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

1. QA: QA

Page: 1 of: 116

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

Describe use:

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

5. Document Identifier (including Rev. No. and Change No., if applicable):
ANL-NBS-MD-000004 Rev 00 ICN 01

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12. Remarks:

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

Enclosure 5

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD
Complete Only Applicable Items

2. Analysis or Model Title:

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

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

ANL-NBS-MD-000004 Rev 00 ICN 01

4. Revision/Change No.	5. Description of Revision/Change
Rev 00 ICN 00	Initial Issue
Rev 00 ICN 01	ICN to address additional requirements of FEPs database and to reflect current design without backfill. Check Copy

CONTENTS

PAGE

TABLES

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ACRONYMS

AECL	Atomic Energy of Canada, Ltd.
AMR	Analysis/Model Report
CRWMS	Civilian Radioactive Waste Management System
CSNF	Commercial Spent Nuclear Fuel
DDT	Discrete heat source, Drift-scale, Thermal-conduction model
DOE	U.S. Department of Energy
DSNF	DOE Spent Nuclear Fuel
DST	Drift Scale Test
EBS	Engineered Barrier System
EDZ	Excavation Disturbed Zone
ENFE	Evolution of the Near-Field Environment
EPA	U.S. Environmental Protection Agency
FEPs	Features, Events, and Processes
HLW	High Level Waste
HMIP	Her Majesty Inspectorate of Pollution
IRSR	Issue Resolution Status Report
LDTH	Line-load, Discrete heat source, Thermal-Hydrologic model
M&O	Management & Operating (Contractor)
MSTHM	Multi-Scale Thermal-Hydrologic Methodology
NAGRA	National Cooperative for the Disposal of Radioactive Waste (Nationale Genossenschaft Fur die Lagerung Radioaktiver Abfalle)
NEA	Nuclear Energy Agency
NFE	Near-Field Environment
NRC	U.S. Nuclear Regulatory Commission
PMR	Process Model Report
PTn	Paintbrush Tuff, non-welded
QARD	Quality Assurance Requirements and Description
SDT	Smeared heat source, Drift-scale, Thermal-conduction model
SKB	Svensk Karnbranslehantering AB (Swedish Nuclear Fuel and Waste Management Co.)
SKI	Swedish Nuclear Power Inspectorate
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
TM	Thermal-Mechanical

ACRONYMS (Continued)

TSPA	Total System Performance Assessment
TSPA-SR	Total System Performance Assessment - Site Recommendation
TSw	Topopah Spring welded
UK	United Kingdom
UZ	Unsaturated Zone
YMP	Yucca Mountain Project
WF	Waste Form
WIPP	U.S. 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 potential geologic repository; (2) examines the effects of such FEPs on the performance of the potential 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.

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 potential 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 NFE FEPs screening decisions and associated screening arguments and to assist reviewers during the license review process.

1.1 SCOPE

This analysis has been prepared to satisfy the FEP screening documentation requirements in the Work Scope/Objectives/Tasks section of the development plan entitled *Technical Work Plan for Nearfield Environment Thermal Analyses and Testing* (CRWMS M&O 2000a). The NFE is treated in Total System Performance Assessment - Site Recommendation (TSPA-SR) (CRWMS M&O 2000b) 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 (CRWMS M&O 2000c) consists of 1797 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. 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

Table 1. Primary NFE FEPs (Continued)

FEP Name – Yucca Mountain Project (YMP) FEP #
Redissolution of precipitates directs more corrosive fluids to container – YMP 2.2.08.04.00
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 potential 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 2000c). 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 (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 United Kingdom, and the U.S. Waste Isolation Pilot Plant (WIPP) program. An additional 292 FEPs have been identified from YMP literature and site studies, 82 FEPs have been identified during YMP project staff workshops, 9 FEPs were identified by subject matter experts during the preparation of Rev 00 of the database, and 2 were identified during external review by the NRC. These FEPs are organized under 151 categories, based on NEA category headings, resulting in a total of 1797 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. The Secondary FEPs for each of the Primary FEPs are listed in section 6 of this AMR.

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 (UZ), 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 *The Development of Information Catalogued in REV00 of the YMP FEP Database* (CRWMS M&O 2000c). 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 (CRWMS M&O 2000d; CRWMS M&O 2000e; CRWMS M&O 2000f;

CRWMS M&O 2000g; CRWMS M&O 2000h). 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 DOE's interim guidance (Dyer 1999), the 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 (Dyer 1999, Section 115).

- They can be shown to have a probability of occurrence less than 10^{-4} in 10^{4} years (Dyer 1999, Section 114d).

- Their occurrence can be shown to have no significant effect on the overall performance of the system (Dyer 1999, Section 114e,f).

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.

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 (expected annual dose). 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 has constructed a dynamic electronic database to assist project reviewers during the license application 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, and identification as a heading entry or a Primary or Secondary FEP for the purposes of the TSPA. 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.

The structure of the database is discussed in CRWMS M&O 2000c and briefly summarized here. 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 first digit (x) indicates the layer and the second digit (y) indicates the category. The next four digits (zz.pp) define a grouping structure for the FEPs, with zz designating the heading, and pp designating the primary FEP number. Finally, the last two digits (qq) provide a unique identifier for secondary FEPs. For primary FEPs, the last two digits have qq=00. Each heading has a Primary FEP associated with it, and may or may 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 AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities* and were determined to be quality affecting and subject to the requirements of the U.S. DOE Office of Civilian Radioactive Waste Management *Quality Assurance Requirements and Description* (QARD) (DOE 2000). This evaluation is documented in Attachment III to the *Technical Work Plan for Nearfield Environment Thermal Analyses and Testing* (CRWMS M&O 2000a). 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 *Technical Work Plan for Nearfield Environment Thermal Analyses and Testing* (CRWMS M&O 2000a).

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. The methods used to control the electronic management of data as required by AP-SV.1Q, *Control of the Electronic Management of Information*, were not specified in *Technical Work Plan for Nearfield Environment Thermal Analyses and Testing* (CRWMS M&O 2000a). With regard to the development of this analysis, the control of electronic management of data was evaluated in accordance with AP-SV.1Q, *Control of the Electronic Management of Data*. The evaluation (Andrews 2000) determined that current work processes and procedures are adequate for the control of electronic management of data for this activity. The procedure AP-3.15Q, *Managing Technical Product Inputs* was also followed in the preparation of this report. 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 is documented in the *The Development of Information Catalogued in REV00 of the YMP FEP Database* (CRWMS M&O 2000c).

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. The EDA II design has been superseded by the design described in *Monitored Geologic Repository Project Description Document* (CRWMS M&O 2000i). 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 not include 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 in DOE's interim guidance (Dyer 1999, Section 114d):

> 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 Regulatory Criteria

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 (Dyer 1999, Section 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.

In this AMR, no FEPs were excluded due to regulatory criteria.

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; they pertain to the future geologic setting and the repository closure.

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. 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 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 Environment* (NRC 1999a) 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, UZ, waste package, waste form, and EBS FEP AMRs (CRWMS M&O 2000j; CRWMS M&O 2000k; CRWMS M&O 2000l; CRWMS M&O 2000m; CRWMS M&O 2000n).

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* (CRWMS M&O 1999), 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, 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 superseded by *Monitored Geologic Repository Project Description Document* (CRWMS M&O 2000i). 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 analysis 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 Process-Level Model Assumptions

An assumption is also made that all of the assumptions that are made in the calculations and AMRs 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 2000o)
- Section 5 of *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000p)
- Section 5 of *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q)

- Section 5 of *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r).

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 2000c, Appendix D), 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 to verify that they were assigned to the appropriate primary FEP 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 analysis 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 *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000p), *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r), *Abstraction of Drift-Scale Coupled Processes* (CRWMS M&O 2000s), *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q), and *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux* (CRWMS M&O 2000t). For the most part, the other AMRs provide supporting modeling detail that support these abstractions, but do not feed the TSPA directly. The Mountain-Scale thermal-hydrologic (TH) model was used to evaluate the effects of fully coupled three-dimensional TH processes throughout the mountain. The Multi-Scale Thermal-Hydrologic Methodology (MSTHM) model uses numerous conduction-only and thermal-hydrologic sub models to generate temperature, relative humidity, and flow variables at repository locations throughout the mountain that are used in TSPA. This model included edge effects as well as individual waste packages but did not contain any of the thermally-driven chemistry effects that may alter the hydrologic properties. The coupled thermal-hydrologic-chemical model was used to generate the chemistry of the gas and water that were used in the TSPA models. Due to the complexity of this model, the THC model was only run at one location in the repository. This model was run without allowing lateral loss of heat due to edge effects; this would result in the highest and longest lasting temperatures which would bound the thermally-driven chemistry effects. The chemistry changes that would affect the hydrologic behavior of the system (dissolution and precipitation processes that change the permeability and fracture porosity) were found to be small and so these effects were not implemented into the MSTHM or the mountain-scale TH models. The drift seepage model is comprised of a methodology to generate thermally altered seepage into the drift in TSPA. This model takes simulation results from the MSTHM and produces seepage based on how much water is expected to flow into a drift from isothermal seepage model results.

In the FEP section, related primary FEPs to each primary FEP. The PMR that covers each of the related primary FEP is listed to assist users of this document to quickly identify where screening arguments for these related FEPs can be found. Also provided in each FEP section, as appropriate, is a cross reference to key technical issues identified by the NRC (NRC 1999a;

NRC 1999b, NRC 1999c) as being important for the potential Yucca Mountain repository. These are identified as Issue Resolution Status Report (IRSR) issues.

The subissues identified in the *Thermal Effects on Flow* (NRC 1999b) IRSR that relate to this AMR are:

- TEF1 Is the U.S. Department of Energy thermohydrologic testing program, including performance confirmation testing, sufficient to evaluate the potential for thermal reflux to occur in the near field?
- TEF2 Is the U.S. Department of Energy thermohydrologic modeling approaches sufficient to predict the nature and bounds of thermal effects on flow in the near field?
- TEF3 Does the U.S. Department of Energy total system performance assessment adequately account for thermal effects on flow?

The subissues identified in the *Evolution of the Near-Field Environment* (NRC 1999a) IRSR that relate to this AMR are:

- ENFE1 Effects of coupled thermal-hydrologic-chemical processes on seepage and flow
- ENFE2 Effects of coupled thermal-hydrologic-chemical processes on the waste package chemical environment
- ENFE4 Effects of coupled thermal-hydrologic-chemical processes on the radionuclide transport.

The subissue identified in the *Repository Design and Thermal-Mechanical Effects* (NRC 1999c) IRSR that relates to this AMR is:

- RDTME3 Thermal-mechanical effects on underground facility design and performance

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.

Related Primary FEPs: 2.2.01.01.00 (UZ, NFE), 2.2.01.03.00 (NFE), 2.2.01.04.00 (WF), 2.2.01.05.00 (UZ), 2.1.07.02.00 (DE, EBS), 3.3.06.01.00 (SYS), 2.2.06.04.00 (UZ)

Secondary FEPs:

1.1.02.00.01	Blasting and vibration
1.1.02.00.02	Geochemical alteration (excavation)
1.1.02.00.03	Groundwater chemistry (excavation)
1.1.02.00.04	Influx of oxidizing water
1.1.02.00.05	Influx of oxidizing water

Screening Decision and Basis: Included (fracture effects)
Excluded - Low consequence (chemistry related effects)
Excluded - Low probability (some secondary FEPs not relevant to YMP)

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 insignificant compared to 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 that are implemented into the TSPA, the excavation/construction related chemistry changes are excluded based on low consequence to expected annual dose.

Some secondary FEPs are based on a saturated zone repository. The potential Yucca Mountain repository is located in the unsaturated zone so these secondary FEPs are not credible and are excluded on the basis of low probability. These non-Yucca Mountain, site-specific secondary FEPs were retained in the database for completeness.

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 in the AMR *Calibrated Properties Model* (CRWMS M&O 2000u, 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 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 model as described in the AMR *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r) and in the Line-load Discrete heat source Thermal-Hydrologic (LDTH) MSTHM sub-model simulations as described in the AMR *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q). The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA. The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

The hydrologic fracture properties, developed in *Calibrated Properties Model* (CRWMS M&O 2000u), used in all thermal-hydrologic and thermal-hydrologic-chemical process-level models have been calibrated using fracture mapping information from excavated drifts as described in *Unsaturated Zone Flow and Transport Model Process Model Report* (CRWMS M&O 2000d, Section 3.6.3.2).

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

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 1.1.02.00.01 Blasting and vibration

Relationship to Primary FEP: This FEP pertains to the excavation effects due to construction due to blasting (Atomic Energy of Canada, Ltd. [AECL]). This FEP represents just the mechanical fracturing aspect of the primary FEP. This FEP could also have been mapped to FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

1.1.02.00.02 Geochemical alteration (excavation)
Relationship to Primary FEP: This FEP pertains to geochemical effects due to desaturation and resaturation of the excavation/disturbed zone during excavation (National Cooperative for the Disposal of Radioactive Waste [NAGRA]). This FEP represents the chemistry aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock) and FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), but placement under this primary FEP is appropriate.
Screening and Disposition: This FEP applies to a repository that is located below the water table. This FEP was introduced by the Swiss organization NAGRA. NAGRA has been investigating a saturated zone repository (McCombie and Thury 1991). The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

1.1.02.00.03 Groundwater chemistry (excavation)
Relationship to Primary FEP: This FEP pertains to the pore water chemistry changes during desaturation and resaturation associated with the excavation through the pre-closure period (NAGRA). This FEP represents the chemistry aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock) and FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), but placement under this primary FEP is appropriate.
Screening and Disposition: This FEP applies to a repository that is located below the water table. This FEP was introduced by the Swiss organization NAGRA. NAGRA has been investigating a saturated zone repository (McCombie and Thury 1991). The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

1.1.02.00.04 Influx of oxidizing water
Relationship to Primary FEP: This FEP pertains to the influx of oxidizing water through fractures during the construction period that may change the hydrochemistry and minerology of the system

(NAGRA). This FEP represents the chemistry aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock), FEP 2.2.01.04.00 (Elemental solubility in excavation disturbed zone), and FEP 2.2.01.05.00 (Radionuclide transport in excavation disturbed zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

1.1.02.00.05 Influx of oxidizing water
Relationship to Primary FEP: This FEP pertains to the influx of oxidizing water through fractures during the construction period that may change the hydrochemistry and minerology of the system (NAGRA) This FEP represents the chemistry aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock), FEP 2.2.01.04.00 (Elemental solubility in excavation disturbed zone), and FEP 2.2.01.05.00 (Radionuclide transport in excavation disturbed zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.1.11.01.00 (NFE, WF, EBS), 2.1.08.10.00 (NFE, WF)

Secondary FEPs: 1.1.02.02.01 Gas generation, near-field rock

Screening Decision and Basis: Included (primary FEP)
Excluded - Low probability (secondary not relevant to YMP)

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 2000v) documents an analysis of the pre-closure ventilation period. This AMR 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 2000v, Section 6.5).

The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA. The TH model used in TSPA (MSTHM) generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes at locations throughout the mountain that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

The secondary FEP is based on a saturated zone repository. The potential Yucca Mountain repository is located in the unsaturated zone so the secondary FEP is not credible and is excluded on the basis of low probability. This non-Yucca Mountain, site-specific secondary FEP was retained in the database for completeness.

Supplemental Discussion: 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 calculations 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 the Calculation *Heat Decay Data and Repository Footprint for Thermal-Hydrologic and Conduction-Only Models for TSPA-SR* (CRWMS M&O 2000w). 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 2000n, Section 5.2). The ventilation was implemented into the three thermal-hydrologic (Mountain-Scale TH, MSTHM, & THC) process-level models as described in the AMRs *Mountain-Scale Coupled Processes (TH) Models, Multiscale Thermohydrologic Model,* and *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000p; CRWMS M&O 2000q; CRWMS M&O 2000r). 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 2000w, Figure 2).

The ventilation model 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 the AMR *Ventilation Model,* the wall temperature is shown to be always higher than the ventilation air temperature (CRWMS M&O 2000v, Figures 4 and 5).

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 1.1.02.02.01 Gas generation, near-field rock

Relationship to Primary FEP: This FEP pertains to air entering the repository during the construction/operational phase and resaturation after closure (Swedish Nuclear Power Inspectorate [SKI]). This FEP deals with dry out of the rock which is similar in nature to the primary FEP. This FEP could also have been mapped to

FEP 2.1.08.10.00 (Desaturation/dewatering of the repository) but placement under this primary FEP is appropriate.

Screening and Disposition: This FEP applies to a repository that is located below the water table. This FEP was introduced by the Swedish organization SKI. SKI has been investigating a saturated zone repository (Bäckblom and Ahlström 1991). The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

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.

Related Primary FEPs: 2.2.03.02.00 (UZ, SZ), 2.2.07.08.00 (UZ), 2.2.06.01.00 (NFE, DE), 2.2.07.13.00 (SZ), 2.2.07.02.00 (UZ), 2.2.07.04.00 (UZ)

Secondary FEPs:

1.2.02.01.01 Changes in fracture properties
1.2.02.01.02 Fracturing

Screening Decision and Basis: Included (seepage)
Excluded - Low consequence (permanent effects)

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

Sensitivity studies performed in *Radionuclide Transport Models Under Ambient Conditions* (CRWMS M&O 2000x, Section 6.6.1 and 6.6.2) show that the transport of radionuclides through the Topopah Spring repository host rock units are very quick when compared with transport through the Calico Hills. The transport of the non-sorbing Technecium-99 will take approximately one year to reach the base of the Topopah Spring unit while the highly sorbing Plutonium-239 will take approximately 300 years to travel through the TSw geologic unit. The transport of the non-sorbing Technecium-99 will take several hundred years to travel through the Calico Hills unit while the highly sorbing Plutonium-239 will take over 100,000 years to travel through the Calico Hills geologic unit. Permanent thermal-mechanical effects on vertical fractures should not extend more than a few drift diameters around the emplacement drifts so any change in total transport time as a result of permanent changes to the fracture system will be insignificant compared with the total unsaturated zone transport time and will not result in a change in expected annual dose. Therefore, permanent thermal-mechanical effects on transport can be excluded on the basis of low consequence to expected annual dose.

TSPA Disposition: 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 flow and transport (UZ) models used in TSPA. The fracture system has been incorporated into the property sets used in the THC and the MSTHM models. The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA. The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 1.2.02.01.01 Changes in fracture properties

Relationship to Primary FEP: This FEP pertains to fractures through which radionuclides may travel after release (WIPP). This FEP is similar to the primary FEP. This FEP could also have been mapped to FEP 2.2.03.02.00 (Rock properties of host rock and other units), FEP 2.2.07.08.00 (Fracture flow in the unsaturated zone), FEP 2.2.06.01.00 (Changes in stress [due to thermal,

seismic, or tectonic effects] change porosity and permeability of rock), FEP 2.2.07.02.00 (Unsaturated groundwater flow in geosphere), or FEP 2.2.07.04.00 (Focusing of unsaturated flow [fingers, weeps]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

1.2.02.01.02 Fracturing
Relationship to Primary FEP: This FEP has no description (NEA) but the title of the FEP is identical to the associated primary FEP. This FEP could also have been mapped to FEP 2.2.03.02.00 (Rock properties of host rock and other units), FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), FEP 2.2.07.08.00 (Fracture flow in the unsaturated zone), or FEP 2.2.07.02.00 (Unsaturated groundwater flow in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.2.07.04.00 (UZ), 2.2.07.05.00 (UZ), 2.2.07.11.00 (UZ), (1.3.01.00.00 (UZ, Bio)

Secondary FEPs: 2.1.08.01.01 Waste container is thermally quenched by rapid influx of water

Screening Decision and Basis: Included (climate change)
Excluded - Low consequence (rapid quenching of waste packages).

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.

The rapid quenching of the hot waste package aspect of the is FEP not explicitly captured in any of the TH models. In TSPA, the quantity and timing of seepage into the drift is based on the fracture liquid flux five meters above the crown of the drift as described in the AMR *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux* (CRWMS M&O 2000t, 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 still 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 2000y, Section 6.4). Since the drip shield lasts much longer than the duration of the thermal pulse, this part of the FEP is excluded based on low consequence to expected annual dose. Should the longevity of the drip shield 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 TSPA The 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 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 transition 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). This AMR discusses the paleoclimate reconstructions, orbital clock, and sedimentary mass accumulation records used to forecast the future climate state for the Yucca Mountain region.

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 2000r). 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 as documented in the AMR *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q, Section 6.3.6 and Table XVI-2).

The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA. The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

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

Supplemental Discussion: The average infiltration rates over the repository block in the MSTHM (CRWMS M&O 2000q, Table XVI-2) are shown in Table 2 of this AMR (ANL-NBS-HS-000004 Rev 00 ICN 01).

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

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 2.1.08.01.01 Waste container is thermally quenched by rapid influx of water

Relationship to Primary FEP: This FEP pertains to one of the consequences of increased water flux at the repository. This FEP could also have been mapped to FEP 1.3.01.00.00 (Climate change, global), FEP 2.2.07.04.00 (Focusing of unsaturated flow [fingers, weeps]), or FEP 22.07.11.00 (Return flow from condensation cap / resaturation of dry-out zone), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP

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.

Related Primary FEPs: 2.2.07.04.00 (UZ)

Secondary FEPs: None

Screening Decision and Basis: Included

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

TSPA Disposition: This FEP concerns the effect of the circular opening on the flow of water into and around the drift. A circular drift that allows water to cross from the host rock into the drift was included in both the MSTHM as documented in the AMR *Multiscale Thermo-hydrologic Model* (CRWMS M&O 2000q) and the seepage model as documented in the AMR *Seepage Model for PA Including Drift Collapse* (CRWMS M&O 2000z) that are used in TSPA. A circular opening was incorporated into the THC model but no fluid flow was allowed to cross into the drift.

The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA. The seepage model and abstraction is in the TSPA since it produces the probability that a waste package experiences seepage based on the local percolation flux.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: No secondary FEPs

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.

Related Primary FEPs: 2.1.08.10.00 (NFE, WF), 2.1.11.04.00 (WF, EBS), 2.2.01.03.00 (NFE), 2.2.10.12.00 (NFE)

Secondary FEPs: None

Screening Decision and Basis: Included

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 TH 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 2000p), *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q), and *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r).

The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA. The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA.

IRSR-Issues: TEF2, TEF3, ENFE1

Treatment of Secondary FEPs: No secondary FEPs

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.

Related Primary FEPs: 2.1.08.09.00 (EBS), 2.1.08.03.00 (NFE), 2.1.11.04.00 (WF, EBS), 2.2.01.03.00 (NFE)

Secondary FEPs:
2.1.08.10.01 Dewatering of host rock (in waste and EBS)
2.1.08.10.02 Dewatering

Screening Decision and Basis: Included (primary)
Excluded - Low Probability (secondary FEPs not relevant to YMP)

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

The secondary FEPs are based on a saturated zone repository. The potential Yucca Mountain repository is located in the unsaturated zone so these secondary FEPs are not credible and are excluded on the basis of low probability. This non-Yucca Mountain, site-specific secondary FEPs was retained in the database for completeness.

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 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 2000p), *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q), and *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r).

The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA. The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA.

IRSR-Issues: TEF2, TEF3.

Treatment of Secondary FEPs: 2.1.08.10.01 Dewatering of host rock (in waste and EBS)

Relationship to Primary FEP: This FEP has no description (NEA) but the title of the FEP is a subset of the dewatering aspect of the primary FEP. This FEP could also have been mapped to FEP 2.1.08.03.00 (Repository dry-out due to waste heat) and FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), but placement under this primary FEP is appropriate.

Screening and Disposition: Dewatering implies the draining of a saturated system. This FEP applies to a repository that is located below the water table. The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

2.1.08.10.02 Dewatering
Relationship to Primary FEP: This FEP pertains to dewatering of the rock near the repository as a result of groundwater pumping or draining of the rock during construction of the repository. (AECL). This FEP is a subset of the dewatering aspect of the primary FEP. This FEP could also have been mapped to FEP 2.1.08.03.00 (Repository dry-out due to waste heat) and FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), but placement under this primary FEP is appropriate.
Screening and Disposition: This FEP applies to a repository that is located below the water table. This FEP was introduced by the Canadian organization AECL. AECL has been investigating a saturated zone repository (Dormuth et al. 1991). The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

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.

Related Primary FEPs: 2.1.08.09.00 (EBS), 2.2.07.10.00 (NFE, UZ), 2.2.07.11.00 (NFE, UZ), 2.2.01.03.00 (NFE), 2.2.07.09.00 (UZ)

Secondary FEPs:
2.1.08.11.01 Reflooding (in waste and EBS)
2.1.08.11.02 Brine inflow (in waste and EBS)

Screening Decision and Basis: Included (primary FEP)
Excluded - Low probability (secondary FEPs not relevant to YMP)

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

One secondary FEP is based on a saturated zone repository. The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability. The other secondary FEP is based on the WIPP repository, which is located in a bedded salt deposit, and the concern about brine inflow into the repository. The potential Yucca Mountain repository is not located near any salt deposits so this secondary FEP is not credible and is excluded on the basis of low probability. These non-Yucca Mountain, site-specific secondary FEPs were retained in the database for completeness.

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 2000r), in Figure 46 of the MSTHM abstraction AMR (CRWMS M&O 2000t) and in the TH mountain-scale process-level model in Figure 30 of *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000p). Consequently, this FEP is included in the process-level models for TSPA. The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA. The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes at locations throughout the repository that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 2.1.08.11.01 Reflooding (in waste and EBS)

Relationship to Primary FEP: This FEP pertains to water refilling the repository after closure that could lead to higher temperatures and pressures (AECL). This FEP is a similar in nature to the primary FEP. This FEP could also have been mapped to FEP 2.2.07.11.00 (Return flow from condensation cap/resaturation of dry-out zone), FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), or to FEP 2.2.07.09.00 (Matrix imbibition in the unsaturated zone), but placement under this primary FEP is appropriate.

Screening and Disposition: This FEP applies to a repository that is located below the water table. This FEP was introduced by the

Canadian organization AECL. AECL has been investigating a saturated zone repository (Dormuth et al. 1991). The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

2.1.08.11.02 Brine inflow (in waste and EBS)
Relationship to Primary FEP: This FEP pertains to a possible brine inflow into the repository through the disturbed rock zone (WIPP). This FEP was mapped to the primary FEP since it pertains to fluids returning to the repository after closure
Screening and Disposition: There is no brine source at Yucca Mountain. Consequently, this secondary FEP is not credible and is excluded on the basis of low probability.

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.

Related Primary FEPs: 2.1.06.01.00 (EBS), 2.2.08.01.00 (UZ, SZ), 2.2.08.02.00 (UZ, SZ), 2.2.08.03.00 (NFE, UZ, SZ), 2.2.08.07.00 (UZ, SZ), 2.2.10.06.00 (NFE, UZ, SZ)

Secondary FEPs:

2.1.09.01.01	Reactions with cement pore water
2.1.09.01.02	Reactions with cement pore water
2.1.09.01.03	Induced chemical changes (in waste and EBS)
2.1.09.01.04	Interactions of host materials and ground water with repository material
2.1.09.01.05	TRU silos cementitious plume
2.1.09.01.06	Water chemistry, canister
2.1.09.01.07	Transport of chemically-active substances into the near-field
2.1.09.01.08	Incomplete near-field chemical conditioning
2.1.09.01.09	Chemical processes (in waste and EBS)
2.1.09.01.10	Hyperalkaline carrier plume forms
2.1.09.01.11	Chemical interactions (in waste and EBS)
2.1.09.01.12	TRU alkaline or organic plume
2.1.09.01.13	Interactions of waste and repository materials with host materials

2.1.09.01.14 TRU alkaline or organic plume

Screening Decision and Basis: Included (primary FEP and some secondary FEPs)
Excluded - Low consequence (cement interactions)
Excluded - Low probability (several secondary FEPs not relevant to YMP)

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

Some secondary FEPs are concern the interaction of large quantities of cement introduced into the repository from waste containers or in the lining of the drift. Another secondary FEP deals with the water chemical interactions within multiple layers of a waste package. The potential Yucca Mountain repository design does not include these features so these secondary FEPs are not credible and are excluded on the basis of low probability. These non-Yucca Mountain, site-specific secondary FEPs were retained in the database for completeness.

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 as documented in the AMR *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r, 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 2000r) 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 2000r). The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA.

IRSR-Issues: TEF2, TEF3, ENFE2, ENFE4

Treatment of Secondary FEPs: 2.1.09.01.01 Reactions with cement pore water

Relationship to Primary FEP: This FEP pertains to the interaction of cement pore water with the cement resulting in changes to temperature, composition, and pH (SKI/Svensk Karnbranslehantering AB [SKB]). This FEP deals with the water-cement interaction aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry / composition in UZ and SZ), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.

Screening and Disposition: This FEP is of secondary importance due to the small amount of concrete in and around the emplacement drifts. Concrete will be limited to the grout for the rock bolts used for ground support which occurs only in localized regions in the repository. The small amount of cement in the grout is expected to carbonate quickly. Due to the limited volume of grout in the system, the change, due to interactions with the reaction products, in overall pH of the seepage is expected to be insignificant and so this secondary FEP can be excluded on the basis of low consequence to expected annual dose.

2.1.09.01.02 Reactions with cement pore water

Relationship to Primary FEP: This is a duplicate of FEP 2.1.09.01.01.

2.1.09.01.03 Induced chemical changes (in waste and EBS)

Relationship to Primary FEP: This FEP has no description (NEA) but title implies this FEP contains the same chemical interaction processes in the EBS contained in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and

SZ), FEP 2.2.08.02.00 (Radionuclide transport occurs in a carrier plume in geosphere), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP

2.1.09.01.04 Interactions of host materials and ground water with repository material
Relationship to Primary FEP: This FEP has no description (NEA) but title implies this FEP contains the same chemical interaction processes with the EBS that are in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.02.00 (Radionuclide transport occurs in a carrier plume in geosphere), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.1.09.01.05 TRU silos cementitious plume
Relationship to Primary FEP: This FEP deals with the plume of high pH water leaching from the cement TRU silos interacting with high level waste (NAGRA). This FEP addresses the same general water-cement interaction problems associated with the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry / composition in UZ and SZ), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: This FEP does not apply to the Yucca Mountain repository because waste will not be emplaced in cement

silos. Consequently, this secondary FEP is not credible and is excluded on the basis of low probability.

2.1.09.01.06 Water chemistry, canister

Relationship to Primary FEP: This FEP concerns the changing chemistry of water that would be seen in the void between an outer copper and an inner steel waste package as well as that within the steel waste package (SKI). This FEP addresses the same general chemical interaction issues in the EBS associated with the primary FEP. Another primary FEPs that this FEP could have been mapped to is FEP 2.2.08.01.00 (Groundwater chemistry/ composition in UZ and SZ), but placement under this primary FEP is appropriate.

Screening and Disposition: The part of the secondary FEP that deals with water in the void space between the layers of the waste package is not credible since there is no void space. Therefore, this part of the FEP is excluded on the basis of low probability. The part of the secondary FEP dealing with the water in the waste package is a waste form issue and not discussed here.

2.1.09.01.07 Transport of chemically-active substances into the near-field

Relationship to Primary FEP: This FEP pertains to flowing groundwater that may carry various species in solution, or in suspension as particulates or colloids. These flows may then influence leaching and transport of radionuclides (United Kingdom [UK]-Her Majesty Inspectorate of Pollution [HMIP]). This FEP addresses the same general chemical interaction issues in the near field host rock associated with the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.

Screening and Disposition: This secondary FEP deals with EBS transport issues and is not discussed here.

2.1.09.01.08 Incomplete near-field chemical conditioning

Relationship to Primary FEP: This FEP pertains to the development of a hyperalkaline, reducing conditions around the

waste packages forming a barrier to radionuclide transport (UK-HMIP). This FEP concerns the same carrier plume chemistry issues that are contained in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: The screening and disposition for chemistry issues are the same as that of the primary FEP. The radionuclide transport part of the FEP are EBS transport issues and is not discussed here.

2.1.09.01.09 Chemical processes (in waste and EBS)
Relationship to Primary FEP: This FEP has no description (NEA) but the title is similar to that of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.1.09.01.10 Hyperalkaline carrier plume forms
Relationship to Primary FEP: This FEP refers to the development of a hyperalkaline plume as water flows through the concrete liner (YMP). This FEP addresses the same general water-cement interaction problems associated with the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: This FEP is not credible since the reference repository design does not specify the use of a concrete

liner for ground support. Consequently, this secondary FEP is excluded in the basis of low probability.

2.1.09.01.11 Chemical interactions (in waste and EBS)
Relationship to Primary FEP: This FEP pertains to chemical interactions that occur at high temperatures and pressure and how they may affect waste package corrosion, dissolution, and sorption processes (AECL). This FEP addresses the same chemical interaction issues in the EBS associated with the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ) or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.1.09.01.12 TRU alkaline or organic plume
Relationship to Primary FEP: This FEP refers to the TRU waste silos that contain large quantities of cement and small quantities of organic materials. Water can interact with these materials resulting in a plume of cementitious and organic material that can alter the minerology of water-conducting features in its path (NAGRA). This FEP addresses the same general water-cement interaction along with carrier plume issues associated with the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry / composition in UZ and SZ), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: This FEP is not credible since the repository will not contain cementitious TRU silos that contain organic materials. Consequently, this secondary FEP is excluded in the basis of low probability.

2.1.09.01.13 Interactions of waste and repository materials with host materials
Relationship to Primary FEP: This FEP has no description (NEA) but the title implies that the FEP concerns the general chemical interaction processes that are associated with the primary FEP.

Other primary FEPs that this FEP could have been mapped to include FEP 2.1.06.01.00 (Degradation of cementitious materials in drift), FEP 2.2.08.01.00 (Groundwater chemistry / composition in UZ and SZ), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), or FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/ dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.1.09.01.14 TRU alkaline or organic plume
Relationship to Primary FEP: This FEP is a duplication of FEP 2.1.09.01.12.
Screening and Disposition: Same as 2.1.09.01.12.

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.

Related Primary FEPs: 2.2.01.02.00 (NFE), 2.2.10.01.00 (UZ, SZ), 2.2.08.01.00 (UZ, SZ), 2.2.08.03.00 (NFE, UZ, SZ), 2.2.10.06.00 (NFE, UZ, SZ)

Secondary FEPs: 2.1.09.12.01 Deep alteration of the porosity of drift walls

Screening Decision and Basis: Included (THC model)
Excluded - Low consequence (TH model, effects on transport)

Screening Argument: The formation of a rind driven by THC processes is 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 fracture porosity does not change by more than 0.5% (e.g. fracture porosity change from 0.01 to between 0.00995 and 0.01005) in any of the THC process model simulations (CRWMS M&O 2000r, Section 6.3.5.2). The effect of including fracture porosity changes in the THC process-level model results is presented in *Abstraction of Drift-Scale Coupled Processes* (CRWMS M&O 2000s, 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. Since the total fracture porosity does not produce significant changes to thermal-hydrologic process-level model results, they will not have an impact on TSPA calculations. Therefore, the formation of a rind was excluded from the MSTHM and the unsaturated zone transport model due to low consequence to expected annual dose.

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 2000r, 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.

The effect of including chemistry in the THC process-level model results is presented in *Abstraction of Drift-Scale Coupled Processes* (CRWMS M&O 2000s, 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. The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA.

IRSR-Issues: TEF2, TEF3, ENFE1

Treatment of Secondary FEPs: 2.1.09.12.01 Deep alteration of the porosity of drift walls

Relationship to Primary FEP: This FEP pertains to the dissolution and alteration of minerals in the drift wall. These alterations can reduce the fracture porosity and form a rind with different hydrologic properties (YMP). This FEP covers the same issues associated with rind formation found in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.01.02.00 (Thermal and other waste and EBS-related changes in the adjacent host rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

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 DOE Spent Nuclear Fuel (DSNF), into account.

Related Primary FEPs: 2.1.11.07.00 (WF, EBS), 2.1.11.05.00 (WP, WF, EBS), 2.1.11.09.00 (WF, EBS, NFE), 2.1.11.03.00 (WF, EBS), 2.1.11.10.00 (WF, EBS, NFE), 2.1.11.06.00 (WP), 2.1.11.02.00 (NFE), 2.1.11.04.00 (WF, EBS), 2.1.02.05.00 (WF), 2.1.11.08.00 (WF, NFE, EBS), 2.1.01.02.00 (WF), 2.2.10.12.00 (NFE), 2.1.08.03.00 (NFE)

Secondary FEPs:

2.1.11.01.01	Glass temperature (in waste and EBS)
2.1.11.01.02	Canister temperature
2.1.11.01.03	Temperature, bentonite buffer
2.1.11.01.04	Temperature, canister
2.1.11.01.05	Temperature, tunnel backfill
2.1.11.01.06	Heat generation from waste containers
2.1.11.01.07	Radioactive decay heat
2.1.11.01.08	DOE SNF expected waste heat generation
2.1.11.01.09	DOE SNF expected waste heat generation

Screening Decision and Basis: Included (primary FEP and some secondary FEPs)
Excluded - Low probability (some secondary FEPs not relevant to YMP)

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

Some secondary FEPs are based on a repository that uses bentonite backfill around waste packages. The potential Yucca Mountain repository does not specify the use of bentonite backfill around waste packages so these secondary FEPs are not credible and are excluded on the basis of low probability. These non-Yucca Mountain, site-specific secondary FEPs were retained in the database for completeness.

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 calculation *Heat Decay Data and Repository Footprint for Thermal-Hydrologic and Conduction-Only Models for TSPA-SR* (CRWMS M&O 2000w). This calculation discusses how the TSPA-SR waste stream was created and the salient characteristics of the various heat decay curves that are described in the discussion section. Geothermal gradients were incorporated as initial conditions into all of the TH models. All major features of the drift were included in both the THC and the MSTHM process level models.

The heat loads were used in both the MSTHM and the THC models. The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA. The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

Supplemental Discussion: The initial overall heat output for the entire repository is 76.4 MW or 72.7 kW/acre (CRWMS M&O 2000w, Section 5.1). This thermal loading was used in the Smeared-heat source, Drift scale, Thermal-conduction (SDT) and the Smeared-heat source, Mountain scale, Thermal-conduction (SMT) sub-models of the MSTHM as well as in the three-dimensional mountain scale TH models (CRWMS M&O 2000q; CRWMS M&O 2000p). 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 2000w, Section 5.2). The line load of the waste packages in this model was 1.54 kW/meter which is 6% higher than the actual drift loading of 1.45 kW/meter. To compensate for this difference, the waste package heat outputs were scaled down so that the lineal heat output for this model was 1.45 kW/m. The initial line load of 1.45 kW/meter was used in the two-dimensional THC process-level model (CRWMS M&O 2000r) 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 source, 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 5.2.3). 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.

IRSR-Issues: TEF2, TEF3.

Treatment of Secondary FEPs: 2.1.11.01.01 Glass temperature (in waste and EBS)

Relationship to Primary FEP: This FEP pertains to the temperature of glass waste packages (NAGRA). This FEP is related to the primary FEP since the heat output from glass waste packages will contribute to the overall energy generated from the waste packages. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.02.05.00 (Glass cracking and surface area), FEP 2.1.11.04.00 (Temperature effects/coupled

processes in waste and EBS), or FEP 2.1.01.02.00 (Co-disposal/ co-location of waste), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.1.11.01.02 Canister temperature
Relationship to Primary FEP: This FEP refers to how the waste package temperatures are determined by the thermal properties of the material around the waste packages as well as the heat output from the waste (NAGRA). This FEP is related to the waste package temperature aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.04.00 (Temperature effects/coupled processes in waste and EBS), FEP 2.1.11.05.00 (Differing thermal expansion of repository components), or FEP 2.1.11.08.00 (Thermal effects: chemical and microbiological changes in the waste and EBS), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.1.11.01.03 Temperature, bentonite buffer
Relationship to Primary FEP: This FEP refers to the temperature gradients in the bentonite backfill around the waste package (SKI). This FEP is related to the primary FEP because it could directly affect the temperature of the waste package aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to are FEP 2.1.11.04.00 (Temperature effects/coupled processes in waste and EBS) and FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), but placement under this primary FEP is appropriate.
Screening and Disposition: This FEP is not credible since there is no bentonite backfill around the waste package in the current design. Therefore, this secondary FEP is excluded on the basis of low probability.

2.1.11.01.04 Temperature, canister
Relationship to Primary FEP: This FEP refers to the changing of the temperature in the canister as a result of radioactive decay of the fuel. This also includes the thermal properties of the waste package and the thermal properties of the bentonite backfill (SKI). This FEP contains both the waste package heat generation and waste package temperature aspects of the primary FEP. Other primary FEPs that this FEP could have been mapped to include 2.1.11.04.00 (Temperature effects/coupled processes in waste and

EBS) and FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), but placement under this primary FEP is appropriate.

Screening and Disposition: The part of the secondary FEP that deals with a bentonite backfill is not credible since there is no bentonite backfill around the waste package in the current design. Therefore, that part of the secondary FEP is excluded on the basis of low probability. The screening decision and disposition for the temperature effects due to radioactive decay of fuel aspect of the secondary FEP can be found in the primary FEP screening decision.

2.1.11.01.05 Temperature, tunnel backfill

Relationship to Primary FEP: This FEP refers to the changes in the temperature gradients in the backfill material as the result of waste package heat (SKI). This FEP relates to the primary FEP as it pertains to thermal resistance of the volume surrounding the waste package. Other primary FEPs that this FEP could have been mapped to include 2.1.11.04.00 (Temperature effects/coupled processes in waste and EBS) and FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.1.11.01.06 Heat generation from waste containers

Relationship to Primary FEP: This FEP pertains to the waste heat generated from the waste packages (SKI). This FEP comprises the heat output aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.04.00 (Temperature effects/coupled processes in waste and EBS) and FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.1.11.01.07 Radioactive decay heat

Relationship to Primary FEP: This FEP pertains to the waste heat generated from the waste packages (SKI/SKB). This FEP comprises the heat output aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.04.00 (Temperature effects/coupled processes in waste and EBS) and FEP 2.1.11.09.00 (Thermal effects on liquid or two-

phase fluid flow in the waste and EBS), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.1.11.01.08 DOE SNF expected waste heat generation
Relationship to Primary FEP: This FEP pertains to the waste heat generated from the DOE SNF waste packages (YMP). This FEP comprises part of the heat output aspect of the primary FEP. Another primary FEP that this FEP could have been mapped to is FEP 2.1.11.04.00 (Temperature effects/coupled processes in waste and EBS), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.1.11.01.09 DOE SNF expected waste heat generation
Relationship to Primary FEP: This FEP pertains to the waste heat generated from the DOE SNF waste package. (YMP). This FEP comprises part of the heat output aspect of the primary FEP. Another primary FEP that this FEP could have been mapped to include FEP 2.1.11.04.00 (Temperature effects/coupled processes in waste and EBS), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.1.11.01.00 (NFE, WF, EBS), 2.1.08.04.00 (NFE, EBS), 2.2.07.10.00 (NFE, UZ)

Secondary FEPs:
2.1.11.02.01 Panel/repository edge effects – thermal
2.1.11.02.02 Panel/repository edge effects – post-thermal
2.1.11.02.03 Vault heating effects

Screening Decision and Basis: Included (TH and THC aspects)
Excluded - Low consequence (TM effects)

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 the TH model used in the TSPA as described in the TSPA disposition. Mountain-scale TM effects were excluded based on low consequence.

When the mountain heats up, the host rock expands causing vertical fractures in and around the repository to close, reducing the fracture permeability. Horizontal fractures above and below the repository will undergo shear, increasing the fracture permeability, due to the differing thermal expansion resulting from the temperature gradients. The horizontal fractures at the edge of the repository will experience the greatest amount of shear since rock at the edges will not be constrained like the rock near the center of the repository. On cooling, the vertical fractures will reversibly return to their initial state but the horizontal fractures will likely retain some of the displacement due to non-linear and/or inelastic shear deformation. A small change in horizontal permeability at the edge of the repository is not expected to change expected annual dose since the increase in fracture permeability would allow water to be diverted away from the drifts and around the edges of the repository. A reduction in the water available to seep into the drift will result in a reduction of seepage into the drift. Since water is needed to degrade the drip shield, waste package, and waste form, as well as to advectively transport radionuclides out of the drift, a reduction in seepage is considered to be good for repository performance. Consequently, mountain-scale TM effects are excluded based on low consequence to expected annual dose.

TSPA Disposition:

Thermal-hydrologic edge effects are included in the models contained in *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q). The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

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.

Supplemental Discussion: Liquid fluxes as well as saturations are calculated for locations at both CSNF and HLW waste packages at 610 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 2000q). 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 610 locations given as output from the TH multi-scale model. The local temperature and flow inhomogeneities in the rock caused by variations in adjacent waste package heat output 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 3.9 °C (CRWMS M&O 2000t, Figure 48). This difference decreases to less than 1.5 °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.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 2.1.11.02.01 Panel/repository edge effects – thermal

Relationship to Primary FEP: This FEP pertains to repository center/edge effects and how thermal effects during heating such as rock compression and dry-out are different for edge and interior repository locations (YMP). This FEP pertains to the thermal-mechanical effects resulting from a non-uniform heat distribution as well as non-uniform dry-out aspects of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.04.00 (Condensation forms on backs of drifts) and FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2 .1.11.02.02 Panel/repository edge effects – post-thermal

Relationship to Primary FEP: This FEP pertains to repository center/edge effects and how thermal effects during cooling such as rock compression and dry-out are different for edge and interior repository locations (YMP). This FEP pertains to the thermal-mechanical effects resulting from a non-uniform heat distribution as well as non-uniform re-saturation aspects of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.04.00 (Condensation forms on backs of drifts) and FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.1.11.02.03 Vault heating effects

Relationship to Primary FEP: This FEP pertains to the alteration of the groundwater flow fields, the possible formation of convection cells, and possible thermal-mechanical effects due to the heating of the repository (AECL). This FEP refers to the thermal-mechanical aspect of non-uniform heat distribution as well as the mountain-scale thermal-hydrologic model aspects of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.04.00 (Condensation forms on backs of drifts) and FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.2.01.02.00 (NFE), 2.1.07.01.00 (WP, DE, WF, EBS, Tec), 1.1.02.00.00 (NFE, UZ, EBS), 2.1.07.02.00 (DE, EBS), 2.2.06.01.00 (NFE, DE)

Secondary FEPs:

2.2.01.01.01	Disturbed rock zone
2.2.01.01.02	Mechanical effects - Excavation/backfilling effects
2.2.01.01.03	Formation of cracks (host rock disturbed zone)
2.2.01.01.04	Damaged zone (host rock disturbed zone)
2.2.01.01.05	Excavation/backfilling effects on nearby rock
2.2.01.01.06	Mechanical effects - Excavation/backfilling effects
2.2.01.01.07	Enhanced rock fracturing
2.2.01.01.08	Creeping of rock mass, near-field
2.2.01.01.09	Excavation effects on nearby rock
2.2.01.01.10	Disturbed zone (hydromechanical) effects
2.2.01.01.11	Excavation-induced changes in stress

Screening Decision: Included (initial effects on seepage)
Excluded - Low consequence (permanent THC and TM effects)

Screening Argument: Excavation will produce some disturbances of the rocks surrounding the drifts due to stress relief. Additionally, disturbances 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 (fracture porosity and permeability) 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 2000s). Permanent mechanical effects on the excavation disturbed zone are not included in TSPA. In *Calculation of Permeability Change due to Coupled Thermal-Hydraulic-Mechanical Effects* (CRWMS M&O 2000o), it is shown that the permanent thermal-mechanical effects on the fracture system are an order of magnitude higher in the regions above and below the drift and a factor of three higher in the regions to the side of the drift. The seepage model shows the trend that the seepage into the drift decreases with increasing fracture permeability since increasing the fracture permeability allows more water to flow around the drift. Since decreasing the seepage into the drift will result in slower radionuclide release from the drift, permanent thermal-mechanical effects have a beneficial effect and may reduce expected annual dose. No credit is taken for this FEP in TSPA. This FEP is therefore excluded on the basis of low consequence to expected annual dose.

TSPA Disposition: Initial excavation and construction-related changes in the adjacent host rock are included in the TSPA.

Initial effects on the excavation disturbed zone are included in the seepage model. In this model, a range of permeability and van Genuchten alpha (that spanned the range from undisturbed to the post-excavation conditions) were implemented into seepage model as documented in the AMR *Seepage Model for PA Including Drift Collapse* (CRWMS M&O 2000z, Figure 1). The quantity of seepage into the drift was increased by 71% over the expected seepage values to account for effects of drift degradation (partial drift collapse), rock bolts, and to account for the seepage model assumption that the k and van Genuchten alpha parameters should have been correlated. This was documented in the AMR *Abstraction of Drift Seepage* (CRWMS M&O 2000aa, Section 6.4). The results of the seepage model along with the percolation flux taken from the MSTHM form the seepage abstraction implemented in TSPA.

IRSR-Issues: TEF2

Treatment of Secondary FEPs: 2.2.01.01.01 Disturbed rock zone

Relationship to Primary FEP: This FEP concerns the excavation induced changes in stress near the waste emplacement tunnels. This can lead to failure in the rock around the opening creating a disturbed rock zone of fractures (WIPP). The FEP represents the formation of the excavation/disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.01.01.02 Mechanical effects - Excavation/backfilling effects
Relationship to Primary FEP: This FEP concerns mechanical effects in the excavation/disturbed zone (SKI/SKB). The FEP represents the properties of the excavation/disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.03 Formation of cracks (host rock disturbed zone)
Relationship to Primary FEP: This FEP concerns the formation of cracks or faults near the vault that could affect the performance of seals, grouts, and the buffer (AECL). The FEP represents the excavation/disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.04 Damaged zone (host rock disturbed zone)
Relationship to Primary FEP: This FEP concerns enhanced groundwater flow or contaminant transport that could occur in the region around the rock that is damaged during blasting or excavation (AECL). The FEP represents processes that occur resulting from the creation of the excavation/disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.05 Excavation/backfilling effects on nearby rock
Relationship to Primary FEP: This FEP pertains to changing the hydrologic properties of fractures as a result of changing fracture

apertures from thermal-mechanical effects (SKI/SKB). The FEP represents the formation of the excavation/disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.06 Mechanical effects - Excavation/backfilling effects
Relationship to Primary FEP: This FEP concerns mechanical effects in the excavation/disturbed zone (SKI/SKB). The FEP represents the formation of the excavation/disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.07 Enhanced rock fracturing
Relationship to Primary FEP: This FEP pertains to new fractures forming as a result of excavation of the repository through blasting and stress redistribution (SKI/SKB). The FEP represents the formation of the excavation/disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.08 Creeping of rock mass, near-field
Relationship to Primary FEP: This FEP concerns creeping of the rock mass in connection with stress changes. This could result in rockfall into the emplacement drift (SKI). The FEP represents the effects of the disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include

FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.01.00 (Rockfall [large block]), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.09 Excavation effects on nearby rock
Relationship to Primary FEP: This FEP pertains to the changes in the stress state of the system due to excavation, operation, and sealing of the rock (SKI). The FEP represents the effects of the disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.10 Disturbed zone (hydromechanical) effects
Relationship to Primary FEP: This FEP pertains to the changes to hydrologic properties in the regions around the disposal vaults and access excavations (UK-HMIP). The FEP represents the effects of the disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/ construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.01.11 Excavation-induced changes in stress
Relationship to Primary FEP: This FEP concerns the construction of the repository changing the stress in the surrounding rock leading to the formation of a disturbed rock zone of fractures around the repository (WIPP). The FEP represents the effects of the disturbed zone aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.1.02.00.00 (Excavation/construction), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), or FEP 2.2.06.01.00

(Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.1.11.07.00 (WF, EBS), 2.2.01.01.00 (NFE, UZ), 2.2.03.02.00 (UZ, SZ), 2.1.07.01.00 (WP, WF, DE, WF, EBS), 2.1.07.02.00 (DE, EBS), 2.2.01.03.00 (NFE), 2.2.06.01.00 (NFE, DE), 2.2.10.04.00 (NFE, UZ)

Secondary FEPs:

2.2.01.02.01 Hydraulic conductivity change (host rock disturbed zone)
2.2.01.02.02 Water flow at the bentonite-host rock interface
2.2.01.02.03 Properties of near-field rock (host rock disturbed zone)
2.2.01.02.04 Stress changes of conductivity

Screening Decision and Basis: Excluded - Low consequence (TM effects)
Excluded - Low Probability (THC and backfill effects)

Screening Argument: There is no backfill in the current repository design so the probability of THC effects from backfill is less than one chance in 10,000 of occurring over 10,000 years and the FEP is excluded on the basis of low probability (not credible). If backfill becomes part of the reference repository design, then the influence of the backfill will have to be evaluated.

In *Calculation of Permeability Change due to Coupled Thermal-Hydraulic-Mechanical Effects* (CRWMS M&O 2000o), it is shown that the permanent thermal-mechanical effects on the fracture system are an order of magnitude higher in the regions above and below the drift and a factor of three higher in the regions to the side of the drift. The seepage model shows the trend that the seepage into the drift decreases with increasing fracture permeability since increasing the fracture permeability allows more water to flow around the drift. Since decreasing the seepage into the drift will result in slower radionuclide release from the drift, permanent thermal-mechanical effects have a beneficial effect and may reduce expected annual dose. The thermal-mechanical effects on seepage part of the FEP is therefore excluded on the basis of low consequence to expected annual dose.

Sensitivity studies performed in *Radionuclide Transport Models Under Ambient Conditions* (CRWMS M&O 2000x, Section 6.6.1 and 6.6.2) show that the transport of radionuclides through the Topopah Spring host rock units are very quick when compared with transport through the Calico Hills. The transport of the non-sorbing Technecium-99 will take approximately one year to reach the base of the Topopah Spring unit while the highly sorbing Plutonium-239 will take approximately 300 years to travel through the TSw geologic unit. The transport of the non-sorbing Technecium-99 will take several hundred years to travel through the Calico Hills unit while the highly sorbing Plutonium-239 will take over 100,000 years to travel through the Calico Hills geologic unit. Permanent thermal-mechanical effects on vertical fractures should not extend more than a few drift diameters around the emplacement drifts so any change in total transport time as a result of permanent changes to the fracture system will be small compared with the total unsaturated zone transport time and will not result in a change in expected annual dose. Therefore, permanent thermal-mechanical effects on radionuclide transport can be excluded on the basis of low consequence to expected annual dose.

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

IRSR-Issues: TEF2, ENFE1

Treatment of Secondary FEPs: 2.2.01.02.01 Hydraulic conductivity change (host rock disturbed zone)

Relationship to Primary FEP: This FEP concerns the effects of excavation and backfilling on the excavation/disturbed zone (SKI/SKB). This FEP corresponds to the rock fracturing as well as the effect of backfill aspects of the primary FEP. Another primary FEP that this FEP could have been mapped to was FEP 2.2.01.01.00 (Excavation and construction-related changes in the

adjacent host rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.02.02 Water flow at the bentonite-host rock interface
Relationship to Primary FEP: This FEP pertains to the water flow at the interface of the excavation/disturbed zone and the bentonite (NAGRA). This FEP consists of general flow issues in the material surrounding the waste package that are pertinent to the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock) and FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), but placement under this primary FEP is appropriate.
Screening and Disposition: There is no bentonite backfill in the current repository design so this secondary FEP is not credible and excluded on the basis of low probability.

2.2.01.02.03 Properties of near-field rock (host rock disturbed zone)
Relationship to Primary FEP: This FEP refers to the time varying hydrologic, mineral, mechanical, thermal, and gas transport properties in the near-field rock which can affect the engineered barriers and radionuclide transport (SKI). This FEP pertains to the same near-field rock property issues addressed in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.07.00 (Thermally-induced stress changes in waste and EBS), FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock), FEP 2.2.03.02.00 (Rock properties of host rock and other units), FEP 2.1.07.01.00 (Rockfall [large block]), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), or FEP 2.2.10.04.00 (Thermo-mechanical alteration of fractures near repository), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.01.02.04 Stress changes of conductivity
Relationship to Primary FEP: This FEP concerns the coupled thermal-hydrologic-mechanical processes which can alter hydrologic processes (SKI/SKB). This FEP pertains to the same

near-field rock property issues addressed in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.07.00 (Thermally-induced stress changes in waste and EBS), FEP 2.2.01.01.00 (Excavation and construction-related changes in the adjacent host rock), FEP 2.2.03.02.00 (Rock properties of host rock and other units), FEP 2.1.07.02.00 (Mechanical degradation or collapse of drift), FEP 2.2.01.03.00 (Changes in fluid saturations in the excavation disturbed zone), FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), or FEP 2.2.10.04.00 (Thermo-mechanical alteration of fractures near repository), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.1.08.10.00 (NFE, WF), 2.1.08.11.00 (NFE, EBS), 2.1.11.09.00 (WF, NFE, EBS), 2.2.10.10.00 (NFE, UZ), 2.2.07.10.00 (NFE, UZ), 2.2.07.11.00 (NFE, UZ), 2.1.08.03.00 (NFE), 2.2.10.12.00 (NFE)

Secondary FEPs: 2.2.01.03.01 Gas transport/dissolution (in the EDZ)

Screening Decision and Basis: Excluded - Low consequence
Excluded - Low probability (secondary FEP not relevant to YMP)

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 the waste cools 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 to expected annual dose.

The secondary FEP is based on a saturated zone repository. The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability. These non-Yucca Mountain, site-specific secondary FEPs were retained in the database for completeness.

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

IRSR-Issues: TEF2

Treatment of Secondary FEPs: 2.2.01.03.01 Gas transport/dissolution (in the EDZ)

Relationship to Primary FEP: This FEP concerns gas in the excavation/disturbed zone that is trapped at repository closure being able to move freely in the fractures, dissolve in the pore water, or escape to the transmissive elements of the low permeability rocks (NAGRA). This FEP is relevant to the fluid flow aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), FEP 2.1.08.10.00 (Desaturation/dewatering of the repository), and FEP 2.1.08.11.00 (Resaturation of repository), but placement under this primary FEP is appropriate.

Screening and Disposition: This secondary FEP is relevant for a repository located below the water table. This FEP was introduced by the Swiss organization NAGRA. NAGRA has been investigating a saturated zone (McCombie and Thury 1991). The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

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.

Related Primary FEPs: 2.2.01.01.00 (NFE, UZ), 2.2.01.02.00 (NFE), 2.2.10.04.00 (NFE, UZ), 2.2.10.05.00 (NFE, UZ), 1.2.02.01.00 (NFE, UZ, SZ, DE, Tec), 1.2.02.02.00 (UZ, SZ, DE, Tec), 1.2.03.01.00 (UZ, SZ, DE, Tec), 2.2.06.02.00 (UZ, SZ, DE, Tec), 2.2.06.03.00 (UZ, SZ, DE, Tec)

Secondary FEPs:

2.2.06.01.01	Stress-produced porosity changes
2.2.06.01.02	Stress-produced permeability changes
2.2.06.01.03	Stress-produced permeability changes
2.2.06.01.04	Regional stress regime
2.2.06.01.05	Regional stress regime
2.2.06.01.06	Regional stress regime
2.2.06.01.07	Stress field (in geosphere)
2.2.06.01.08	Changes in the stress field
2.2.06.01.09	Changes in regional stress
2.2.06.01.10	Stress changes - hydrogeological effects

Screening Decision: Excluded - Low consequence
Excluded - Low probability (one secondary FEP not relevant to YMP)

Screening Argument: This FEP deals with stresses due to TM, tectonic, and seismic effects. Tectonic and seismic effects are disruptive events issues and will not be discussed here.

Thermal-mechanical effects can affect flow around the drifts by changing the fracture porosity and permeability fields. In *Calculation of Permeability Change due to Coupled Thermal-Hydraulic-Mechanical Effects* (CRWMS M&O 2000o), it is shown that the permanent thermal-mechanical effects on the fracture system are an order of magnitude higher in the regions above and below the drift and a factor of three higher in the regions to the side of the drift. The seepage model shows the trend that the seepage into the drift decreases with increasing fracture permeability since increasing the fracture permeability allows more water to flow around the drift. Since decreasing the seepage into the drift will result in slower radionuclide release from the drift (for which no credit is taken in TSPA), permanent thermal-mechanical effects on seepage into the drift can be excluded on the basis of low consequence to expected annual dose.

Sensitivity studies performed in *Radionuclide Transport Models Under Ambient Conditions* (CRWMS M&O 2000x, Section 6.6.1 and 6.6.2) show that the transport of radionuclides through the Topopah Spring host rock units are very quick when compared with transport through the Calico Hills. The transport of the non-sorbing Technecium-99 will take approximately one year to reach the base of the Topopah Spring unit while the highly sorbing Plutonium-239 will take approximately 300 years to travel through the TSw geologic unit. The transport of the non-sorbing Technecium-99 will take several hundred years to travel through the Calico Hills unit while the highly sorbing Plutonium-239 will take over 100,000 years to travel through the Calico Hills geologic unit. Permanent thermal-mechanical effects on vertical fractures should not extend more than a few drift diameters around the emplacement drifts so any change in total transport time as a result of permanent changes to the fracture system will be insignificant compared with the total unsaturated zone transport time and will not result in a change in expected annual dose. Therefore, permanent thermal-mechanical effects have a beneficial effect and may reduce expected annual dose. Consequently, the thermal-mechanical effects on radionuclide transport part of the FEP is excluded on the basis of low consequence to expected annual dose

One secondary FEP is based on the WIPP repository, which is located in a bedded salt deposit, and the concern about salt creep. The potential Yucca Mountain repository is not located in a salt deposit so this secondary FEP is not credible and is excluded on the basis of low probability. This non-Yucca Mountain, site-specific secondary FEPs was retained in the database for completeness.

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: TEF2, RDTME3

Treatment of Secondary FEPs: 2.2.06.01.01 Stress-produced porosity changes

Relationship to Primary FEP: This FEP refers to tectonic and seismic events altering porosity throughout the repository (YMP). This FEP is relevant to the tectonic or seismic porosity change issues that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.2.02.02.00 (Faulting), FEP 1.2.03.01.00 (Seismic activity). FEP 2.2.06.02.00 (Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), or FEP 2.2.06.03.00 (Changes in stress [due to seismic or tectonic effects] alter perched water zones), but placement under this primary FEP is appropriate.

Screening and Disposition: Seismic and tectonic issues are disruptive events issues and are not discussed here.

2.2.06.01.02 Stress-produced permeability changes

Relationship to Primary FEP: This FEP refers to tectonic and seismic events altering permeability throughout the repository (YMP). This FEP is relevant to the tectonic or seismic permeability change issues that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.2.02.02.00 (Faulting), FEP 1.2.03.01.00 (Seismic activity). FEP 2.2.06.02.00 (Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), or FEP 2.2.06.03.00 (Changes in stress [due to seismic or tectonic effects] alter perched water zones), but placement under this primary FEP is appropriate.

Screening and Disposition: Seismic and tectonic issues are disruptive events issues and are not discussed here.

2.2.06.01.03 Stress-produced permeability changes

Relationship to Primary FEP: This FEP refers to tectonic and seismic events altering permeability throughout the repository (YMP). This FEP is relevant to the tectonic permeability change issues that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.2.02.02.00 (Faulting), FEP 1.2.03.01.00 (Seismic activity), FEP 2.2.06.02.00

(Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), or FEP 2.2.06.03.00 (Changes in stress [due to seismic or tectonic effects] alter perched water zones), but placement under this primary FEP is appropriate.
Screening and Disposition: Seismic and tectonic issues are disruptive events issues and are not discussed here.

2.2.06.01.04 Regional stress regime
Relationship to Primary FEP: This FEP pertains to estimations of the orientation of the regional stress regime (NAGRA). This FEP concerns the initial stress state of the system which is needed to understand the thermal, seismic, and tectonic permeability and porosity change aspects of the primary FEP. Another primary FEP that this FEP could have been mapped to is FEP 2.2.06.02.00 (Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.06.01.05 Regional stress regime
Relationship to Primary FEP: This FEP pertains to estimations of the orientation of the regional stress regime (NAGRA). This FEP concerns the initial stress state of the system. This is needed to understand how the stress changes which is the driving force of the primary FEP. Another primary FEPs that this FEP could have been mapped to is FEP 2.2.06.02.00 (Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.06.01.06 Regional stress regime
Relationship to Primary FEP: This FEP pertains to estimations of the orientation of the regional stress regime (NAGRA). This FEP concerns the initial stress state of the system. This is needed to understand how the stress changes which is the driving force of the primary FEP. Another primary FEPs that this FEP could have been mapped to is FEP 2.2.06.02.00 (Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.06.01.07 Stress field (in geosphere)
Relationship to Primary FEP: This FEP refers to the thermally perturbed stress field and how it may affect the hydrologic properties of the fractures and, consequently, groundwater flow (SKI). This FEP concerns the thermal-mechanical affects on porosity and permeability aspects of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.10.04.00 (Thermo-mechanical alteration of fractures near repository) and FEP 2.2.10.05.00 (Thermo-mechanical alteration of rocks above and below the repository), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.06.01.08 Changes in the stress field
Relationship to Primary FEP: This FEP refers to salt creep changing the stress field, compacting the waste and containers, and consolidation of the system (WIPP). This FEP deals with the same general mechanical changes to the permeability system as contained in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.10.04.00 (Thermo-mechanical alteration of fractures near repository) and FEP 2.2.10.05.00 (Thermo-mechanical alteration of rocks above and below the repository), but placement under this primary FEP is appropriate.
Screening and Disposition: This secondary FEP is not credible since it refers to a repository in a deforming mass of salt. The proposed Yucca Mountain repository is not located in a mass of salt. Consequently, this FEP is excluded on the basis of low probability.

2.2.06.01.09 Changes in regional stress
Relationship to Primary FEP: This FEP deals with changes in regional stress due to tectonic events (WIPP). This FEP deals with the same tectonic effects on flow properties in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.2.02.02.00 (Faulting), FEP 1.2.03.01.00 (Seismic activity), FEP 2.2.06.02.00 (Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), or FEP 2.2.06.03.00 (Changes in stress [due to seismic or tectonic effects] alter perched water zones), but placement under this primary FEP is appropriate.

Screening and Disposition: This FEP deals with tectonic issues and is not discussed here.

2.2.06.01.10 Stress changes - hydrogeological effects
Relationship to Primary FEP: This FEP refers to seismic events causing changes in stress in the rock. This change in stress can change the aperture of the fractures resulting in altered hydrologic flow properties (NAGRA). This FEP deals with the same seismic effects on flow properties in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.2.02.02.00 (Faulting), FEP 1.2.03.01.00 (Seismic activity), FEP 2.2.06.02.00 (Changes in stress [due to thermal, seismic, or tectonic effects] produce change in permeability of faults), or FEP 2.2.06.03.00 (Changes in stress [due to seismic or tectonic effects] alter perched water zones), but placement under this primary FEP is appropriate.
Screening and Disposition: Seismic issues are disruptive events issues and are not discussed here.

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.

Related Primary FEPs: 2.2.10.10.00 (NFE, UZ), 2.2.07.11.00 (NFE, UZ), 2.2.10.01.00 (UZ, SZ), 2.1.11.02.00 (NFE)

Secondary FEPs:

2.2.07.10.01	Condensation cap forms above repository
2.2.07.10.02	Formation of condensate over individual containers
2.2.07.10.03	Formation of condensate over individual panels
2.2.07.10.04	Formation of condensate over the entire repository
2.2.07.10.05	Shedding of condensation cap over one drift to another drift
2.2.07.10.06	Vault geometry

Screening Decision and Basis: Included

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 2000p), *Multiscale Thermohydrologic Model* (CRWMS M&O 2000q), and *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r).

The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA. The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA.

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 as documented in the AMR *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux* (CRWMS M&O 2000t, Figures 43 and 44) meaning that there was always a large part of the pillar available for condensate to drain. Because of this, water is not expected to condense over one drift, be redirected and shed over another drift.

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 as documented in the AMR *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000p, 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 Spring 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.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 2.2.07.10.01 Condensation cap forms above repository

Relationship to Primary FEP: This FEP concerns water accumulating above the repository during the thermal period as a result of evaporation and condensation processes (YMP). This FEP is a subset of the general condensate zone issues described by the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.10.10.00 (Two-phase bouyant flow/heat pipes) and FEP 2.2.07.11.00 (Return flow from condensation cap/resaturation of dry-out zone), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.07.10.02 Formation of condensate over individual containers

Relationship to Primary FEP: This FEP concerns the accumulation of water above an individual waste package during the thermal period as a result of evaporation and condensation processes (YMP). This FEP is a subset of the general condensate zone issues described by the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.10.10.00 (Two-phase bouyant flow / heat pipes) and FEP 2.2.07.11.00 (Return flow from condensation cap / resaturation of dry-out zone), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.07.10.03 Formation of condensate over individual panels

Relationship to Primary FEP: This FEP concerns the accumulation of water above individual drifts (panels) during the thermal period as a result of evaporation and condensation processes (YMP).

This FEP is a subset of the general condensate zone issues described by the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.10.10.00 (Two-phase bouyant flow / heat pipes) and FEP 2.2.07.11.00 (Return flow from condensation cap / resaturation of dry-out zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.07.10.04 Formation of condensate over the entire repository
Relationship to Primary FEP: This FEP concerns the accumulation of water above the repository during the thermal period as a result of evaporation and condensation processes (YMP). This FEP is a subset of the general condensate zone issues described by the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.02.00 (Nonuniform heat distribution / edge effects in repository), FEP 2.2.10.10.00 (Two-phase bouyant flow / heat pipes), and FEP 2.2.07.11.00 (Return flow from condensation cap / resaturation of dry-out zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.07.10.05 Shedding of condensation cap over one drift to another drift
Relationship to Primary FEP: This FEP refers to condensate forming over one drift and being redirected or shed to another drift (YMP). This FEP is a subset of the general condensate zone issues described by the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.02.00 (Nonuniform heat distribution / edge effects in repository), FEP 2.2.10.10.00 (Two-phase bouyant flow / heat pipes) and FEP 2.2.07.11.00 (Return flow from condensation cap / resaturation of dry-out zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.07.10.06 Vault geometry
Relationship to Primary FEP: This FEP pertains to the condensation related issues with respect to the three-dimensional geometry of the repository (AECL). This FEP is a subset of the general condensate zone issues described by the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.11.02.00 (Nonuniform heat distribution / edge effects in repository), FEP 2.2.10.10.00 (Two-phase bouyant flow/heat pipes), and FEP 2.2.07.11.00 (Return flow from

condensation cap/resaturation of dry-out zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

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.

Related Primary FEPs: 2.2.07.10.00 (NFE, UZ), 2.1.08.11.00 (NFE, EBS), 2.2.01.03.00 (NFE), 2.2.07.09.00 (UZ)

Secondary FEPs:

2.2.07.11.01	Auto-catalytic drainage of locally saturated flow thru condensation cap
2.2.07.11.02	Resaturation, near-field rock
2.2.07.11.03	Return of condensate to same panel
2.2.07.11.04	Resaturation of dry-out zone is affected by vapor flow
2.2.07.11.05	Resaturation of dry-out zone is effected by liquid under capillary forces
2.2.07.11.06	Unsaturated flow plume returns flow from the condensation cap

Screening Decision and Basis: Included (all but one secondary FEP)
Excluded - Low probability (one secondary FEPs not relevant to YMP)

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

One secondary FEP is based on a saturated zone repository. The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability. This non-Yucca Mountain, site-specific secondary FEPs was retained in the database for completeness.

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 2000p, 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 2000r).

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 (CRWMS M&O 2000q). 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.

The THC model generates incoming gas and seepage water composition that is fed into the in-drift geochemistry model, which, in turn, feeds the waste package degradation and the waste form degradation/EBS transport models in TSPA. The MSTHM generates waste package surface temperatures, invert temperatures, invert relative humidities, invert evaporation rates, invert liquid saturations, and invert fluxes that are used in the TSPA model. These data feed the seepage, the in-drift chemistry, the waste package degradation and the waste form degradation/EBS transport model in TSPA.

IRSR-Issues:

TEF2, TEF3.

Treatment of Secondary FEPs: 2.2.07.11.01 Auto-catalytic drainage of locally saturated flow thru condensation cap

Relationship to Primary FEP: This FEP refers to episodic flow in fractures penetrating the condensation cap which could eventually lead to water contacting the waste and flowing through the repository (YMP). This FEP is a specific subset of the re-saturation of the repository aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to is FEP 2.1.08.11.00 (Resaturation of repository) and FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.07.11.02 Resaturation, near-field rock

Relationship to Primary FEP: This FEP concerns water returning to the repository located in the saturated zone after closure. The flow paths and the chemistry are expected to change (SKI). This FEP contains both the re-saturation and water chemistry attributes of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.11.00 (Resaturation of repository) and FEP 2.2.07.09.00 (Matrix imbibition in the unsaturated zone), but placement under this primary FEP is appropriate.

Screening and Disposition: This FEP applies to a repository that is located below the water table. This FEP was introduced by the Swedish organization SKI. SKI has been investigating a saturated zone repository (Bäckblom and Ahlström 1991). The potential Yucca Mountain repository is located in the unsaturated zone so this secondary FEP is not credible and is excluded on the basis of low probability.

2.2.07.11.03 Return of condensate to same panel

Relationship to Primary FEP: This FEP pertains to condensate returning to the same panel through fractures or matrix as the host rock cools in the post-thermal period (YMP). This FEP contains the re-saturation attribute of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.11.00 (Resaturation of repository), FEP 2.2.07.09.00 (Matrix imbibition in the unsaturated zone), and FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.07.11.04 Resaturation of dry-out zone is affected by vapor flow

Relationship to Primary FEP: This FEP refers to the resaturation of the dry-out zone from water transported as vapor phase from the water table or the host rock (YMP). This FEP concerns the re-saturation attribute of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.11.00 (Resaturation of repository), FEP 2.2.07.09.00 (Matrix imbibition in the unsaturated zone), or FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.07.11.05 Resaturation of dry-out zone is affected by liquid under capillary forces

Relationship to Primary FEP: This FEP refers to the resaturation of the dry-out zone from water transported by capillary forces (YMP). This FEP contains the re-saturation attribute of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.11.00 (Resaturation of repository), FEP 2.2.07.09.00 (Matrix imbibition in the unsaturated zone), and FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.07.11.06 Unsaturated flow plume returns flow from the condensation cap

Relationship to Primary FEP: This FEP pertains to the formation of a non-uniform condensation cap that, as the rock cools, returns to the rocks around the drift and the drift in a non-uniform manner (YMP). This FEP contains the re-saturation attribute of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.08.11.00 (Resaturation of repository), FEP 2.2.07.09.00 (Matrix imbibition in the unsaturated zone), and FEP 2.2.07.10.00 (Condensation zone forms around drifts), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.2.08.01.00 (UZ, SZ), 2.2.08.07.00 (UZ, SZ), 2.2.08.09.00 (UZ, SZ, Bio), 2.2.08.10.00 (UZ, SZ), 2.2.10.06.00 (NFE, UZ, SZ), 2.1.09.12.00 (NFE, WF, EBS)

Secondary FEPs:

2.2.08.03.01	Far-field transport: Changes in groundwater chemistry and flow direction
2.2.08.03.02	Effects of dissolution (in geosphere)
2.2.08.03.03	Rock property changes (in geosphere)
2.2.08.03.04	Hydraulic properties-evolution
2.2.08.03.05	Dissolution of fracture fillings/precipitations (in geosphere)
2.2.08.03.06	Weathering of flow paths (in geosphere)
2.2.08.03.07	Fracture mineralization and weathering (in geosphere)
2.2.08.03.08	Alteration/weathering of flow paths
2.2.08.03.09	Precipitation and dissolution (release/migration factors)
2.2.08.03.10	Chemical precipitation (release/migration factors)
2.2.08.03.11	Dissolution, precipitation and crystallization (release/migration factors)
2.2.08.03.12	Kinetics of precipitation and dissolution (release/migration factors)
2.2.08.03.13	Speciation (contaminant speciation and solubility)
2.2.08.03.14	Speciation (geosphere) (contaminant speciation and solubility)
2.2.08.03.15	Recrystallization (contaminant speciation and solubility)
2.2.08.03.16	Speciation (contaminant speciation and solubility)
2.2.08.03.17	Kinetics of speciation (contaminant speciation and solubility)
2.2.08.03.18	Groundwater chemistry (sorption/desorption processes)

Screening Decision and Basis: Include (changes of fracture porosity in THC model)
Excluded - Low consequence (changes of fracture porosity in radionuclide transport model).

Screening Argument: Geochemical interactions in geosphere and effects on radionuclide transport were excluded from the TSPA. The change in fracture porosity due to coupled THC effects was calculated in the AMR *Drift-Scale Coupled Processes (DST and THC Seepage) Models* and found to be less than 0.5% (CRWMS M&O 2000r, Section 6.3.5.2). Because the fractures in the unsaturated zone are nearly dry, a change in fracture porosity of 0.5% will result in negligible changes into the unsaturated zone flow field and consequently, insignificant changes to the unsaturated zone radionuclide transport calculations. Since the fracture porosity changes do not change the transport of radionuclide, this part of the FEP can be excluded on the basis of low consequence to expected annual dose.

Other effects (radionuclide solubility, sorption, and colloidal) on radionuclide transport that are part of this FEP are unsaturated zone flow and transport issues and are not discussed here.

TSPA Disposition: The process 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 2000r, 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.

Component of FEP 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 2000r) indicate that fracture properties remain nearly constant in the reactive transport model results.

IRSR-Issues: TEF2, ENFE1

Treatment of Secondary FEPs: 2.2.08.03.01 Far-field transport: Changes in groundwater chemistry and flow direction

Relationship to Primary FEP: This FEP refers to changing groundwater flow chemistry and flow direction due to climate change. This could affect the sorption and desorption processes in the far-field rocks (UK-HMIP). This FEP concerns the changing chemistry effect on radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP. The process-level THC model contains transient infiltration rate boundary conditions representative of future climate changes. This FEP concerns sorption and desorption processes which are UZF&T issues and are not discussed here.

2.2.08.03.02 Effects of dissolution (in geosphere)

Relationship to Primary FEP: This FEP refers to natural changes in groundwater chemistry and how this could affect chemical retardation and the stability of colloids (WIPP). This FEP concerns the evolving chemistry effect on radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.08.03.03 Rock property changes (in geosphere)

Relationship to Primary FEP: This FEP concerns the changing of the porosity and permeability may result in an alteration of the groundwater flow-field and radionuclide transport in the far-field. (UK-HMIP). This FEP concerns the evolving groundwater chemistry effect on radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in

waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry / composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.04 Hydraulic properties-evolution
Relationship to Primary FEP: This FEP concerns precipitation and dissolution of material affecting the groundwater flow by plugging or opening pores or fractures (AECL). This FEP concerns the changing chemistry effect on water flow aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.05 Dissolution of fracture fillings/precipitations (in geosphere)
Relationship to Primary FEP: This FEP refers to the dissolution of fracture fillings by groundwater by some thermal or chemical process (SKI/SKB). This FEP concerns the groundwater chemistry induced effects on water flow aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.06 Weathering of flow paths (in geosphere)
Relationship to Primary FEP: This FEP refers to chemical reactions between the groundwater, rock, and fracture materials. These reactions can result in weathering of the rock material and healing of now or existing fractures (SKI/SKB). This FEP concerns

the groundwater chemistry induced effects on water flow and transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP. Primary FEP only considers geochemical interactions that may result from the evolution of the disposal system. The fracture continuum contains initial mineral volume fractions that change with time according to reaction processes.

2.2.08.03.07 Fracture mineralization and weathering (in geosphere)
Relationship to Primary FEP: This FEP has no description but the title is similar to the dissolution, precipitation and weathering part of the primary FEP (NEA). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP. Primary FEP only considers geochemical interactions that may result from the evolution of the disposal system. The fracture continuum contains initial mineral volume fractions that change with time according to reaction processes.

2.2.08.03.08 Alteration/weathering of flow paths
Relationship to Primary FEP: This FEP refers to chemical reactions between the groundwater, rock, and fracture materials. These reactions can result in weathering of the rock material and healing of now or existing fractures (SKI). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/

composition in UZ and SZ), and FEP 2.2.10.06.00 (Thermo-chemical alteration [solubility, speciation, phase changes, precipitation/dissolution]), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP. Primary FEP only considers geochemical interactions that may result from the evolution of the disposal system. The fracture continuum contains initial mineral volume fractions that change with time according to reaction processes.

2.2.08.03.09 Precipitation and dissolution (release/migration factors)
Relationship to Primary FEP: This FEP pertains to the temperature gradients, chemistry, flow rates, mineralogy, and the presence of microbes resulting in variations in precipitation and dissolution at different locations along the flow paths (AECL). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.10 Chemical precipitation (release/migration factors)
Relationship to Primary FEP: This FEP refers to chemical precipitation affecting the mobility of radionuclides in the environment (AECL). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.11 Dissolution, precipitation and crystallization (release/migration factors)

Relationship to Primary FEP: This FEP has no description but the title is similar to the dissolution and precipitation part of the primary FEP (NEA). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.08.03.12 Kinetics of precipitation and dissolution (release/migration factors)

Relationship to Primary FEP: This FEP refers to variations in the kinetic rates of reactions for precipitation and dissolution reactions (WIPP). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.08.03.13 Speciation (contaminant speciation and solubility)

Relationship to Primary FEP: This FEP involves chemical speciation that can affect dissolution and precipitation as the repository heats and then cools (AECL). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.01.00 (Groundwater chemistry/ composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in

UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.14 Speciation (geosphere) (contaminant speciation and solubility)
Relationship to Primary FEP: This FEP concerns speciation of contaminants controlled by differing inorganic and organic components affecting mobility and sorption (AECL). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.15 Recrystallization (contaminant speciation and solubility)
Relationship to Primary FEP: This FEP concerns precipitation, dissolution, and recrystallization effects on solubility and water chemistry (SKI/SKB). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.16 Speciation (contaminant speciation and solubility)
Relationship to Primary FEP: This FEP deals with radionuclide transport behavior as a function of the chemical form of the contaminant (NAGRA). This FEP concerns the groundwater chemistry induced effect on radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in

UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.17 Kinetics of speciation (contaminant speciation and solubility)
Relationship to Primary FEP: This FEP refers to the reaction kinetics in aqueous systems. Specifically, this FEP deals with specific reactions that occur rapidly and are accurately described by thermodynamic equilibrium models that neglect consideration of reaction kinetics. (WIPP). This FEP concerns the groundwater chemistry induced effect on radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.08.03.18 Groundwater chemistry (sorption/desorption processes)
Relationship to Primary FEP: This FEP concerns the groundwater chemistry being controlled by rock minerology, recharge conditions, residence time, temperature, and EBS composition. (NAGRA). This FEP concerns the groundwater chemistry induced effects on water flow and radionuclide transport aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.08.01.00 (Groundwater chemistry/composition in UZ and SZ), FEP 2.2.08.07.00 (Radionuclide solubility limits in the geosphere), FEP 2.2.08.09.00 (Sorption in UZ and SZ), and FEP 2.2.08.10.00 (Colloidal transport in geosphere), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

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.

Related Primary FEPs: 2.2.07.11.00 (NFE, UZ), 2.2.08.12.00 (WF)

Secondary FEPs: None

Screening Decision and Basis: Included (THC model)
Excluded - Low consequence (TH model)

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.

In the THC model, the maximum change in fracture porosity due to precipitation found anywhere in the model was less than 0.5% (CRWMS M&O 2000r, Section 6.3.5.2). This change was not included in the MSTHM model. Since the changes were small, they would not have had a significant effect on the TH results from that model and hence, not have a significant effect on expected annual dose calculations. Consequently, redissolution of precipitates was excluded from the MSTHM on the basis of low consequence to expected annual dose.

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 2000r, 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.

IRSR-Issues: TEF2, ENFE1

Treatment of Secondary FEPs: No secondary FEPs

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.

Related Primary FEPs: 1.2.02.01.00 (NFE, UZ, SZ, DE, Tec), 2.1.11.02.00 (NFE), 2.2.01.02.00 (NFE), 2.2.06.01.00 (NFE, DE), 2.1.11.07.00 (WF, EBS)

Secondary FEPs:

2.2.10.04.01	Thermal expansion closes most fractures close to repository
2.2.10.04.02	Thermally-induced fracturing around containers creates a capillary barrier
2.2.10.04.03	Host rock fracture aperture changes

Screening Decision: Excluded - 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.

The seepage calculations presented in *Seepage Model for PA including Drift Collapse* (CRWMS M&O 2000z, Tables 4 through 8) show that the quantity of seepage that enters the drift is a strong function of fracture permeability; with more seepage entering the drift when the average fracture permeability is lower than when the average fracture permeability was higher. In *Calculation of Permeability Change due to Coupled Thermal-Hydraulic-Mechanical Effects* (CRWMS M&O 2000o), a calculation is presented showing that the permanent thermal-mechanical effects on the fracture system are an order of magnitude higher in the regions above and below the drift and a factor of three higher in the regions to the side of the drift. Since decreasing the seepage into the drift will result in slower radionuclide release from the drift, this FEP has a beneficial effect for which no credit is taken in TSPA. Permanent thermal-mechanical effects are excluded on a low consequence basis to expected annual dose.

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

IRSR-Issues: TEF2, RDTME3

Treatment of Secondary FEPs: 2.2.10.04.01 Thermal expansion closes most fractures close to repository

Relationship to Primary FEP: This FEP refers to the closing of fractures near the repository during repository heating. The water can be diverted into fractures with larger apertures (YMP). This FEP concerns the thermal-mechanical effects due to heating aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock) and FEP 2.1.11.07.00 (Thermally-induced stress changes in waste and EBS), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.10.04.02 Thermally-induced fracturing around containers creates a capillary barrier

Relationship to Primary FEP: This FEP concerns the fractures around the drift causing a capillary barrier to moisture movement between rock matrix blocks. This can cause film flow on vertically emplaced waste packages resulting in accelerated corrosion and waste dissolution. (YMP) This FEP concerns the same thermal-mechanical effects on fracture flow that are in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock) and FEP 2.1.11.07.00 (Thermally-induced stress changes in waste and EBS), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.10.04.03 Host rock fracture aperture changes

Relationship to Primary FEP: This FEP does not have a description (NEA) but it refers to the same processes as does the primary FEP. This FEP concerns the same thermal-mechanical

effects on fracture flow that are in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock) and FEP 2.1.11.07.00 (Thermally-induced stress changes in waste and EBS), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.2.10.04.00 (NFE, UZ), 2.2.06.01.00 (NFE, DE)

Secondary FEPs:

2.2.10.05.01 Thermal expansion of rocks below repository opens fractures in Paint Brush unwelded
2.2.10.05.02 Thermo-mechanical alteration of surface infiltration

Screening Decision: Excluded - Low Consequence

Screening Argument: Currently, the Paintbrush Tuff non-welded (PTn) unit is thought to be relatively intact, diverting infiltration or allowing localized penetration of episodic flow events. The PTn will undergo thermal expansion during heating. This thermal expansion of the rock will result in the expansion of the volume of the rock or compressive stresses. Since the unit is constrained laterally, the thermal expansion will result in compressive stresses in the rock. Consequently, the related tension physically does not exist in the PTn above repository. Because of this, tension fractures will not form in the PTn.

When the mountain heats up, the host rock expands causing vertical fractures in and around the repository to close, reducing the fracture permeability. Horizontal fractures above and below the drift will undergo shear, increasing the fracture permeability, due to the differing thermal expansion resulting from the temperature gradients. The horizontal fractures at the edge of the repository will experience the greatest amount of shear since rock at the edges will not be constrained like the rock near the center of the repository. On cooling, the vertical fractures will reversibly return to their initial state but the horizontal fractures will likely retain some of the displacement due to non-linear and/or inelastic shear deformation. A change in horizontal permeability at the edge of the repository is not expected to change expected annual dose since the increase in fracture permeability would allow water, that might otherwise have seeped into the drift, to be diverted away from the drifts and around the edges of the repository. Since decreasing the seepage into the drift will result in slower radionuclide release from the drift, this FEP has a beneficial effect for which no credit is taken in TSPA. Permanent thermal-mechanical effects are excluded on a low consequence basis to expected annual dose.

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

IRSR-Issues: TEF2, RDTME3

Treatment of Secondary FEPs: 2.2.10.05.01 Thermal expansion of rocks below repository opens fractures in Paint Brush unwelded

Relationship to Primary FEP: This FEP concerns the possible formation of fractures in the PTn driven by the thermal expansion of the repository rock. These fractures could cause local zones of increased flux through the units below (YMP). This FEP concerns the same mountain-scale thermal-mechanical effects that are in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.10.04.00 (Thermo-mechanical alteration of fractures near repository) and FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.10.05.02 Thermo-mechanical alteration of surface infiltration

Relationship to Primary FEP: This FEP refers to the production of tension fracturing in rocks at the repository which can reach the surface and affect the location and amount of infiltration (YMP). This FEP concerns the same mountain-scale thermal-mechanical effects that are in the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.10.04.00

(Thermo-mechanical alteration of fractures near repository) and FEP 2.2.06.01.00 (Changes in stress [due to thermal, seismic, or tectonic effects] change porosity and permeability of rock), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.1.09.01.00 (NFE, WF, EBS), 2.1.09.12.00 (NFE, WF, EBS), 2.2.08.03.00 (NFE, UZ, SZ), 2.2.10.07.00 (UZ, SZ), 2.2.10.08.00 (SZ)

Secondary FEPs:

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

Screening Decision and Basis: Included (in-drift geochemical model that uses water chemistry and gas-phase composition from the drift-scale THC model that includes thermal-chemical alteration)
Excluded - Low Consequence (effects in TH models)

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 2000s, Section 6.2 and 6.3).

This FEP also concerns precipitation of minerals that may selectively plug up small fractures. In the THC model, the maximum change in fracture porosity due to precipitation found anywhere in the model was less than 0.5% (CRWMS M&O 2000r, Section 6.3.5.2). Since the fracture porosity changes are so small, even if this precipitation selectively plugged small fractures, only a small fraction of fractures could be plugged. The active fracture conceptual flow model only specifies a certain fraction of fractures contain flowing water, the effect of the precipitation is even smaller. Since permanent THC effects have a minimal effect on the flow of water around the drift, it will not have a significant affect on expected annual dose. Consequently, plugging of small fractures can be excluded on the basis of low consequence to expected annual dose.

This FEP also is concerned with the possibility that silica phase minerals in the tuffs could undergo phase transition accompanied by a volume change and dewater at temperatures as low as 150 °C. The bin-averaged drift wall temperatures are presented in Figure 48 of the AMR *Multiscale Thermohydrologic Model* and show that these temperatures never reach 150 °C.

The zeolitized layers within the Calico hills contain the mineral clinoptilolite which has significant sorptive properties for some radionuclides. Upon heating to 90 to 100°C, this mineral can undergo a conversion to analcime, which has poor sorptive properties (CRWMS M&O 1998c, Page 7-20). The Calico Hills zeolitic units are not expected to be altered by high temperatures since the top of the Calico Hills never exceeded 70 °C (CRWMS M&O 2000p, Section 6.8.2.1) in any of the mountain-scale TH simulations documented in the AMR *Mountain-Scale Coupled Processes (TH) Models*.

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.

IRSR-Issues: TEF2, ENFE4

Treatment of Secondary FEPs: 2.2.10.06.01 Silica phase changes (accompanied by volume change) occur due to elevated temperature

Relationship to Primary FEP: This FEP refers to the certain minerals that can undergo a phase transition and dewater at relatively low temperatures (less than 150 °C). This phase transition can result in a large volume change (YMP). This FEP concerns the temperature driven chemistry effects on radionuclide transport that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), FEP 2.2.10.07.00 (Thermo-chemical alteration of the Calico Hills unit), and FEP 2.2.10.08.00 (Thermo-chemical alteration of the saturated zone), but placement under this primary FEP is appropriate.

Screening and Disposition: Maximum host rock temperatures in the drift-scale THC model remain well below 150°C at all times after waste emplacement. Therefore, this secondary FEP does not apply to the Yucca Mountain project.

2.2.10.06.02 Thermochemical change

Relationship to Primary FEP: This FEP concerns all temperature dependent effects on chemical equilibrium (SKI/SKB). This FEP concerns the temperature driven chemistry effects that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), FEP 2.2.10.07.00 (Thermo-chemical alteration of the Calico Hills unit), and FEP 2.2.10.08.00 (Thermo-chemical alteration of the saturated zone), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as primary FEP.

2.2.10.06.03 Alteration of rock properties because of 2-phase flow

Relationship to Primary FEP: This FEP concerns thermally driven two-phase flow that will produce altered phases (vitric units into clay and volume changes in zeolites) which can alter the host rock permeability (YMP). This FEP concerns the temperature driven chemistry effects that are part of the primary FEP. Other primary

FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), FEP 2.2.10.07.00 (Thermo-chemical alteration of the Calico Hills unit), and FEP 2.2.10.08.00 (Thermo-chemical alteration of the saturated zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.10.06.04 Heat-induced chemical reactions plug small fractures; flow is preferentially redirected to large fractures
Relationship to Primary FEP: This FEP concerns chemical precipitation plugging small fractures and this diverts flow into the larger fractures (YMP). This FEP concerns the temperature driven chemistry effects that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), FEP 2.2.10.07.00 (Thermo-chemical alteration of the Calico Hills unit), and FEP 2.2.10.08.00 (Thermo-chemical alteration of the saturated zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.10.06.05 Alteration of minerals to clays (in geosphere)
Relationship to Primary FEP: This FEP refers to the thermal alterations of zeolites and clays (YMP). This FEP concerns the temperature driven chemistry effects that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), FEP 2.2.10.07.00 (Thermo-chemical alteration of the Calico Hills unit), and FEP 2.2.10.08.00 (Thermo-chemical alteration of the saturated zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.10.06.06 Calcite precipitation in hot region produces fluids depleted in calcite which dissolve calcite below the repository

Relationship to Primary FEP: This FEP refers to thermally-induced calcite precipitation and dissolution (YMP). This FEP concerns the temperature driven chemistry effects that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), FEP 2.2.10.07.00 (Thermo-chemical alteration of the Calico Hills unit), and FEP2.2.10.08.00 (Thermo-chemical alteration of the saturated zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

2.2.10.06.07 Precipitates from dissolved constituents of tuff and repository materials form by evaporation during thermal period

Relationship to Primary FEP: This FEP pertains to minerals precipitating in fractures that could clog pores and divert flow into fractures (YMP). This FEP concerns the temperature driven chemistry effects that are part of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.1.09.12.00 (Rind [altered zone] formation in waste, EBS, and adjacent rock), FEP 2.2.08.03.00 (Geochemical interactions in geosphere [dissolution, precipitation, weathering] and effects on radionuclide transport), FEP 2.2.10.07.00 (Thermo-chemical alteration of the Calico Hills unit), and FEP 2.2.10.08.00 (Thermo-chemical alteration of the saturated zone), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as primary FEP.

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).

Related Primary FEPs: 2.2.07.10.00 (NFE, UZ), 2.1.11.09.00 (WF, EBS, NFE), 2.2.10.12.00 (NFE)

Secondary FEPs:

2.2.10.10.01 Heat pipe – evolving
2.2.10.10.02 Heat pipe – continuing
2.2.10.10.03 Heat pipe formation, 2-phase system

Screening Decision and Basis: Included (Heatpipes and changing THC effects in THC model)
Excluded - Low consequence (THC effects in TH models)

Screening Argument: Two-phase buoyant flow/heatpipes are included inherently in the TSPA as described in the TSPA disposition. THC effects on flow properties (fracture porosity) are included in the THC model. The maximum change in fracture porosity in the THC model was found to be a 0.5% change as documented in the AMR *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (CRWMS M&O 2000r, Section 6.3.5.2). This small change was not included in the MSTHM and is so small that it will not result in any consequential changes the TH results that were used in the TSPA. Therefore, the effects of THC driven fracture porosity changes on two-phase buoyant flow and heat pipes can be excluded from TSPA on the basis of low consequence to expected annual dose.

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 as documented in the AMR *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000p, 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 2000p, Figure 26). Consequently, evidence of the formation of two-phase buoyant flows is seen in the process-level models.

Since the thermal-hydrologic physics that were in the mountain scale TH model are the same as those implemented into the MSTHM as well as the THC model, these two models will also contain the two-phase zones seen in the mountain scale model.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 2.2.10.10.01 Heat pipe – evolving

Relationship to Primary FEP: This FEP concerns the evolution of a heat pipe as the region of rock around the repository dries out (YMP). This FEP deals with the initiation of the heat pipe component of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.07.10.00 (Condensation zone forms around drifts), FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), or FEP 2.2.10.12.00 (Geosphere dry-out due to waste heat), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.10.10.02 Heat pipe – continuing

Relationship to Primary FEP: This FEP concerns the continuation and eventual collapse of a heat-pipe as the heat generation rate drops (YMP). This FEP deals with the continuation of the heat pipe component of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.07.10.00 (Condensation zone forms around drifts), FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), or FEP 2.2.10.12.00 (Geosphere dry-out due to waste heat), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

2.2.10.10.03 Heat pipe formation, 2-phase system

Relationship to Primary FEP: This FEP concerns the formation of a heat pipe in the repository (YMP). This FEP deals with the initiation of the heat pipe aspect of the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.07.10.00 (Condensation zone forms around drifts), FEP 2.1.11.09.00 (Thermal effects on liquid or two-phase fluid flow in the waste and EBS), or FEP 2.2.10.12.00 (Geosphere dry-out due to waste heat), but placement under this primary FEP is appropriate.
Screening and Disposition: Same as Primary FEP.

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.

Related Primary FEPs: 2.1.08.03.00 (NFE), 2.2.10.10.00 (NFE, UZ), 2.2.01.03.00 (NFE)

Secondary FEPs: None

Screening Decision and Basis: Included

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 2000r) and in the TH mountain-scale process-level model in Figure 30 of *Mountain-Scale Coupled Processes (TH) Models* (CRWMS M&O 2000p). 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.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: No secondary FEPs

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.

Related Primary FEPs: 2.2.07.14.00 (SZ), 1.2.06.00.00 (UZ, SZ)

Secondary FEPs:

2.2.10.13.01	Density-driven groundwater flow (thermal)
2.2.10.13.02	Density-driven groundwater flows (temperature/ salinity differences)
2.2.10.13.03	Thermal buoyancy

Screening Decision and Basis: Included

Screening Argument: This FEP is included since the thermal gradient in the unsaturated zone has been implemented as an initial condition and the density of water is dependent upon temperature 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 are 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 (CRWMS M&O 2000q; CRWMS M&O 2000r; CRWMS M&O 2000p). 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 2000p, 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.

IRSR-Issues: TEF2, TEF3

Treatment of Secondary FEPs: 2.2.10.13.01 Density-driven groundwater flow (thermal)

Relationship to Primary FEP: This FEP pertains to thermal variations in groundwater density producing a driving force for ground water flow (NAGRA). This FEP is identical to the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 1.2.06.00.00 (Hydrothermal activity) and FEP 2.2.07.14.00 (Density effects on groundwater flow), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.10.13.02 Density-driven groundwater flows (temperature/ salinity differences)

Relationship to Primary FEP: This FEP pertains to thermal and salinity variations in groundwater density producing a driving force for ground water flow (NAGRA). This FEP deals with the same density driven water flow subject matter as the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.07.14.00 (Density effects on groundwater flow) and FEP 1.2.06.00.00 (Hydrothermal activity), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

2.2.10.13.03 Thermal buoyancy

Relationship to Primary FEP: This FEP refers to the temperature effects on water density and water viscosity and how this could affect flow. This FEP deals with the same density driven water flow subject matter as the primary FEP. Other primary FEPs that this FEP could have been mapped to include FEP 2.2.07.14.00 (Density effects on groundwater flow) and FEP 1.2.06.00.00 (Hydrothermal activity), but placement under this primary FEP is appropriate.

Screening and Disposition: Same as Primary FEP.

7. CONCLUSIONS

Table 3 provides a summary of the NFE FEP screening decisions and the bases for excluding FEPs.

Table 3. Summary of NFE FEP Screening Decisions

FEP Number	FEP Name and Significance of FEP	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/non-YMP site-specific secondary FEPs excluded	Meets all criteria/low consequence/low probability
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.	Included Primary/Non-YMP site specific secondary FEP excluded	Meets all criteria/low probability
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.	Included seepage/ excluded 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.	Included 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.	Included	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.	Included	Meets all criteria
2.1.08.10.00	**Desaturation/dewatering of the repository.** "Desaturation" of rock at Yucca Mountain occurs because of ventilation and because of repository heating.	Primary Included/non-YMP site specific secondary FEPs excluded	Meets all criteria/low probability
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.	Primary Included/non-YMP site specific secondary FEPs excluded	Meets all criteria/low probability
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.	Primary and some secondary FEPs Included/cement from grout excluded/non-YMP site specific secondary FEPs excluded	Meets all criteria/low consequence/low probability

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 and EBS Transport	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.	Primary and some secondary FEPs included/non-YMP site specific secondary FEPs excluded	Meets all criteria/low probability
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.	TH and THC Included/ excluded TM effects	Meets all criteria/TM low consequence
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.	Included (initial condition/ Excluded (permanent changes)	Low consequence
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.	Excluded	TM Low consequence/ THC Low probability
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.	Excluded	Low consequence primary/low probability secondary
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.	Excluded	Low consequence all but one secondary/low probability for one non-YMP site specific secondary
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.	Included	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.	Included primary and all but one secondary/non-YMP site specific secondary excluded	Meets all criteria/low probability
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 changes in fracture porosity in THC model/Dissolution & Precipitation effects excluded	Meets all criteria/ Low Consequence
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.	Included in THC model/Exclude in TH model	Meets all criteria/ Low Consequence
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.	Excluded	Low consequence
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.	Excluded	Low consequence
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.	Excluded except for THC input to some geo-chemical models	Low consequence
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.	Included TH effects/THC effects partially included	Meets all criteria/ Low consequence

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

FEP Number	FEP Name	Screening Decision	Screening Basis
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.	Included	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.	Included	Meets all criteria

8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

Andrews, R.W. 2000. "AP-SV.1Q Control of the Electronic Management of Data Evaluation for Natural Systems Analysis/Model Reports." Letter from R.W. Andrews (CRWMS M&O) to S.P. Mellington (DOE/YMSCO), April 11, 2000, LV.PA.RWA.04/00-039, with enclosure. ACC: MOL.20000412.0785.

Bäckblom, G. and Ahlström, P-E. 1991. "Swedish Program for Disposal of Radioactive Waste - Site Characterization for a High-Level Waste Repository." Chapter 15 of *Proceedings, Workshop W3B, 28th International Geological Congress, Washington, D.C., July 15-16, 1989, Geological Problems in Radioactive Waste Isolation, A World Wide Review.* Witherspoon, P.A., ed. LBL-29703. Berkeley, California: Lawrence Berkeley National Laboratory. TIC: 206746.

Cranwell, R.M.; Guzowski, R.V.; Campbell, J.E.; and Ortiz, N.R. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste, Scenario Selection Procedure.* NUREG/CR-1667. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: NNA.19900611.0073.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998a. *Subsurface Facility System Description Document.* BCA000000-01717-1705-00014 REV 00. Two volumes. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980826.0161.

CRWMS M&O 1998b. *Ground Control System Description Document.* BCA000000-01717-1705-00011 REV 00. Two volumes. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980825.0286.

CRWMS M&O 1998c. *Controlled Design Assumptions Document.* B00000000-01717-4600-00032 REV 05. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980804.0481.

CRWMS M&O 1999. *License Application Design Selection Report.* B00000000-01717-4600-00123 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990511.0325.

CRWMS M&O 2000a. *Technical Work Plan for Nearfield Environment Thermal Analyses and Testing.* TWP-NBS-TH-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001201.0026.

CRWMS M&O 2000b. *Total System Performance Assessment for the Site Recommendation.* TDR-WIS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001005.0282.

CRWMS M&O 2000c. *The Development of Information Catalogued in REV00 of the YMP FEP Database.* TDR-WIS-MD-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000705.0098.

CRWMS M&O 2000d. *Unsaturated Zone Flow and Transport Model Process Model Report.* TDR-NBS-HS-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000320.0400.

CRWMS M&O 2000e. *Saturated Zone Flow and Transport Process Model Report.* TDR-NBS-HS-000001 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000821.0359.

CRWMS M&O 2000f. *Engineered Barrier System Degradation, Flow, and Transport Process Model Report.* TDR-EBS-MD-000006 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000724.0479.

CRWMS M&O 2000g. *Waste Form Degradation Process Model Report.* TDR-WIS-MD-000001 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000713.0362.

CRWMS M&O 2000h. *Disruptive Events Process Model Report.* TDR-NBS-MD-000002 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000727.0085.

CRWMS M&O 2000i. *Monitored Geologic Repository Project Description Document.* TDR-MGR-SE-000004 REV 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001031.0062.

CRWMS M&O 2000j. *Features, Events, and Processes in UZ Flow and Transport.* ANL-NBS-MD-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000502.0240.

CRWMS M&O 2000k. *FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation.* ANL-EBS-PA-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000526.0334.

CRWMS M&O 2000l. *Miscellaneous Waste-Form FEPs.* ANL-WIS-MD-000009 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000526.0339.

CRWMS M&O 2000m. *Clad Degradation – FEPs Screening Arguments.* ANL-WIS-MD-000008 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000525.0378.

CRWMS M&O 2000n. *Engineered Barrier System Features, Events, and Processes, and Degradation Modes Analysis.* ANL-EBS-MD-000035 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000727.0092.

CRWMS M&O 2000o. *Calculation of Permeability Change Due to Coupled Thermal-Hydrological-Mechanical Effects.* CAL-NBS-MD-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000711.0192.

CRWMS M&O 2000p. *Mountain-Scale Coupled Processes (TH) Models.* MDL-NBS-HS-000007 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0528.

CRWMS M&O 2000q. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001208.0062.

CRWMS M&O 2000r. *Drift-Scale Coupled Processes (DST and THC Seepage) Models.* MDL-NBS-HS-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0523.

CRWMS M&O 2000s. *Abstraction of Drift-Scale Coupled Processes.* ANL-NBS-HS-000029 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000525.0371.

CRWMS M&O 2000t. *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux.* ANL-EBS-HS-000003 REV 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20001206.0143.

CRWMS M&O 2000u. *Calibrated Properties Model.* MDL-NBS-HS-000003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0520.

CRWMS M&O 2000v. *Ventilation Model.* ANL-EBS-MD-000030 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000107.0330.

CRWMS M&O 2000w. *Heat Decay Data and Repository Footprint for Thermal-Hydrologic and Conduction Only Models for TSPA-SR.* CAL-MGR-HS-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000516.0007.

CRWMS M&O 2000x. *Radionuclide Transport Models Under Ambient Conditions.* MDL-NBS-HS-000008 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0529.

CRWMS M&O 2000y. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000526.0332.

CRWMS M&O 2000z. *Seepage Model for PA Including Drift Collapse.* MDL-NBS-HS-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0525.

CRWMS M&O 2000aa. *Abstraction of Drift Seepage.* ANL-NBS-MD-000005 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000322.0671.

DOE (U.S. Department of Energy) 1996. *Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant.* DOE/CAO-1996-2184. Twenty-one volumes. Carlsbad, New Mexico: U.S. Department of Energy, Carlsbad Area Office. TIC: 240511.

Dormuth, K.W.; Hancox, W.T.; and Whitaker, S.H. 1991. "Geological Consideration for Disposal of Nuclear Fuel Waste in Canada." Chapter 4 of *Proceedings, Workshop W3B, 28th International Geological Congress, Washington, D.C., July 15-16, 1989, Geological Problems in Radioactive Waste Isolation, A World Wide Review.* Witherspoon, P.A., ed. LBL-29703. Berkeley, California: Lawrence Berkeley National Laboratory. TIC: 206746.

Liu, H.H.; Doughty, C.; and Bodvarsson, G.S. 1998. "An Active Fracture Model for Unsaturated Flow and Transport in Fractured Rocks." *Water Resources Research, 34,* (10), 2633-2646. Washington, D.C.: American Geophysical Union. TIC: 243012.

McCombie, C. and Thury, M. 1991. "Swiss HLW Programme: Status and Key Issues." Chapter 16 of *Proceedings, Workshop W3B, 28th International Geological Congress, Washington, D.C., July 15-16, 1989, Geological Problems in Radioactive Waste Isolation, A World Wide Review.* Witherspoon, P.A., ed. LBL-29703. Berkeley, California: Lawrence Berkeley National Laboratory. TIC: 206746.

NRC (U.S. Nuclear Regulatory Commission) 1999a. *Issue Resolution Status Report Key Technical Issue: Evolution of the Near-Field Environment.* Rev. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.19990810.0640.

NRC (U.S. Nuclear Regulatory Commission) 1999b. *Issue Resolution Status Report Key Technical Issue: Thermal Effects on Flow.* Rev. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.19991021.0156.

NRC (U.S. Nuclear Regulatory Commission) 1999c. *Issue Resolution Status Report Key Technical Issue: Repository Design and Thermal-Mechanical Effects.* Rev. 02. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20000306.0670.

SAM (Safety Assessment Management) [1997]. Safety Assessment of Radioactive Waste Repositories, An International Database of Features, Events and Processes. Unpublished Draft, June 24, 1997. ACC: MOL.19991214.0522.

Skagius, K. and Wingefors, S. 1992. *Application of Scenario Development Methods in Evaluation of the Koongarra Analogue.* Volume 16 of *Alligator Rivers Analogue Project.* SKI TR 92:20-16. DOE/HMIP/RR/92/086. Manai, New South Wales, Australia: Australian Nuclear Science and Technology Organisation. TIC: 231268.

Steefel, C.I. and Lasaga, A.C. 1994. "A Coupled Model for Transport of Multiple Chemical Species and Kinetic Precipitation/Dissolution Reactions with Application to Reactive Flow in Single Phase Hydrothermal Systems." *American Journal of Science, 294,* (5), 529-592. New Haven, Connecticut: Kline Geology Laboratory, Yale University. TIC: 235372.

USGS (U.S. Geological Survey) 2000. *Future Climate Analysis.* ANL-NBS-GS-000008 REV 00. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20000629.0907.

Wilkins, D.R. and Heath, C.A. 1999. "Direction to Transition to Enhanced Design Alternative II." Letter from D.R. Wilkins (CRWMS M&O) and C.A. Heath (CRWMS M&O) to Distribution, June 15, 1999, LV.NS.JLY.06/99-026, with enclosures, "Strategy for Baselining EDA II Requirements" and "Guidelines for Implementation of EDA II." ACC: MOL.19990622.0126; MOL.19990622.0127; MOL.19990622.0128.

8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

64 FR 46976. Environmental Radiation Protection Standards for Yucca Mountain, Nevada. Readily available.

64 FR 8640. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada. Readily available.

AP-3.10Q, Rev. 2, ICN 3. *Analyses and Models.* Washington, DC: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000918.0282.

AP-3.15Q, Rev. 2, ICN 0. *Managing Technical Product Inputs.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20001109.0051.

AP-2.21Q, Rev. 0, ICN 0. *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities.*. Washington, DC: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000802.0003.

AP-SI.1Q, Rev. 2, ICN 4, ECN 1. *Software Management.* Washington, DC: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20001019.0023.

AP-SV.1Q, Rev. 0 ICN 0. *Control of the Electronic Management of Data.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000329.1181.

AP-SV.1Q, Rev. 0 ICN 2. *Control of the Electronic Management of Information.* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.20000831.0065.

DOE (U.S. Department of Energy) 2000. *Quality Assurance Requirements and Description.* DOE/RW-0333P, Rev. 10. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20000427.0422.

Dyer, J.R. 1999. "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from J.R. Dyer (DOE/YMSCO) to D.R. Wilkins (CRWMS M&O), September 3, 1999, OL&RC:SB-1714, with enclosure, "Interim Guidance Pending Issuance of New NRC Regulations for Yucca Mountain (Revision 01)." ACC: MOL.19990910.0079.

NLP-2-0, Rev. 5. *Determination of Importance Evaluations*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981116.0120.

QAP-2-3, Rev. 10. *Classification of Permanent Items*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990316.0006.

8.3 REFERENCE DATA, LISTED BY DATA TRACKING NUMBER

LL000113904242.089. TSPA-SR Lower Calculations. Submittal date: 01/28/2000.

LL000114004242.090. TSPA-SR Mean Calculations. Submittal date: 01/28/2000.

LL000114104242.091. TSPA-SR Upper Calculations. Submittal date: 01/28/2000.

LL000313504243.036. Calculation of Permeability Change Due to Coupled Thermal-Hydrologic-Mechanical Effects. Submittal date: 03/10/2000.