0.0. Assessment Basis

1.0. External Factors
- 1.1 Repository Issues
- 1.2 Geological Processes and Effects
- 1.3 Climatic Processes and Effects
- 1.4 Future Human Actions (Active)
- 1.5 Other

2.0. Disposal System - Environmental Factors
- 2.1 Wastes and Engineered Features
- 2.2 Geologic Environment
- 2.3 Surface Environment
- 2.4 Human Behavior

3.0. Disposal System - Radionuclide/Contaminant Factors
- 3.1 Contaminant Characteristics
- 3.2 Contaminant Release/Migration Factors
- 3.3 Exposure Factors

The next four digits (zz.pp) define a grouping structure for the FEPs, with zz designating the category, and pp designating the heading. The exact details of this grouping structure are not important to the evaluation, since each FEP will be evaluated regardless of the database organization. Finally, the last two digits (qq) signify whether the FEP is primary (00) or Secondary (other than 00). Each heading has a Primary FEP associated with it, and may or not have any Secondary FEPs. In those cases where Secondary FEPs do exist, the Primary FEP encompasses all the issues associated with the Secondary FEPs. The Secondary FEPs either provide additional detail concerning the primary, or are a restatement of the primary based on redundant input from a different source.

2. QUALITY ASSURANCE

The activities documented in this AMR were evaluated in accordance with QAP-2-0, *Conduct of Activities* and were determined to be quality affecting and subject to the requirements of the U.S. DOE Office of Civilian Radioactive Waste Management (OCRWM) *Quality Assurance Requirements and Description* (QARD) (DOE 2000). This evaluation is documented in *Conduct of Performance Assessment* (CRWMS M&O 1999c). Accordingly, the modeling or analysis activities documented in this AMR have been conducted in accordance with the Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) quality assurance program, using approved procedures identified in the development plan *Features, Events, and Processes in Thermal Hydrology and Coupled Processes* (CRWMS M&O 1999a).

More specifically, this AMR has been developed in accordance with procedure AP-3.10Q, *Analyses and Models*. All associated records (e.g., data, software, planning) have been submitted per the appropriate procedure cited in AP-3.10Q. Requirements of other procedures included by reference in AP-3.10Q have also been addressed as appropriate. Preparation of this analysis did not require the classification of items in accordance with QAP-2-3, *Classification of Permanent Items.* This activity is not a field activity. Therefore, an evaluation in accordance with NLP-2-0, *Determination of Importance Evaluations* was not required.

The list of the 26 FEPs addressed in this AMR was derived from the *YMP FEP Database Rev. 00C* (CRWMS M&O 1999b). Rev 00 of the FEPs database is currently scheduled as a Level 3 Milestone, as part of the TSPA-SR deliverables and will be maintained in accordance with AP-SV.1Q, *Control of the Electronic Management of Data*.

3. COMPUTER SOFTWARE AND MODEL USAGE

This AMR uses no computational software or models. The AMR was developed using only commercially available software (Microsoft Word 98) for word processing, which is exempt from qualification requirements in accordance with AP-SI.1Q, *Software Management*. There were no additional applications (routines or macros) developed using this commercial software. The analyses and arguments presented herein are based on regulatory requirements, results of analyses presented and documented in other AMRs, or technical literature.

4. INPUTS

4.1 DATA AND PARAMETERS

The nature of the FEPs screening arguments and TSPA dispositions is such that cited data and values form the basis of reasoned argument, as opposed to inputs to computational analyses or models. The data cited in the FEPs screening arguments is largely non-critical, and conclusions will be formulated such that they will not be affected by any expected degrees of uncertainties. The *Guidelines for Implementation of EDA II* (Wilkins and Heath 1999) was used as input for the process level thermal-hydrologic models used as input for this analysis. This the EDA II design has been superceded by the design described in *Monitored Geologic Repository Project Description Document* (CRWMS M&O 1999d). The differences between the two documents that would affect thermal-hydrologic model results are (1) reducing the drip-shield thickness from 20 mm to 15 mm, (2) changing the wording relating to the spacing between the waste packages from “10 centimeters” to “a minimum of 10 cm,” and (3) the changing of the ventilation time from 50 years to between 50 and 125 years. This design does consider the use of backfill material within the drift.

4.2 CRITERIA

This AMR complies with the DOE interim guidance (Dyer 1999). Subparts of the interim guidance that apply to this analysis or modeling activity are those pertaining to the characterization of the Yucca Mountain site (Dyer 1999, Subpart B, Section 15). In particular, relevant parts of the guidance include the compilation of information regarding geology, hydrology, and geochemistry of the site (Dyer 1999, Subpart B, Section 21(c)(1)(ii)), and the definition of geologic, hydrologic, and geochemical parameters and conceptual models used in performance assessment (Dyer 1999, Subpart E, Section 114(a)).

Technical screening criteria are provided in DOE’s interim guidance (Dyer 1999) and have also been identified by the NRC in the proposed 10 CFR Part 63 (64 FR 8640) and by the EPA in the proposed 40 CFR Part 197 (64 FR 46976). Both proposed regulations specifically allow the exclusion of FEPs from the TSPA if they are of low probability (less than one chance in 10,000 of occurring in 10,000 years) or if occurrence of the FEP can be shown to have no significant effect on expected annual dose. There is no quantified definition of “significant effect” in the guidance or proposed regulations.

4.2.1 Low Probability

The probability criterion is explicitly stated by the NRC in the proposed 10 CFR §63.114 (d):

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

The EPA provides essentially the same criterion in the proposed 40 CFR §197.40:

> The DOE’s performance assessments should not include consideration of processes or events that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal.

4.2.2 Low Consequence

Criteria for low consequence screening arguments are provided in DOE’s interim guidance (Dyer 1999, Subpart E, Section 114(e) and (f)), which indicates that performance assessment shall:

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

(f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission.

The EPA provides essentially the same criteria in the proposed 40 CFR §197.40:

> …with the NRC’s approval, the DOE’s performance assessment need not evaluate, in detail, the impacts resulting from any processes and events or sequences of processes and events with a higher chance of occurrence if the results of the performance assessment would not be changed significantly.

The terms “significantly changed” and “changed significantly” are undefined terms in the DOE interim guidance and in the EPA’s proposed regulations. These terms are inferred for FEPs screening purposes to be equivalent to having no or negligible effect. Because the relevant performance measures differ for different FEPs (e.g., effects on performance can be measured in terms of changes in concentrations, flow rates, travel times, and other measures, as well as overall expected annual dose), there is no single quantitative test of “significance.”

4.2.3 Reference Biosphere

Both DOE’s interim guidance (Dyer 1999) and EPA’s proposed regulations specify assumptions (which in effect serve as criteria) pertinent to screening many of the NFE FEPs. Particularly germane are explicit assumptions regarding the reference biosphere (proposed 10 CFR §63.115), and less so are assumptions regarding the location and use of groundwater by the critical group used for calculation of exposure doses.

The assumptions pertaining to the characteristics of the reference biosphere are presented in DOE’s interim guidance (Dyer 1999, Subpart E, Section 115(a)(1,4)). The specified characteristics pertinent to the NFE FEPs are that:

(1) Features, events, and processes …shall be consistent with present knowledge of the conditions in the region surrounding the Yucca Mountain site.

(4) Evolution of the geologic setting shall be consistent with present knowledge of natural processes.

The EPA has specified a similar assumption in proposed 40 CFR §197.15. This assumption is stated as:

> … DOE must vary factors related to the geology, hydrology, and climate based on environmentally protective but reasonable scientific predictions of the changes that could affect the Yucca Mountain disposal system over the next 10,000 years.

4.3 CODES AND STANDARDS

There are no Codes or Standards directly applicable to this analysis.

5. ASSUMPTIONS

5.1 GENERAL ASSUMPTIONS

There are two general assumptions that are used throughout this document in the screening of the NFE FEPs.

5.1.1 Future Geologic Setting

As directed by DOE's interim guidance (Dyer 1999, Subpart E, Section 114(1)), the TSPA assumes that future geologic settings will be within the range of conditions that are consistent with present knowledge of natural processes.

This assumption is germane to NFE FEPs, since the FEPs are screened based on known processes or phenomena that could potentially affect future states of the system. Discernible impacts from past events on the geologic setting are inherently reflected in the present knowledge of natural processes that form the basis of the TSPA. If the subject FEP phenomena do not have a documented past occurrence within the geologic time scale of concern and/or within the study area, or if past events are of an insignificant consequence, then it is by definition a low probability or low consequence event and can be excluded from consideration. Consequently, this assumption does not require verification.

5.1.2 Repository Closure

The TSPA is based on an assumption that the repository will be constructed, operated, and closed according to regulatory requirements during the construction period.

This assumption is particularly germane to FEPs involving off-normal events during the construction phase of the repository or deviations from the as-designed repository configuration. By definition, such events and/or design deviations will not be explicitly considered in the TSPA.

These two assumptions are justified based on the conditions specified in DOE's interim guidance (Dyer 1999), which require special and periodic reporting of (1) progress of construction, (2) data not within predicted limits on which the facility design is based, and (3) any deficiency, that if uncorrected, could adversely affect safety. Additionally, restrictions on subsequent changes to the features or procedures will be a condition of construction authorization. Furthermore, the existing regulations specified in Subpart F (Dyer 1999) require that a performance confirmation program be instituted. A "to be verified" (TBV) is not required for a performance confirmation program. The focus of the program is to confirm the geotechnical design parameters and to ensure that appropriate action is taken to inform the NRC of changes needed to accommodate actual field conditions. It also includes provisions for design testing and monitoring of testing of waste packages to verify in-situ performance of the waste package design. The requirement is for these activities to be conducted in a manner that does not adversely affect the ability of the geologic and engineered elements of the geologic repository to meet the performance objectives. Additionally, all of these activities are subject to the quality assurance requirements specified in Subpart G (Dyer 1999). Regardless of this assumption, the TSPA includes the possibility that engineered systems may not perform optimally for the full 10,000 years. For example, the premature failure of some waste packages is included in the TSPA through the probabilistic treatment of waste package degradation.

5.2 FEP-SPECIFIC ASSUMPTIONS

This section lists the NFE-specific assumptions used in Section 6. All of the assumptions were used as reference or logical analysis assumptions to facilitate the identification and analysis of FEPs. Some of the assumptions require further substantiation and, hence, will need to carry a TBV. It is particularly noted that, conceptually, all of the events and processes identified are potential scenarios, and as such, are assumed to occur for the purpose of analysis. It is also noted that the EDA II design (Wilkins and Heath 1999) is used as a point of departure for FEP identification, but the latter is not restricted by the configuration or design requirements specified in that baseline. Examples of FEPs that go "beyond" the baseline are the development of gaps between drip shield segments due to a seismic event.

5.2.1 Near Field Environment Description

The NFE is assumed to include the thermal processes in all the rock in the unsaturated zone (e.g. not including the insides of the drift which is considered the EBS). Thus, the determination of seepage flow into the drift, including the impact of geophysical changes in this region of the rock, is an NFE issue while chemical processes involving rock bolts and the surrounding cement are considered EBS issues. Consequently, all flow into the tunnel is provided as boundary conditions to EBS from the NFE analyses. This assumption is reasonable and does not require verification.

The NRC categorization of NFE issues encompasses much more than the issues that are included in this AMR. The NRC NFE issues covered in the *Issue Resolution Status Report Key Technical Issue: Evolution of the Near Field Environmen*t include coupled Thermal-Hydrologic-Chemical (THC) effects on seepage and flow, waste package chemical environment, the chemical environment on radionuclide release, effects of THC processes on radionuclide transport through engineered and natural barriers, and coupled THC processes affecting potential nuclear criticality in the near field (NRC 1999a, page 4). The NRC NFE issues will be covered in the NFE, UZFT, waste package, waste form, and EBS FEP AMRs.

5.2.2 Reference Repository Design

The Enhanced Design Alternative II, as described in *Direction to Transition to Enhanced Design Alternative II* (Wilkins and Heath 1999), is used as the reference design for FEP identification. Additional information is provided in the *License Application Design Selection Report* (LADS) (CRWMS M&O 1999e), as well as earlier documentation on subsurface facilities (CRWMS M&O 1998a) and ground control systems (CRWMS M&O 1998b). Key features of this design include the waste package sitting atop a pedestal and invert, a drip shield to minimize water contact with the waste packages, Overton sand backfill to protect the drip shield from rock fall, and 81 meter spacing between emplacement drifts. An extended period of preclosure ventilation (50 years) ensures that maximum waste package temperatures are kept below allowable limits.

However, departures from the baseline due to the potential occurrence of FEPs are also addressed.

The document that was used as input to the thermal-hydrologic process level models has been superceded by *Monitored Geologic Repository Project Description Document* (CRWMS M&O 1999d). The three differences that affect the thermal-hydrologic models are listed in Section 4.1. As long as the structural integrity of the drip shield gives the same protection to the waste packages from rockfall, reducing the drip shield thickness by 5 millimeters should not change thermal-hydrologic results. Increasing the waste package spacing, thereby reducing the areal mass loading of the repository, or increasing the ventilation time would result in a cooler repository. An impact review will have to be performed and this AMR updated with each design change. A TBV is not needed for this assumption since the controlled document system and impact reviews will provide the impetus to update this document when the design changes.

5.2.3 Thermal-Mechanical Effects

The Thermal-Mechanical (TM) effects on repository performance are assumed to be negligible. This assumption is used in the FEPs that deal with thermal-mechanical changes in Section 6.2.

The basis for this assumption is that TM effects are expected to close fractures as the repository rock heats up and open/shear fractures as the repository cools off. Since the waste packages are expected to survive intact throughout the heating and through much of the cooling period, it is only the permanent effects of the fractures due to TM effects that will affect the performance of the repository. The two main effects that changing fractures will have on radionuclide transport is on seepage into the drift, which may accelerate the corrosion of the waste package and eventual dissolution of the waste form and the transport of radionuclides out of the drift through the unsaturated zone. The expected changes to the permeability field due to permanent TM effects show an increase in permeability by up to a factor of 10 in the region around the drift (CRWMS M&O 2000a). The quantity of seepage that enters the drift has been shown to decrease as the bulk permeability increases (CRWMS M&O 2000b, Tables 4 through 8). The quantity of expected seepage that gets into the drift in the TSPA model has been increased by 71% to account for drift degradation and other uncertainties (CRWMS M&O 2000c, Section 6.4). Analyses have shown that transport from the drift to the water table is not a strong function of fracture aperture size (CRWMS M&O 2000d). These analyses show that this assumption is reasonable but still requires further verification and will require a TBV.

5.2.4 Thermal-Hydrologic-Chemical Effects of Backfill

The THC effects from backfill are assumed to be negligible. This assumption is used in the FEP that deals with THC effects on backfill in Section 6.2.14.

The quartz backfill is expected to be chemically inert and large changes in backfill properties are not expected to happen based on the small quantity of dissolution and precipitation found in the THC models (CRWMS M&O 2000e).

This assumption requires further verification and will require a TBV.

5.2.5 Thermal-Hydrologic-Chemical Effects on Small Fractures

The THC effects from the plugging of small fractures are assumed to be negligible. This assumption is used in part for a primary FEP that deals with chemical changes resulting in plugging of smaller fractures but not plugging larger fractures (Section 6.2.23).

The basis for this assumption is that THC effects only reduce the fracture porosity by 1% (CRWMS M&O 2000e). This is small and should not change the flow characteristics of the fracture continuum.

This assumption requires further verification and will require a TBV.

5.2.6 Process-Level Model Assumptions

An assumption is also made that all of the assumptions that are made in the calculations and analysis/model reports are still valid. These assumptions can be found in the following documents and are not repeated here:

- Section 3 of *Calculation of Permeability Change Due to Coupled Thermal-Hydraulic-Mechanical Effects* (CRWMS M&O 2000a)
- Section 5 of *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f)
- Section 5 of *Multiscale Thermohydrologic Model* (CRWMS M&O 2000g)
- Section 5 of *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e).

The status of the assumptions in these four AMRs are tracked by the Document Input Reference System and so the process-level model assumption does not require a TBV.

6. ANALYSIS/MODEL

The method used for this analysis is a combination of qualitative and quantitative screening of FEPs. The analyses are based on the criteria provided in the DOE's interim guidance (Dyer 1999) and by the EPA in the proposed 40 CFR Part 197 (64 FR 46976). These criteria are used to determine whether each FEP should be included in the TSPA.

For FEPs that are excluded based on specific regulatory requirements (e.g., requirements regarding the location and composition of the critical group), the screening argument includes the regulatory reference and a short discussion of the applicability of the standard.

For FEPs that are excluded from the TSPA based on DOE's interim guidance or EPA criteria, the screening argument includes the basis of the exclusion (low probability, low consequence) and provides a short summary of the screening argument. As appropriate, screening arguments cite work done outside this activity, such as in other AMRs.

For FEPs that are included in the TSPA, the TSPA disposition includes a reference to the AMR that describes how the FEP has been incorporated in the process models or the TSPA abstraction.

6.1 ALTERNATIVE APPROACHES

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

The approach used to identify, analyze, and screen the FEPs (as described in Sections 1.2 and 1.3) was also considered. Alternative classification of FEPs as Primary or Secondary is possible in an almost infinite range of combinations. Classification into Primary and Secondary FEPs is based primarily on redundancy and on subject matter. Subsequent assignment and analysis by knowledgeable subject matter experts for evaluation appeared to be the most efficient methodology for ensuring a comprehensive assessment of FEPs as they relate to the TSPA. Alternative classifications and assignments of the FEPs are entirely possible, but would still be based on subjective judgement. Alternative approaches for determining probabilities and consequences used as a basis for screening are discussed in Section 6.2 under the individual FEP analysis.

In practice, regulatory-type criteria were examined first, and then either probabilities or consequences were examined. FEPs that are retained on one criterion are also considered against the others. Consequently, the application of the analyst's judgement regarding the order in which to apply the criteria does not affect the final decision. Allowing the analyst to choose the most appropriate order to apply the criteria prevents needless work, such as developing quantitative probability arguments for low consequence events or complex consequence models for low probability events. For example, there is no need to develop detailed models of the response of the repository to faults shearing a waste package (WP), if it can be shown that this event has a probability below the criteria threshold.

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

The FEPs screening decisions may also rely on the results of analyses performed and documented as separate activities. Alternate approaches related to separate activities and analyses are addressed in the AMRs for those analyses and are not discussed in this AMR.

6.2 NFE FEPs EVALUATION AND ANALYSIS

This AMR addresses the 26 Primary FEPs that have been identified as NFE FEPs. The section title for each discussion provides the FEP name as incorporated in the FEPs database (CRWMS M&O 1999b), as well as the Yucca Mountain FEP number that has been assigned. The FEP description is also taken from the database, with the exception that in several cases additional text has been added to reference applicable secondary FEPs relevant to the NFE discussion. Secondary FEPs have been reviewed and secondary descriptions have been included in the YMP Primary definitions.

The original list of NFE FEPs contained 31 FEPs. Five of those FEPs are not discussed in this AMR since they are best discussed primarily in other FEP AMRs. Those five FEPs and the subject area that they are discussed in are:

1. 2.1.08.04.00 Condensation forms on backs of drifts (EBS)
2. 2.1.11.08.00 Thermal effects: chemical and microbiological changes in the waste and EBS (WF and EBS)
3. 2.1.11.09.00 Thermal effects on liquid or two-phase fluid flow in the waste and EBS (WF and EBS)
4. 2.1.11.10.00 Thermal effects on diffusion (Soret effect) in waste and EBS (WF and EBS)
5. 2.2.10.02.00 Thermal convection cell develops in saturated zone (SZ).

The ongoing modeling and analysis of the NFE is documented in numerous AMRs. These AMRs represent the principal references for the discussion on how each FEP is dealt with in the TSPA. It should be noted that the key AMRs that define most of the direct feeds to the TSPA are U0105 *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f), N0120 *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e), N0125 *Abstraction of Drift-Scale Coupled Processes* (CRWMS M&O 2000h), E0120 *Multiscale Thermohydrologic Model* (CRWMS M&O 2000g), and E0130 *Abstraction of Near Field Environment Drift Thermodynamic Environment and Percolation Flux* (CRWMS M&O 2000i).

For the most part, the other AMRs provide supporting modeling detail that support these abstractions, but do not feed the TSPA directly.

Also provided in each FEP section, as appropriate, is a cross reference to key technical issues identified by the NRC (NRC 1999a; NRC 1999b) as being important for the Yucca Mountain repository. These are identified as Issue Resolution Status Report (IRSR) issues.

6.2.1 Excavation/Construction 1.1.02.00.00

FEP Description: This category contains FEPs related to the excavation of the underground regions of the repository and effects of this excavation on the long-term behavior of the engineered and natural barriers. Excavation-related effects include changes to rock properties due to boring and blasting and geochemical changes to rock and groundwater.

Screening Decision: Include fracture effects/exclude chemistry related effects.

Screening Decision Basis: Meets all Criteria/low consequences

Screening Argument: The fractures caused by excavation/construction activities are included in TSPA as described in the TSPA Disposition.

Chemistry effects are not included since the geochemical changes due to boring and blasting are expected to be much smaller than the chemical changes due to the thermal perturbation caused by the heat from the waste packages. Since the THC effects are captured in process level models, the excavation/construction related chemistry changes are excluded based on low consequence.

TSPA Disposition: The fractures caused by excavation/construction are included in the in the seepage models. Parameters like the fracture spacing are part of the hydrologic property sets used in the unsaturated zone flow.

Two rock property sets were created (CRWMS M&O 2000j, Sections 6.1 and 6.2) for use in TSPA; a mountain-scale and a drift scale property set. Two property sets were created because of scaling issues using pneumatic (which capture mountain scale processes) and air injection tests (which correspond to scales on the order of a few meters). A mountain-scale property set was created using both sets of data for use in mountain scale simulations. This property set had larger fracture permeabilities and was used in the mountain-scale thermal-hydrologic (TH) simulations. The drift-scale property set was created using the air injection tests and resulted in lower fracture permeabilities. This property set was used in the THC (CRWMS M&O 2000e) and in the Line-load Discrete heat source Thermal-Hydrologic (LDTH) Multi-Scale Thermal-Hydrologic Methodology (MSTHM) (CRWMS M&O 2000g) sub-model simulations.

The hydrologic fracture properties, developed in *Calibrated Properties Model* (CRWMS M&O 2000j), used in all thermal-hydrologic and thermal-hydrologic-chemical process level models have been calibrated using fracture mapping information from excavated drifts (CRWMS M&O 2000k, Section 3.6.3.2).

Chemistry related effects are excluded due to low consequence as described in the screening argument.

Relevant AMRs: *Calibrated Properties Model* (CRWMS M&O 2000j).

IRSR-Issues: Thermal Effects on Flow (TEF) Subissue 2 Technical Acceptance Criterion 1.1. Uncertainties and variabilities in parameter values are accounted for using defensible methods.

TEF Subissue 2 Technical Acceptance Criterion 1.2. Analyses are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated.

6.2.2 Effects of Pre-Closure Ventilation 1.1.02.02.00

FEP Description: The duration of pre-closure ventilation acts together with waste package spacing (as per design) to control the extent of the boiling front.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: The effects of pre-closure ventilation are included in TSPA as described in the TSPA Disposition

TSPA Disposition: Ventilation will be used in the drifts during the first 50 years of waste emplacement (Wilkins and Heath 1999, page 3 of enclosure 2) in order to reduce the thermal disturbance in the drifts as well as to allow access to waste packages up to closure of the repository. Dry air is introduced into the repository through a series of ventilation drifts. The air then flows through the emplacement drifts and removes both heat and moisture from the waste package and drift walls.

Pre-closure ventilation is implemented in the TSPA-SR thermal-hydrologic models by reducing the quantity of heat generated by the waste packages by 70% during the fifty-year ventilation period in the thermal-hydrologic and thermal-hydrologic-chemical process level models. The AMR *Ventilation Model* (CRWMS M&O 2000l) documents an analysis of the pre-closure ventilation period. This calculation shows that 70% of the waste package heat over the first 50 years can be removed with air flow-rates between ten to fifteen cubic meters per second through each emplacement drift (CRWMS M&O 2000l, Section 6.5).

Although water will be removed during the pre-closure ventilation process, this water is not removed in any of the thermal-hydrologic or thermal-hydrologic-chemical process level models. Since the removal of water from the drift walls will delay the ambient seepage that may eventually lead to the failure of a waste package and transport of radionuclides out of the drift, neglecting the removal of water from ventilation in the simulations is considered to bound expected behavior. The ventilation airflow calculations were thermal conduction-only and not thermal-hydrology calculations. Consequently, the actual rock wall temperatures during the ventilation period will be lower in thermal-hydrologic than those predicted in the conduction-only process model results due to the latent heat of evaporation of the water.

The total heat generated from the waste packages throughout the repository is documented in *Input Transmittal, Draft Calculation - "Heat Decay Data and Repository Footprint for Thermal-hydrologic and Conduction-only Models for TSPA-SR" (Francis)* (CRWMS M&O 2000m). Removing 70% of the waste package heat over the first 50 years results in a reduction in the maximum lineal heat load occurring at the time of waste emplacement from 1.54 kW/m to 0.46 kW/m. The peak lineal heat load occurs at 50 years when the ventilation is turned off and the heat load jumps from 0.18 kW/m to 0.61 kW/m (CRWMS M&O 2000m, Section 5.2). The ventilation was implemented into the three thermal-hydrologic process level models (CRWMS M&O 2000f; CRWMS

M&O 2000g; CRWMS M&O 2000e). Ventilation results in a 50% reduction in total heat input into the system over the first 100 years, an 18% reduction in total heat input after 1000 years, an 8% reduction in total heat input over the first 10,000 years, and a 2% reduction in total heat input over 1,000,000 years (CRWMS M&O 2000m, Figure 2).

The ventilation calculation also shows that condensation or deposition of water on waste packages or on the drift wall above the waste package from ventilation air is not expected. Condensation will only occur on when air comes in contact with a surface colder than the dew point. In *Ventilation Model*, the wall temperature is always higher than the ventilation air temperature (CRWMS M&O 2000l, Figures 4 and 5).

Relevant AMRs: Effects of ventilation as described above are implemented in the following AMRs:

Mountain-Scale Coupled Processes (TH) Models (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 1.2. Analyses are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated.

TEF Technical Acceptance Criterion 2.13. Models include the effect of ventilation particularly if ventilation could result in deposition or condensation of moisture on a WP surface.

6.2.3 Fractures 1.2.02.01.00

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

Screening Decision: Include in seepage/Exclude permanent effects

Screening Decision Basis: Meets criterion for seepage/Excluded due to low consequence

Screening Argument: Due to thermal-hydrologic-mechanical couplings, it is expected that fractures close to the drifts will close during the thermal period and there will be plugging because of rock-water interactions, and in the post-thermal periods as the mountain cools, fractures will reopen and new fractures will form.

The present day fracture system is included in the unsaturated zone (UZ) flow and transport models used in TSPA. Sensitivity studies performed in *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000d) show that transport is not affected by changes in fracture properties. Since transport of radionuclides is not affected by the changes in fractures, the dose does not change, and this FEP can be excluded due to low consequences.

TSPA Disposition: The fracture system is included in TSPA but changes to the fracture system do not affect transport and are excluded from TSPA.

Relevant AMRs: *Fault Displacement Effects on Transport in the Unsaturated Zone* (CRWMS M&O 2000d)

6.2.4 Increased Unsaturated Water Flux at the Repository 2.1.08.01.00

FEP Description: An increase in the unsaturated water flux at the repository affects thermal, hydrologic, chemical, and mechanical behavior of the system. Extremely rapid influx could reduce temperatures below the boiling point during part or all of the thermal period. Increases in flux could result from climate change, but the cause of the increase is not an essential part of the FEP.

The local influx of water is sufficient to quench (reduce the surface temperature below vaporization) the waste containers it surrounds.

Screening Decision: Include primary FEP but exclude secondary FEP

Screening Decision Basis: Climate change is included but secondary FEP on water quenching hot waste package excluded based on low consequence.

Screening Argument: The effect of climate change on infiltration rate is included in all of the TH process-level models and the implementation is discussed in the TSPA disposition.

If the local influx of water is large and persistent enough, the surface temperature of a waste container could be reduced below the vaporization temperature of water. Rapid aqueous corrosion processes would then occur (particularly of the influx is partially captured in the drift). Presumably, such a rapid influx of water would require an event, like a new fault or an old fault with movement, to provide a pathway and sufficient permeability.

This aspect of the is FEP not explicitly captured in any of the TH models. The quantity and timing of seepage into the drift is based on the fracture liquid flux five meters above the crown of the drift (CRWMS M&O 2000i, Section 6.1). This implementation of seepage into the TSPA allows for seepage to occur at times when water is present five meters above the drift but when the waste package and drift wall are above the local boiling temperature. These histories show that the temperature five meters above the drift does not exceed the local boiling temperature, and consequently, can result in seepage into the drift in TSPA. The temperature of the waste package does not drop in reaction to seepage coming into the drift.

This seepage is available to flow into the drift and contact the drip shield. However, seepage will not reach the waste package until the drip shield has failed which takes place long after the waste packages have dropped below the local vaporization temperature. In *WAPDEG Analysis of Waste Package and Drip Shield Degradation*, the first drip shield failure is expected at 24,000 years (CRWMS M&O 2000n, Section 6.4). Consequently, this part of the FEP is excluded based on the longevity of the drip shield. Should this result change, then water could hit the waste package at any time and this FEP, in its entirety, would be included.

TSPA Disposition: Increased UZ water flux at the repository due to climate change is included in the TSPA as described in the screening arguments. Seepage model also includes thermally enhanced flow since it uses the percolation flux from a thermal-hydrologic model but the secondary FEP is excluded due to assumption made about the longevity of the drip shield.

The infiltration flux over the repository during the first 600 years of the TH simulations corresponds to the present day climate. The infiltration flux between 600 and 2000 years corresponds to the monsoonal climate and the infiltration flux after 2000 years corresponds to the glacial climate. In addition, variability in climate state infiltration rates are also modeled in the TSPA. The rational for the selection of these climate states can be found in *Future Climate Analysis* (USGS 2000, Section 6.6.1).

The average infiltration rates over the repository block in the MSTHM (CRWMS M&O 2000g, Table XVI-2) are shown in Table 2.

Table 2. The Average Infiltration Rates Over the Repository Used in the MSTHM for the Three Different Infiltration Flux Maps and for the Different Climate States

	Present Day (mm/yr)	**Monsoonal (mm/yr)**	**Glacial Transition (mm/yr)**
Low Flux	0.562	5.982	2.985
Mean Flux	5.982	16.074	24.856
High Flux	14.558	26.166	46.726

DTN: LL000113904242.089, LL000114004242.090, LL000114104242.091

Only one set of simulations at a generic repository location was performed using the drift-scale THC model in *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e). The implementation of the high/mean/low infiltration flux cases used infiltration rates based on the repository averaged infiltration fluxes for the Present Day, Monsoonal, and Glacial Transition climates from the MSTHM (CRWMS M&O 2000g, Section 6.3.6 and Table XVI-2).

The mountain scale TH model presented in *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f) used the same three climate time states for only the mean flux maps (CRWMS M&O 2000f, Table 5).

The part of this FEP that concerns local influx of water being sufficient to quench the waste containers is excluded based on the screening argument.

Relevant AMRs: *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e)

References: Rational for climate change found in:

Future Climate Analysis (USGS 2000).

Implementation of seepage into TSPA:

Abstraction of Near Field Environment Drift Thermodynamic Environment and Percolation Flux (CRWMS M&O 2000i).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 2.5. Models are capable of accommodating variation in infiltration.

TEF Subissue 2 Technical Acceptance Criterion 2.14. The media properties of a model contain an adequate level of heterogeneity so that mechanisms such as dripping are not neglected or misrepresented.

TEF Subissue 2 Technical Acceptance Criterion 2.16. Physical mechanisms such as penetration of the boiling isotherm by flow down a fracture are not omitted due to over-simplification of the physical medium or the conceptual model.

6.2.5 Enhanced Influx (Philip's Drips) 2.1.08.02.00

FEP Description: An opening in unsaturated rock alters the hydraulic potential, affecting local saturation around the opening and redirecting flow.

Some of the flow is directed to the opening where it is available to seep into the opening.

Screening Decision: Include

Screening Decision Basis: Meets all criteria

Screening Argument: This FEP is included in the TSPA as described in the TSPA disposition.

TSPA Disposition: Not included in any TH model but included in seepage model (CRWMS M&O 2000b).

Relevant AMRs: *Seepage Model for PA Including Drift Collapse* (CRWMS M&O 2000b)

6.2.6 Repository Dry-Out due to Waste Heat 2.1.08.03.00

FEP Description: Repository heat evaporates water from the UZ rocks near the drifts, as the temperature exceeds the vaporization temperature. This zone of reduced water content (reduced saturation) migrates outward during the heating phase and then migrates back to the containers as heat diffuses throughout the mountain and the radioactive heat sources decay.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: This FEP is included in the TSPA as described in the TSPA disposition.

TSPA Disposition: Before the repository is closed, ventilation is implemented in the TH models as a reduction in waste package heat output with no vapor removal. After closure, if the heat generation is high enough, the rock around the repository can undergo dry-out. If this phenomenon occurs, it will be captured in the multi-scale model, the mountain-scale TH model, and the drift scale THC model.

This FEP is relevant to models contained in *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f), *Multiscale Thermohydrologic Model* (CRWMS M&O 2000g), and

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

Relevant AMRs: *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e)

6.2.7 Desaturation/Dewatering of the Repository 2.1.08.10.00

FEP Description: Decreases in the water content of the EBS may occur because of ventilation and thermal effects.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: Desaturation/dewatering of the repository rock due to thermal effects is included in the TSPA as described in the TSPA disposition.

TSPA Disposition: Desaturation and dewatering of repository rock due to thermal effects are inherently captured in TH models. The water removed from the drift rock due to ventilation or construction is not included as an initial condition to the thermal-hydrologic simulations but is considered to be bound expected behavior since, in the simulation, water can return to the drift wall more quickly which can result in earlier corrosion of the waste package as well as water being present to transport any radionuclides that may dissolve and be transported down through the unsaturated zone.

This FEP is relevant to models contained in Mountain-Scale Coupled Processes (TH) Models (CRWMS M&O 2000f), Multiscale Thermohydrologic Model (CRWMS M&O 2000g), and Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

Relevant AMRs: *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e)

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 2.2. Models include, at a minimum, the processes of evaporation and condensation and the effects of discrete geologic features.

TEF Subissue 2 Technical Acceptance Criterion 2.3. Models include, at a minimum, an evaluation of important thermohydrological phenomena such as: (i) multi-drift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

6.2.8 Resaturation of the Repository 2.1.08.11.00

FEP Description: Water content in the repository will increase following the peak thermal period.

Screening Decision: Include

Screening Decision Basis: Meets all criteria

Screening Argument: Resaturation of the repository is included in the TSPA as described in the TSPA disposition.

TSPA Disposition: The conceptual flow models used in the process level thermal-hydrologic models allowed rock matrix and fracture elements to resaturate as the repository cooled. Saturation time-history curves and saturation profiles for the different process level models are presented in various AMRs. Resaturation can be see in the THC process level model in Figure 20 of *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e) and in the TH mountain-scale process level model in Figure 30 of *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f). Consequently, this FEP is included in the process level models for TSPA.

This FEP is relevant to models contained in *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f), *Multiscale Thermohydrologic Model* (CRWMS M&O 2000g), and

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

Relevant AMRs: *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e)

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 2.2. Models include, at a minimum, the processes of evaporation and condensation and the effects of discrete geologic features.

TEF Subissue 2 Technical Acceptance Criterion 2.3. Models include, at a minimum, an evaluation of important thermohydrological phenomena such as: (i) multi-drift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

6.2.9 Properties of the Potential Carrier Plume in the Waste and EBS 2.1.09.01.00

FEP Description: When the unsaturated zone flow in the drift is reestablished following the peak thermal period, water will have chemical and physical characteristics influenced by the near field host rock and EBS. Water chemistry may be strongly affected by interactions with cementitious materials.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: Properties of the Potential Carrier Plume in the Waste and EBS is included in the TSPA as described in the TSPA disposition.

TSPA Disposition: The argument for this particular FEP will not include a source term from within the emplacement drift. It will include the signature of the repository in terms of a carrier plume that contains alteration of temperature, pH, and dissolved mineral constituents from the host rock. Although at the drift-scale only (2-D drift-scale THC model at repository center) and not on the mountain-scale, the development of a carrier plume as defined above is captured by the solutions of the TOUGHREACT code used to model the drift-scale THC processes of heat flow from the waste package to the host rock and subsequent reactive transport processes in the host rock (CRWMS M&O 2000e, Figures 28-40). The physical characteristics of the carrier plume (e.g., temperature, pH, etc.) can be used by UZ flow and transport TSPA to determine its impacts on radionuclide sorption coefficient (K_d) and hence transport. The results of *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e) will allow TSPA to quantify the strength of sorption behavior in terms of the rock type involved in the interaction and the geochemical conditions of the water contacting the rock.

This FEP is included in *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e).

Relevant AMRs: *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e)

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate Thermal-Hydrologic-Mechanical-Chemical (THMC) coupled processes.

Evolution of the Near Field Environment (ENFE) Effects of Thermal-Hydrologic-Chemical Processes on Waste Package Chemical Environment. Subissue Coupled THC Processed Affecting Waste Package Chemical Environment.

6.2.10 Rind (Altered Zone) Formation in Waste, EBS, and Adjacent Rock 2.1.09.12.00

FEP Description: Thermo-chemical processes involving precipitation, condensation and re-dissolution alter properties of the waste, EBS, and adjacent rock. These alterations form a rind, or altered zone, with hydrologic, thermal and mineralogic properties different from the current conditions.

Screening Decision: Included in THC model/ Excluded from TH model

Screening Decision Basis: Exclude due to low consequence.

Screening Argument: The formation of a rind driven by THC processes are captured in the THC model as described in the TSPA disposition. The formation of a rind was excluded from the MSTHM and mountain scale TH models. The changes on the hydrologic properties were found to be small and so were excluded from the MSTHM and mountain scale TH models due to low consequence.

TSPA Disposition: The 2-D drift-scale THC model at repository center can capture the development of a rind in the solutions of the TOUGHREACT code used to model the drift-scale THC processes of heat flow from the waste package and subsequent reactive transport processes in the host rock (Steefel and Lasaga 1994, pp. 540 – 542; CRWMS M&O 2000e, Section 6.1). Each mineral considered (e.g., in a multicomponent system) in the host rock system is governed by a surface controlled chemical reaction. The reaction rate of each mineral is governed by a rate constant, reactive surface area of the mineral, activation energy, and the chemical affinity of the reaction. The THC model used to estimate the formation of the rind around the drift wall is used to determine the aqueous species concentrations in the water entering the emplacement drift. This is directly applied in TSPA in the abstraction of physical and chemical environment. (Note: since the drift is backfilled at repository closure, the portion of the FEP related to rockfall carrying rind into the drift is not considered in the process-level THC model.)

The effect of including chemistry in the THC process level model results is presented in *Abstraction of Drift-Scale Coupled Processes* (CRWMS M&O 2000h, Section 6.3). This comparison between a process level model including fully coupled THC and a model with thermal-hydrology only show that the effects of THC on flow and state properties in the rind region near the drift wall show only a small effect from chemical alteration of the region around the drift. Because of this, the formation of the rind region can be ignored in the MSTHM simulations that was the source of data input to the corrosion models, seepage models, and the in-drift geochemical models. The change in porosity around the drift from rind formation was less than 1% (CRWMS M&O 2000e, Section 7). Since this is not a large enough change to affect either seepage into the drift or transport out of the drift, which are the two ways that rind formation can affect repository performance, this FEP can be excluded from the TH process level model due to low consequence to dose.

Relevant AMRs: The creation of a rind is calculated in:

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

The effect of the formation of a rind on TH processes is found in:

Abstraction of Drift-Scale Coupled Processes (CRWMS M&O 2000h).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

ENFE Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow. Subissue Coupled Thermal-Hydrologic-Chemical Processes Affecting Flow of Water.

6.2.11 Heat Output/Temperature in Waste and EBS 2.1.11.01.00

FEP Description: Temperature in the waste and EBS will vary through time. Heat from radioactive decay will be the primary cause of temperature change, but other factors to be considered in determining the temperature history include the in-situ geothermal gradient, thermal properties of the rock, EBS, and waste materials, hydrological effects, and the possibility of exothermic reactions (see FEP 2.1.11.03.00). Considerations of the heat generated by radioactive decay should take different properties of different waste types, including Defense Spent Nuclear Fuel (DSNF), into account.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: The waste package heat output is included inherently in the TSPA process level models as described in the TSPA disposition.

TSPA Disposition: The heat released from radioactive decay of the waste packages are accounted for in all of the process level models that include repository heating. The heat decay curves used in the models are documented in the AP-3.12Q calculation *Heat Decay Data and Repository Footprint for Thermal-Hydrologic and Conduction-Only Models for TSPA-SR* (CRWMS M&O 2000m). This calculation discusses how the TSPA-SR waste stream was created and the salient characteristics of the various heat decay curves that are described below.

The initial overall heat output for the entire repository is 76.4 MW or 72.7 kW/acre (CRWMS M&O 2000m, Section 5.1). This thermal loading was used in the Smeared-heat, Drift scale, Thermal-conduction (SDT) and the Smeared-heat, Mountain scale, Thermal-conduction (SMT) sub-models of the MSTHM as well as in the three-dimensional mountain scale TH models. In the two-dimensional mountain scale models with discrete drifts, the 72.7 kW/acre loading was preserved by scaling the total load among the drifts intersected by the model domain. A seven waste-package model was created that contained a representative selection of Commercial Spent Nuclear Fuel (CSNF) and High Level Waste (HLW) packages that had a total heat output close to the 72.7 kW/acre initial total thermal loading (CRWMS M&O 2000m, Section 5.2). The line load of this model was 1.54 kW/meter which is 6% higher than the actual drift loading of 1.45 kW/meter. The line load of 1.54 kW/meter was used in the two-dimensional THC process level model and the LDTH sub-model in the MSTHM. The waste package heat load curves for the CSNF and HLW waste packages were used in the Discrete-heat, Drift-scale, Thermal-conduction model (DDT) sub-model in the MSTHM.

An assumption was made in each of the process level models that ventilation would remove 70% of the waste package heat output for the first 50 years and that the entire repository was loaded at the start of the simulation (process model assumption in Section 5.2.6). This ventilation assumption was implemented by reducing the heat input into the thermal-hydrologic models by 70% during the 50-year ventilation period with no heat output reduction after 50 years. No water was removed from the drift wall as a result of pre-closure ventilation.

Relevant AMRs: The decay heat from waste packages is developed in *Heat Decay Data and Repository Footprint for Thermal-Hydrologic and Conduction-Only Models for TSPA-SR* (CRWMS M&O 2000m).

The decay heat curves are used in the following AMRs:

Mountain-Scale Coupled Processes (TH) Models (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

6.2.12 Nonuniform Heat Distribution/Edge Effects in Repository 2.1.11.02.00

FEP Description: Temperature inhomogeneities in the repository lead to localized accumulation of moisture above it. Wet zones form below the areas of moisture accumulation. Uneven heating and cooling at edges of the repository lead to non-uniform thermal effects during both the thermal peak and the cool-down period.

The repository edges and panel edges see heat only from the repository, so thermal effects such as rock compression and dry-out differ from the interior of the repository. Relaxation of thermal effects such as rock compression and dry-out can occur earlier and may differ throughout the repository.

Groundwater flow will be affected by the time-varying heat source in the vault; the resultant inhomogeneous geothermal gradient may result in formation of convection cells. Thermally-induced stresses superimposed on existing shear stresses might induce fracturing and fracture displacement.

Screening Decision: Primary FEP included. TM effects from secondary FEP excluded.

Screening Decision Basis: All criteria met for primary FEP and secondary FEP excluded on low consequence basis.

Screening Argument: Since waste containers are not identical in thermal output and the surrounding rock is heterogeneous in thermal and hydrologic properties, the condensation zone is likely to be non-uniform. Localized flow may result.

Non-uniform heat distribution/edge effects are included in TSPA as described in the TSPA disposition. The secondary FEPs dealing with TM effects were excluded based on low consequence.

Mountain and drift-scale TM effects are assumed to be small and are excluded on the basis of low consequence. This assumption needs to be verified and should be tracked as TBV (see assumption in Section 5.2.3).

TSPA Disposition:

Liquid fluxes as well as saturations are calculated for locations at both CSNF and HLW waste packages at 623 locations throughout the repository. Each waste package result reflects the variability in local infiltration flux as well as the stratigraphy at a particular location in the repository. The effect of differing local hydrologic stratigraphy is captured in the LDTH sub-model. Lateral heat losses out of the sides of the repository (also called edge effects) are incorporated in the multi-scale TH model in the SMT sub-model. The LDTH and SMT models are discussed in *Multiscale Thermohydrologic Model* (CRWMS M&O 2000g). The water flux and temperatures at repository edge locations are much different from those at the center of the repository. The temperatures around the drift drop much more quickly and liquid returns to the drift much earlier at edge locations than at center locations.

The temperatures in the host rock (5 meters above the crown) at the same location that the percolation fluxes are used in the seepage model have been assumed to be the same for all waste packages at a particular location but different for the 623 locations given as output from the TH multi-scale model. The local temperature and flow inhomogeneities in the rock due to variations in adjacent waste packages are not expected to be significant when compared to the variations seen at different locations throughout the repository. Simulation results from the MSTHM can be used to evaluate how much the warmer CSNF and the cooler HLW waste packages affect the local drift wall temperature. After 100 years, the bin averaged surface temperatures of the drift wall directly above CSNF and HLW waste packages at the same repository location differ, at most, by 4.5 • C (see Figure 1). This difference decreases to less than 1.6 • C after 1000 years. This small difference in drift wall temperatures for the much warmer CSNF waste packages implies that the waste package heat output variations do not affect the flow or the temperature fields deep into the drift wall.

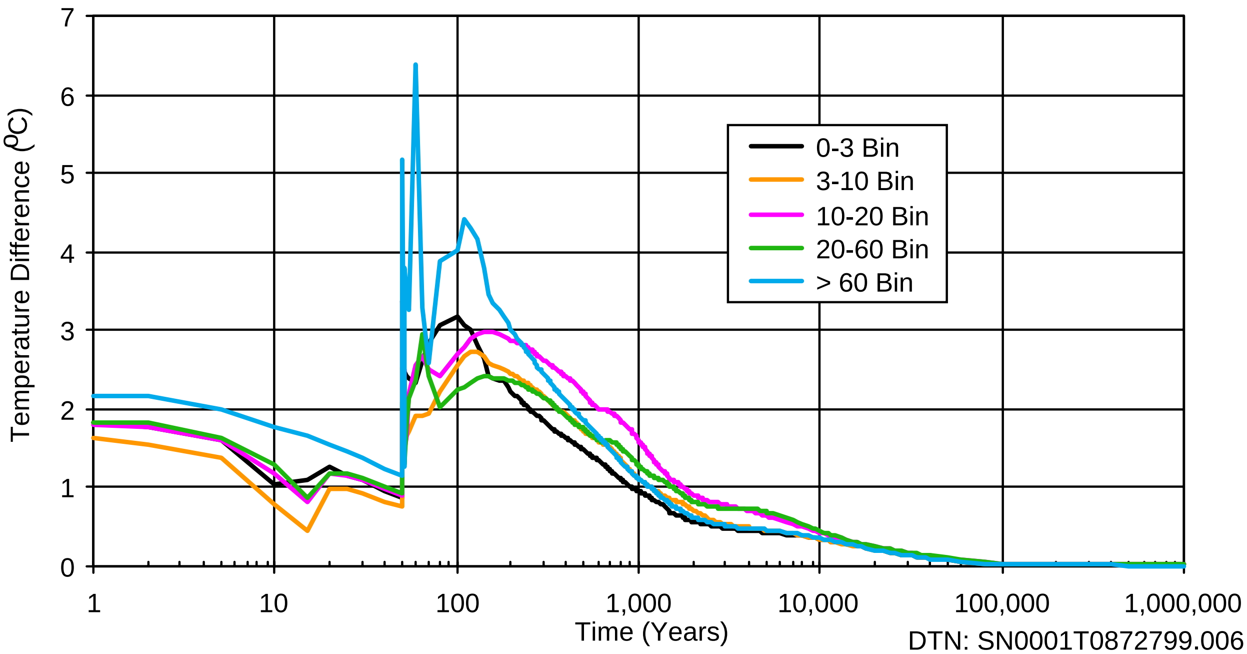

Figure 1. Difference Between CSNF and HLW Upper Drift Wall Temperatures, Drift-Scale Property Set, Site Recommendation Base Case with Backfill, Mean Infiltration Case

Thermal-hydrologic edge effects are included in the models contained in *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f).

Thermal-hydrologic edge effects are not explicitly included in the THC models. The drift scale THC models did not allow axial heat losses that made it behave more like a location at the center of the repository. These locations will experience higher temperatures for longer times and therefore represent a bound of expected behavior for THC effects by allowing for additional temperature driven precipitation processes in the near-field host rock.

Relevant AMRs: Edge effects in a TH model are fully captured in:

Mountain-Scale Coupled Processes (TH) Models (CRWMS M&O 2000f).

Adjustments to account for edge effects are made in:

Multiscale Thermohydrologic Model (CRWMS M&O 2000g).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 2.3. Models include, at a minimum, an evaluation of important thermohydrological phenomena such as: (i) multi-drift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

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

FEP Description: Excavation will produce some disturbance of the rocks surrounding the drifts due to stress relief. Stresses associated directly with excavation (e.g. boring and blasting operations) may also cause some changes in rock properties. Properties that may be affected include rock strength, fracture spacing, and block size and hydrologic properties such as permeability.

Screening Decision: Exclude

Screening Decision Basis: Low consequence

Screening Argument: Excavation will produce some disturbances of the rocks surrounding the drifts due to stress relief. Additionally, disturbance will occur after repository closure in response to heating of the rock, as coupled effects of thermal, mechanical, chemical, and hydrologic processes affect the system.

The permanent chemical effects on the flow properties in the excavation disturbed zone have been shown to be small in Section 6.3 of the *Abstraction of Drift-Scale Coupled Processes* (CRWMS M&O 2000h). Permanent mechanical effects on the excavation disturbed zone are assumed to be small and are excluded on the basis of low consequence. This assumption needs to be verified and should be tracked as TBV (see assumption in Section 5.2.3).

TSPA Disposition: Excavation and construction-related changes in the adjacent host rock are excluded from the TSPA as discussed in the screening argument.

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 1.2. Analyses are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated.

TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

6.2.14 Thermal and Other Waste and EBS-Related Changes in the Adjacent Host Rock 2.2.01.02.00

FEP Description: Changes in host rock properties result from thermal effects or other factors related to emplacement of the waste and EBS, such as mechanical or chemical effects of backfill. Properties that may be affected include rock strength, fracture spacing and block size, and hydrologic properties such as permeability.

Screening Decision: Exclude

Screening Decision Basis: Excluded due to Low Consequence

Screening Argument: In the THC model, the backfill was assumed to not interact chemically in the drift. This assumption needs to be verified and should be tracked as TBV (see assumption in Section 5.2.4).

Permanent mechanical effects on the excavation disturbed zone are assumed to be small and are excluded on the basis of low consequence. This assumption needs to be verified and should be tracked as TBV (see assumption in Section 5.2.3).

TSPA Disposition: Thermal and other waste and EBS-related changes in the adjacent host rock is excluded from TSA based on the screening argument.

Relevant AMRs: System-Level FEPs

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 1.2. Analyses are consistent with site characteristics in establishing initial conditions, boundary conditions, and computational domains for conceptual models evaluated.

TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

ENFE Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow. Subissue Effects of Engineered Materials on Seepage and Flow.

6.2.15 Changes in Fluid Saturations in the Excavation Disturbed Zone (EDZ) 2.2.01.03.00

FEP Description: Fluid flow in the region near the repository will be affected by the presence of the excavation, waste, and EBS. Some dry-out will occur during excavation and operations.

Screening Decision: Exclude

Screening Decision Basis: Exclude based on low consequence.

Screening Argument: During repository construction and operation, the excavation disturbed zone will partially desaturate and the local hydrological regime may be disturbed. Ventilation between the time of tunnel boring, through the emplacement of waste packages, and up until closing will result in the removal of some moisture from the system. After back filling and waste cooling over time, groundwater re-enters host rock zones.

The initial conditions for all process-level TH models were found by equilibrating the models both thermally and hydrologically. Thermal equilibration was achieved by setting the upper and lower boundaries of the models to a fixed temperature and hydrologic equilibrium was achieved by adding the infiltration water into the uppermost rock elements and saturating the rock elements at the top of the water table. The ventilation process was modeled as a reduction of the heat output by 70%. Water that would be removed by the ventilation process was not included in the initial conditions for the thermal-hydrologic models.

This assumption will bound expected behavior since, during the short time that the initial conditions would affect simulation results, the simulations would over-predict liquid fluxes due to the higher saturations around the drift. In the TSPA model, a higher liquid flux implies a higher chance of seepage which, in turn, will result in higher corrosion rates and earlier failure of waste packages.

Since the implementation of ventilation is conservative to performance, this FEP is excluded on the basis of low consequence.

TSPA Disposition: Changes in fluid saturation in the excavation disturbed zone is excluded in the TSPA based on the screening argument.

Relevant AMRs: Ventilation effects that remove heat from the repository but no water from the host rock were implemented in:

Mountain-Scale Coupled Processes (TH) Models (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

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

FEP Description: Changes in stress due to all causes, including heating, seismic activity, and regional tectonic activity, have a potential to result in strains that affect flow properties in rock outside the excavation-disturbed zone.

Screening Decision: Exclude

Screening Decision Basis: Excluded due to low consequence.

Screening Argument: TM effects are assumed to be small and are excluded on the basis of low consequence. This assumption needs to be verified and should be tracked as TBV (see assumption in Section 5.2.3).

TSPA Disposition: Changes in stress (due to thermal, seismic, or tectonic effects) that result in changes in porosity and permeability of rock and are excluded from TSPA.

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

6.2.17 Condensation Zone Forms Around Drifts 2.2.07.10.00

FEP Description: Condensation of the two-phase flow generated by repository heat forms in the rock where the temperature drops below the local vaporization temperature. Waste package emplacement geometry and thermal loading will affect the scale at which condensation caps form (over waste packages, over panels, or over the entire repository), and to the extent to which "shedding" will occur as water flows from the region above one drift to the region above another drift or into the rock between drifts.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: The FEP concerning condensation zones was included in the TSPA as described in the TSPA disposition.

TSPA Disposition: The thermal-hydrologic computer codes were designed to model the conservation of mass and energy as well as mass transport and phase change. These codes were used in models described in *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f), *Multiscale Thermohydrologic Model* (CRWMS M&O 2000g), and *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e).

Although condensation of water occurred in each of the thermal-hydrologic models, a region of higher than ambient saturation above any drift was not seen in any model. A condensation zone would only be seen in the models if the condensate accumulated faster than it could drain through the fractures. The present repository design has an 81 meter gap between loaded drifts. Less than half of any pillar ever reached the local boiling temperatures (CRWMS M&O 2000i, Figures 43 and 44) meaning that there was always a large part of the pillar available for condensate to drain.

The best place to find evidence of the formation of a condensate zone is in the saturation profiles and the fracture flux above the repository in the mountain-scale TH model simulation results (CRWMS M&O 2000f, Figures 65 and 67). The saturation profiles at various times show that the saturation at the repository level drops at early times, but it recovers after 5000 years. The saturation profiles above the repository show a small increase with time. These changes correlate with the climate change events at 600 and 2000 years. The liquid fracture flux profile above the repository gives insight into how liquid is draining in the mountain. In the Topopah Springs unit that is located in the 160 meters above the repository, the flux shows two distinct jumps each corresponding to a climate change. The flux increases slightly in the region just above the repository at 500 years although this is attributed to re-wetting of the repository rock. Consequently, even though the thermal-hydrologic simulation codes allowed for the formation of a condensation zone, there is little evidence that a condensation zone formed.

Relevant AMRs: The AMRs that contain the thermal-hydrologic models that could develop a condensate zone were:

Mountain-Scale Coupled Processes (TH) Models (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 2.2. Models include, at a minimum, the processes of evaporation and condensation and the effects of discrete geologic features.

TEF Subissue 2 Technical Acceptance Criterion 2.3. Models include, at a minimum, an evaluation of important thermohydrological phenomena such as: (i) multi-drift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

6.2.18 Return Flow From Condensation Cap/Resaturation of Dry-Out Zone 2.2.07.11.00

FEP Description: Following the peak thermal period, water in the condensation cap (see FEP 2.2.07.10.00) may flow downward into the drifts. Influx of cooler water from above, such as might occur from episodic flow, may accelerate return flow from the condensation cap by lowering temperatures below the condensation point. Percolating groundwater will also contribute to resaturation of the dry out zone. Vapor flow, as distinct from liquid flow by capillary processes, may also contribute. Water chemistry in the resaturation period may be affected by processes in the condensation cap and dry-out zone.

Screening Decision: Include

Screening Decision Basis: Included in process models used in TSPA.

Screening Argument: Return flow and re-saturation of the dry-out zone is included in the TSPA as described in the TSPA disposition.

TSPA Disposition: The physics contained in the thermal-hydrologic codes TOUGH2 and NUFT allow for water to return to areas that had dried-out from the thermal pulse of heat from the waste packages. The results in *Mountain-Scale Coupled Processes (TH) Models* show that dry-out regions developed near the drifts and that these regions eventually re-wetted (CRWMS M&O 2000f, Figure 65).

The chemistry of water in the reflux zone, as well as the water that re-wets the dry-out zone, is included in the THC process level model described in *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e).

The physics in the thermal-hydrology process level models are capable of modeling the formation of a condensation zone if it forms. Water vapor that is generated at the repository horizon rises and condenses in the colder overburden rock. A condensate zone forms when condensate water accumulates in the region above the repository. A condensate zone will not form if the water can drain through the fractures. A condensate zone did not develop in either the mountain scale thermal-hydrologic model or in the multi-scale thermal-hydrologic model. This is a result of the large spacing between the drifts (81 meters) combined with the thermal output from the waste packages that do not result in a steam zone developing completely between drifts. This region in between the two drifts contained fractures that were always below the local boiling temperature so that water could always flow in these fracture elements.

Relevant AMRs: The AMRs that contain the thermal-hydrologic models that could contain a collapsing condensate zone were:

Mountain-Scale Coupled Processes (TH) Models (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 2.2. Models include, at a minimum, the processes of evaporation and condensation and the effects of discrete geologic features.

TEF Subissue 2 Technical Acceptance Criterion 2.3. Models include, at a minimum, an evaluation of important thermohydrological phenomena such as: (i) multi-drift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

6.2.19 Geochemical Interactions in Geosphere (Dissolution, Precipitation, Weathering and Effects on Radionuclide Transport) 2.2.08.03.00

FEP Description: Geochemical interactions may lead to dissolution and precipitation of minerals along the groundwater flow path, affecting groundwater flow, rock properties and sorption of contaminants. These interactions may result from the evolution of the disposal system or from external processes such as weathering. Effects on hydrologic flow properties of the rock, radionuclide solubilities, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time scale of concern.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: Geochemical Interactions in Geosphere and Effects on Radionuclide Transport are included based on the discussion in the TSPA disposition.

TSPA Disposition: The process included in the fully coupled THC code drives the water and gas composition in the near-field host rock adjacent to the drift wall. The 2-D drift-scale THC model at repository center can capture both the processes of dissolution and precipitation in the solutions of the TOUGHREACT code used to model the drift-scale THC processes of heat flow from the waste package and subsequent reactive transport processes in the host rock (Steefel and Lasaga 1994, pp. 540 – 542; CRWMS M&O 2000e, Section 6.1.3). Each mineral considered (e.g., in a multi-component system) in the host rock system is governed by a surface controlled chemical reaction. The reaction rate of each mineral is governed by a rate constant, reactive surface area of the mineral, activation energy, and the chemical affinity of the reaction.

Included in the TSPA model as it incorporates the water and gas compositions as a boundary condition in the in-drift geochemical models. Figures 41 and 42 in *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e) indicate that fracture properties remain nearly constant in the reactive transport model results.

Relevant AMRs: THC model contained in:

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

ENFE Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow. Subissue Coupled Thermal-Hydrologic-Chemical Processes Affecting Flow of Water.

6.2.20 Redissolution of Precipitates Directs More Corrosive Fluids to Container 2.2.08.04.00

FEP Description: Redissolution of precipitates which have plugged pores as a result of evaporation of groundwater in the hot zone, produces a pulse of fluid reaching the waste containers when gravity-driven flow resumes, which is more corrosive than the original fluid in the rock.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: The TSPA model included water chemistry boundary conditions obtained from the results of a fully coupled reactive transport THC model as described in the TSPA disposition.

TSPA Disposition: The process of redissolution of mineral precipitates is explicitly included in the drift-scale THC model. It is captured by solution of the TOUGHREACT code used to model the drift-scale THC processes of heat flow from the waste package with subsequent reactive transport processes in the surrounding host rock (CRWMS M&O 2000e, Section 6.1). Each mineral considered (e.g., in a multicomponent system) in the host rock system is governed by a surface controlled chemical reaction. The reaction rate of each mineral is governed by a rate constant, reactive surface area of the mineral, activation energy, and the chemical affinity of the reaction. Additionally, the use of the active fracture dual permeability model allows for gravity–dominated, nonequilibrium, preferential liquid flow in fractures (Liu et al. 1998). Using this conceptual flow model and a standard mineral dissolution rate law, the characteristics of the water entering the drifts is established. This FEP is applied directly into TSPA in the abstraction of physical and chemical environment as it uses the aqueous species concentrations of waters that seep into the emplacement drift.

Relevant AMRs: THC model contained in:

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

ENFE Effects of Coupled Thermal-Hydrologic-Chemical Processes on Seepage and Flow. Subissue Coupled Thermal-Hydrologic-Chemical Processes Affecting Flow of Water.

6.2.21 Thermo-Mechanical Alteration of Fractures Near Repository 2.2.10.04.00

FEP Description: Heat from the waste causes thermal expansion of the surrounding rock, generating changes in the stress field that may change the material properties (both hydrologic and mechanical) of fractures in the rock. Cooling following the peak thermal period will also change the stress field, further affecting rock properties near the repository.

Screening Decision: Excluded

Screening Decision Basis: Excluded due to Low Consequence.

Screening Argument: Thermal-mechanical effects on fractures near the repository drifts can affect TSPA results by changing the rate that water seeps into the drift as well as by changing the radionuclide transport characteristics of the fractures to the saturated zone. In the seepage abstraction (CRWMS M&O 2000c, Section 6.4), the quantity of seepage that enters the drift has been increased by 71% over the expected seepage values. This increase was entered to account for effects of drift degradation, rock bolts, and to account for the seepage model assumption that the k and van Genuchten α parameters should have been correlated.

The seepage calculations presented in *Seepage Model for PA including Drift Collapse* (CRWMS M&O 2000b, Tables 4 through 8) show that the quantity of seepage that enters the drift is a strong function of permeability; with more seepage entering the drift when the average permeability is lower than when the average permeability was higher. In *Calculation of Permeability Change due to Coupled Thermal-Hydraulic-Mechanical Effects* (CRWMS M&O 2000a), a calculation is presented which bounds the effects of on permeability.

TM effects are assumed to be small and are excluded on the basis of low consequence. This assumption needs to be verified and should be tracked as TBV (see assumption in Section 5.2.3).

TSPA Disposition: Thermal-mechanical alteration of the fractures near the repository is excluded based on low consequence in the TSPA.

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

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

FEP Description: Thermal-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone.

Screening Decision: Exclude

Screening Decision Basis: Low Consequence

Screening Argument: Currently, the Paintbrush Tuff non-welded (PTn) unit is thought to be relatively intact, diverting infiltration or allowing localized penetration. During the heating of the repository, thermo-mechanical stress - compression near the drifts produces zones of tension above the repository.

Mountain scale TM effects are assumed to be small and are excluded on the basis of low consequence. This assumption needs to be verified and should be tracked as TBV (see assumption in Section 5.2.3).

TSPA Disposition: Thermo-mechanical alteration of rocks above and below the repository are excluded from TSPA as discussed in the screening argument.

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

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

FEP Description: Thermal effects may affect radionuclide transport directly by causing changes in radionuclide speciation and solubility in the UZ and SZ, or indirectly, by causing changes in host rock mineralogy that affect the flow path. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture-filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.

Screening Decision: Exclude except for the in-drift geochemical model that uses water chemistry and gas-phase composition from the drift-scale THC model that includes thermal-chemical alteration.

Screening Decision Basis: Low Consequence

Screening Argument: No THC effects were implemented into the TH models. Sensitivity studies have shown that TH variables are not significantly changed by THC effects (CRWMS M&O 2000h, Section 6.2 and 6.3). Some of the other aspects of the FEP that deal with THC plugging of smaller fractures will require a TBV (see assumption in Section 5.2.5).

TSPA Disposition: Not included in the TSPA except for the drift-scale THC model that provides the in-drift geochemical model boundary conditions of water and gas compositions at the drift wall.

Relevant AMRs: System-Level FEPs

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 3. Evaluate THMC coupled processes.

6.2.24 Two-Phase Buoyant Flow/Heatpipes 2.2.10.10.00

FEP Description: Heat from waste generates two-phase buoyant flow. The vapor phase (water vapor) escapes from the mountain. A heat pipe consists of a system for transferring energy between a hot and a cold region (source and sink respectively) using the heat of vaporization and movement of the vapor as the transfer mechanism. Two-phase circulation continues until the heat source is too weak to provide the thermal gradients required to drive it. Alteration of the rock adjacent to the drift may include dissolution which maintains the permeability necessary to support the circulation (as inferred for some geothermal systems).

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: Two-phase buoyant flow/heatpipes included inherently in the TSPA as described in the TSPA disposition.

TSPA Disposition: Two-phase buoyant flow is included in the TH models. A heatpipe effect will occur in a porous medium when steam is generated near a heat source, the steam moves away from the heat source and condenses, and the condensate then returns to the region near the hear source by gravity drainage or by capillary forces. Large amounts of heat can be transferred by the flowing steam.

Evidence of the existence of a two-phase zone/heatpipe can be inferred if there is a region at steam temperature above the repository that also has liquid fluxes higher than those that would otherwise be expected based on the infiltration rate. Results from mountain scale TH model simulations (CRWMS M&O 2000f, Figure 31) show that fracture fluxes above the repository show a strong increase in the regions where there is a constant temperature zone (CRWMS M&O 2000f, Figure 26). Consequently, evidence of the formation of two-phase buoyant flows is seen in the process level models.

IRSR-Issues: TEF Subissue 2 Technical Acceptance Criterion 2.2. Models include, at a minimum, the processes of evaporation and condensation and the effects of discrete geologic features.

6.2.25 Geosphere Dry-Out Due to Waste Heat 2.2.10.12.00

FEP Description: Repository heat evaporates water from the UZ rocks near the drifts as the temperature exceeds the vaporization temperature. This zone of reduced water content (reduced saturation) migrates outward during the heating phase (about the first 1000 years) and then migrates back to the containers as heat diffuses throughout the mountain and the radioactive sources decay.

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: Geosphere dry-out due to waste heat is included inherently in the TSPA as described in the TSPA disposition.

TSPA Disposition: A reduction in saturation around the drift was seen in all of the process level models during the heat-up period of the repository. Resaturation can be see in the THC process level model in Figure 20 of *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000e) and in the TH mountain-scale process level model in Figure 30 of *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f). In the drift-scale THC model, the elements at the crown, side, and base of the drift dry out after repository closure and does not re-saturate for 1000 years. In the mountain-scale TH model, the matrix saturations at the repository saturation dropped from ambient values near 0.9 down to values as low as 0.2 between closure and several hundred years. A direct comparison of the saturation time-histories from the two models can not be made since the elements from the mountain scale are much larger than those in the drift-scale model.

Relevant AMRs: *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e)

6.2.26 Density-Driven Groundwater Flow (Thermal) 2.2.10.13.00

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

Screening Decision: Include

Screening Decision Basis: Meets all Criteria

Screening Argument: This FEP is included since the thermal gradient in the unsaturated zone has been implemented as an initial condition in all of the TH models.

TSPA Disposition: The natural geothermal gradient is included as an initial condition into all of the TH models. Thermal gradients in the saturated zone caused by the waste heat is a stable system with the warmer (and less dense) water located above cooler water.

Two types of thermal boundary conditions were implemented in the thermal-models; a fixed water temperature at the water table or a fixed water temperature at some fixed distance below the water table. The models that had a fixed water temperature at the water table included the SDT, LDTH, and DDT sub-models in the MSTHM, the two-dimensional THC model, and one of the mountain scale TH models. The models that had a fixed water temperature 1000 meters into the saturated zone were the SMT sub-model in the MSTHM and five of the mountain scale TH models. All models were thermally equilibrated which established the natural thermal gradient before simulations began.

The sensitivity studies performed in *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f, Section 6.8) show that the thermodynamic variables (temperature, saturation, and water fluxes) do not change significantly at the repository horizon between simulations which include or exclude the saturated zone.

The density of water decreases as the temperature increases. This temperature dependence is implemented into the thermal-hydrologic models

Relevant AMRs: *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000f)

Multiscale Thermohydrologic Model (CRWMS M&O 2000g)

Drift-Scale Coupled Processes (DST and THC Seepage) Models (CRWMS M&O 2000e).

7. CONCLUSIONS

Table 3 provides a summary of the NFE FEP screening decisions and the basis for "Exclude" decisions.

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Table 3. Summary of NFE FEP Screening Decisions

FEP Number	FEP Name	Screening Decision	Screening Basis
1.1.02.00.00	**Excavation/Construction.** Excavation-related effects include changes to rock properties.	Fracture effects included/ chemistry effects excluded	Meets all criteria/low consequence
1.1.02.02.00	**Effects of pre-closure ventilation.** Controls the extent of the boiling front. Condensation of moisture as a result of ventilation onto a waste package should not occur during the pre-closure period since the ventilation air is expected to be relatively dry and the air flow rate will be high.	Include	Meets all criteria
1.2.02.01.00	**Fractures.** Generation of new fractures and re-activation of preexisting fractures may significantly change the flow and transport paths. Newly formed and reactivated fractures typically result from thermal, seismic, or tectonic events.	Include seepage/ exclude permanent effects	Meets criteria for seepage/Low consequence
2.1.08.01.00	**Increased unsaturated water flux at the repository.** Extremely rapid influx could reduce temperatures below the boiling point during part or all of the thermal period.	Include climate change/exclude water quenching waste package	Meets all criteria/Low consequence
2.1.08.02.00	**Enhanced influx (Philip's drips).** A mechanism for focusing unsaturated flow to an underground opening and producing local saturation.	Include	Meets all criteria
2.1.08.03.00	**Repository dry-out due to waste heat.** The zone of reduced saturation migrates outward during the heating phase (about the first 1000 years) and then migrates back to the containers as heat diffuses throughout the mountain and the radioactive sources decay.	Include	Meets all criteria
2.1.08.10.00	**Desaturation/dewatering of the repository.** "Dewatering" of rock at Yucca Mountain occurs because of ventilation and because of repository heating. The UZ is unsaturated and "resaturation" (re-entry of water to an equilibrium partial saturation) has a meaning different from that for a repository beneath the water table.	Include	Meets all criteria
2.1.08.11.00	**Resaturation of the repository.** During the resaturation (and sealing) of the repository, flow directions are different and the hydraulic conductivity is different. The conceptual flow models used in the process level thermal-hydrologic models allowed rock matrix and fracture elements to resaturate as the repository cooled.	Include	Meets all criteria
2.1.09.01.00	**Properties of the Potential Carrier Plume in the Waste and EBS.** It is likely that the flow system re-establishes itself before radionuclides are mobile. This re-established flow system, which can be a locally saturated system (fracture flow) or a UZ flow system, carries the signature of the repository (e.g., pH, T, dissolved constituents, etc) and is termed the carrier plume.	Include	Meets all criteria

Table 3. Summary of NFE FEP Screening Decisions (Continued)

FEP Number	FEP Name	Screening Decision	Screening Basis
2.1.09.12.00	**Rind (altered zone) formation in waste, EBS, and adjacent rock.** Thermo-chemical processes alter the rock forming the drift walls mineralogically. These alterations have hydrologic, thermal and mineralogic properties different from the current country rock.	Included in THC model but excluded from TH models	Low consequence
2.1.11.01.00	**Heat output/temperature in waste and EBS.** Decay heat is a major issue in design. High loading density is intended to be part of the waste isolation scheme. Temperatures in the waste and EBS will vary through time.	Include	Meets all criteria
2.1.11.02.00	**Nonuniform heat distribution/edge effects in repository.** Temperature inhomogeneities in the repository lead to localized accumulation of moisture. Uneven heating and cooling at repository edges lead to non-uniform thermal effects during both the thermal peak and the cool-down period.	Include/exclude TM effects	Meets all criteria/TM low consequence (TBV)
2.2.01.01.00	**Excavation and construction-related changes in the adjacent host rock.** Stress relief, leading to dilation of joints and fractures, is expected in an axial zone of up to one diameter width surrounding the tunnels.	Exclude	Low Consequence (TBV)
2.2.01.02.00	**Thermal and other waste and EBS-related changes in the adjacent host rock.** Changes in host rock properties result from thermal effects or other factors related to emplacement of the waste and EBS, such as mechanical or chemical effects of backfill. Properties that may be affected include rock strength, fracture spacing and block size, and hydrologic properties such as permeability.	Exclude	Low consequence (TBV)
2.2.01.03.00	**Changes in fluid saturations in the excavation disturbed zone.** During repository construction and operation, the near field will partially desaturate, and the local hydrological regime maybe disturbed. After backfilling, groundwater reenters host rock zones which were partially desaturated during the operational phase.	Exclude	Low consequence
2.2.06.01.00	**Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock.** Even small changes in the fracture openings cause large changes in permeability. The rock deforms according to the rock stress field. Changes in the groundwater flow and in the temperature field will change the stress acting on the rock which will in turn change the groundwater flow.	Exclude	Low consequence (TBV)
2.2.07.10.00	**Condensation zone forms around drifts.** Repository design will affect the scale at which condensation caps form (over waste packages, over panels, or over the entire repository), and to the extent to which "shedding" will occur as water flows from the region above one drift to the region above another drift or into the rock between drifts.	Include	Meets all criteria

Table 3. Summary of NFE FEP Screening Decisions (Continued)

FEP Number	FEP Name	Screening Decision	Screening Basis
2.2.07.11.00	**Return flow from condensation cap/resaturation of dry-out zone.** When the rocks have cooled enough, there is a return flow toward the drifts from the condensation cap as a plume of unsaturated flow.	Include	Included in process models used in TSPA
2.2.08.03.00	**Geochemical interactions in geosphere (dissolution, precipitation, weathering and effects on radionuclide transport).** Effects on hydrologic flow properties of the rock, radionuclide solubilities, sorption processes, and colloidal transport are relevant. Kinetics of chemical reactions should be considered in the context of the time scale of concern.	Include	Meets all criteria
2.2.08.04.00	**Redissolution of precipitates directs more corrosive fluids to container.** This FEP concerns chemical precipitation plugging pores during heating and dissolution of the plugs during cool-down. When the pores open, the corrosive water is released and drains into the drift.	Include	Meets all criteria
2.2.10.04.00	**Thermo-mechanical alteration of fractures near repository.** Heat from the waste causes thermal expansion of the surrounding rock, generating compressive stresses near the drifts and extensional stresses away from them. The zone of compression migrates with time.	Exclude	Low consequence (TBV)
2.2.10.05.00	**Thermo-mechanical alteration of rocks above and below the repository.** Thermal-mechanical compression at the repository produces tension-fracturing in the PTn and other units above the repository. These fractures alter unsaturated zone flow between the surface and the repository. Extreme fracturing may propagate to the surface, affecting infiltration. Thermal fracturing in rocks below the repository affects flow and radionuclide transport to the saturated zone.	Exclude	Low consequence (TBV)
2.2.10.06.00	**Thermo-chemical alteration (solubility speciation, phase changes, precipitation/dissolution).** Changes in the groundwater temperature in the far-field, if significant, may change the solubility and speciation of certain radionuclides. This would have the effect of altering radionuclide transport processes. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture-filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.	Exclude except for THC input to some geo-chemical models	Low consequence (TBV)
2.2.10.10.00	**Two-phase buoyant flow/heatpipes.** A heat pipe consists of a system for transferring energy between a hot and a cold region using the heat of vaporization and movement of the vapor as the transfer mechanism. Two-phase circulation continues until the heat source is too weak to provide thermal gradients required to drive it.	Include	Meets all criteria

Table 3. Summary of NFE FEP Screening Decisions (Continued)

FEP Number	FEP Name	Screening Decision	Screening Basis
2.2.10.06.00	**Thermo-chemical alteration (solubility speciation, phase changes, precipitation/dissolution).** Changes in the groundwater temperature in the far-field, if significant, may change the solubility and speciation of certain radionuclides. This would have the effect of altering radionuclide transport processes. Relevant processes include volume effects associated with silica phase changes, precipitation and dissolution of fracture-filling minerals (including silica and calcite), and alteration of zeolites and other minerals to clays.	Exclude except for THC input to some geo-chemical models	Low consequence (TBV)
2.2.10.10.00	**Two-phase buoyant flow/heatpipes.** A heat pipe consists of a system for transferring energy between a hot and a cold region using the heat of vaporization and movement of the vapor as the transfer mechanism. Two-phase circulation continues until the heat source is too weak to provide thermal gradients required to drive it.	Include	Meets all criteria
2.2.10.12.00	**Geosphere dry-out due to waste heat.** Repository heat evaporates water near the drifts. The zone of reduced saturation migrates outward during the heating phase (about the first 1000 years) and then migrates back to the containers as heat diffuses throughout the mountain and the radioactive sources decay. The extent and degree of dry-out depends on design and on the loading strategy for emplacement.	Include	Meets all criteria
2.2.10.13.00	**Density-driven groundwater flow (thermal).** The distribution of temperature within the crystalline basement is expected to be correlated with a distribution of groundwater density. Variations in density provide a driving force for groundwater flow. Density driven flow is expected at Yucca Mountain, but with heat supplied by the repository. Based on the geothermal gradient and the depth to the basement rocks, there is not likely to be any significant thermal contribution from the deep rocks.	Include	Meets all criteria

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