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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
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Complete Only Applicable Items

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9. Checker	Bruce Stanley	Bruce T. Stanley	1/26/00
10. Lead/Supervisor	Dwayne A. Chesnut	Dwayne A. Chesnut	1/26/2000
Responsible Manager	Dwayne A. Chesnut	Dwayne A. Chesnut	1/26/2000

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
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FIGURES

TABLES

ACRONYMS

AMR	Analysis and Model Report
EBS	Engineered Barrier System
FEP	Feature, Event, and Process
PMR	Process Model Report
TSPA	Total System Performance Assessment
WP	Waste Package
YMP	Yucca Mountain Site Characterization Project

1. PURPOSE

The purpose, objectives, and work scope of the analysis reported in this analysis and model report (AMR) are to:

1. Identify features, events, and processes (FEPs) that pertain to the Engineered Barrier System (EBS), herein referred to as EBS FEPs
2. Determine which of the identified FEPs can be excluded from further consideration or assessment in the evaluation of repository postclosure performance. This initial screening will be finalized in the EBS FEP Abstraction (in preparation), herein referred to as "the abstracting AMR" (E0110, see Attachment II).
3. Identify the EBS AMRs that address the various FEPs which cannot be excluded
4. Identify common mode degradation processes (processes that have the potential of affecting the degradation of multi-EBS components)
5. Provide the identified FEPs, the initial screening results of this AMR, and the common mode events/processes as input to the abstracting AMR (in preparation).

The abstracting AMR identified above will provide direct input to the:

- Total system performance assessment (TSPA) for the Site Recommendation report
- EBS Degradation Flow and Transport Process Model Report (PMR) (in preparation)
- Yucca Mountain Site Characterization Project (YMP) FEP Database (in preparation), herein referred to as the Database.

The Database currently includes FEPs that have their origin in various international projects, as well as in proposed Yucca Mountain repository designs. For the Site Recommendation, it is planned that this Database will be updated, based on input from FEP AMRs in various repository analysis areas (PMRs) such as EBS, Waste Package (WP), Unsaturated Zone, Near Field Environment, Disruptive Events, etc.

Attachment I lists the FEPs that have been extracted from the Database for reference and screening. Attachment II identifies the various EBS AMRs and the flow of the EBS FEPs. Attachment III provides a preliminary or initial screening of the Database FEPs as input to the abstracting AMR. Attachment IV provides a description of FEPs that were identified using the technical approach of this analysis (independently from the Database) as input to the abstracting AMR.

2. QUALITY ASSURANCE

This document was prepared in accordance with AP-3.10Q, *Analyses and Models*, and the *Development Plan for Engineered Barrier System Features, Events and Processes, and*

Degradation Modes Analysis (CRWMS M&O 1999a), which, in turn, was prepared in accordance with AP-2.13Q, *Technical Product Development Planning*. All inputs to this document have been documented in accordance with AP-3.15Q, *Managing Technical Product Inputs*.

The QAP-2-3, *Classification of Permanent Items*, evaluation entitled *Classification of the Preliminary MGDS Repository Design* (CRWMS M&O 1999e, p. IV-1) has identified the ex-container and subsurface facility systems as QA-2, important to waste isolation. The emplacement drifts and most of the elements of the EBS are included in these two systems. The development of this technical document has been evaluated (CRWMS M&O 1999b) in accordance with QAP-2-0, *Conduct of Activities*, and has been determined to be subject to the requirements of the *Quality Assurance Requirements and Description* (DOE 1999).

In addition to the procedures cited above, the following procedures are applicable to this document: AP-2.14Q, *Review of Technical Products*, AP-3.4Q, *Level 3 Change Control*, AP-3.14Q, *Transmittal of Input*, AP-6.1Q, *Controlled Documents*, and AP-17.1Q, *Record Source Responsibilities for Inclusionary Records*.

3. COMPUTER SOFTWARE AND MODEL USAGE

No software subject to the requirements of the *Quality Assurance Requirements and Description* (DOE 1999) was used in the preparation of this document. The commercial application software Microsoft Access, PowerPoint, and Excel (Office 97) were used to tabulate the FEPs, generate the flow charts, and illustrate the alternative degradation scenarios. This software was appropriate for the application.

4. INPUTS

4.1 DATA AND PARAMETERS

The only input to this document is the EBS FEP subset extracted from the YMP FEP Database (see Attachment I). This input, which contains information, rather than data, was obtained by AP-3.14Q, *Transmittal of Input*, via the *Engineered Barrier System (EBS) Features, Events, and Processes (FEPs) Subset of the Yucca Mountain Project (YMP) FEP Database*, Input Transmittal EBS-PA-99358.T (CRWMS M&O 1999c). The information transmitted is currently unqualified; however, it was used (see Attachment I) for FEP identification and reference only, and has no impact on the results of this analysis; see Section 6.1 below.

In addition to the above input, the potential repository baseline design (Wilkins and Heath 1999) was used as the reference design for the purpose of FEP identification and analysis.

The EBS AMRs, many of which are currently in preparation, are used to provide information to the EBS PMR and, through abstraction, to TSPA. Some of these AMRs are used as corroborative references in this report (see, e.g., Attachment III). Attachment II lists these AMRs and their corresponding document identifier numbers for future reference.

4.2 CRITERIA

This analysis does not satisfy any predetermined criteria or requirements. Specific FEP screening criteria identified in government regulations will be applied and documented in the abstracting AMR.

4.3 CODES AND STANDARDS

No codes or standards were used in the development of this analysis.

5. ASSUMPTIONS

This section lists the assumptions used in Section 6 and identifies (in parentheses) the sections where they are used. All of the assumptions were used as reference or logical analysis assumptions to facilitate the identification and analysis of FEPs and degradation scenarios. None of the assumptions is a requirement that needs to be substantiated or verified and, hence, none carries a TBV. Unless otherwise noted, the basis for all of these assumptions is engineering judgment and professional experience to ensure a conservative identification of FEPs and degradation scenarios. 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 potential repository baseline 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, and the hypothetical construction of drains in the drift floor.

Engineered Barrier System Description–The EBS is assumed to extend as far into the rock as the reach of the ground support system (approximately 5 m if rock bolts are used). The environment around and inside the potential repository will evolve during the regulatory period, driven by the changing heat load and mechanical adjustments of the surrounding rock. Processes and events farther away, but still in the immediate vicinity, influence the behavior of the EBS by altering the amount of water available to seep into the drifts, the pathways by which it reaches the drifts, and the pathways by which it exits the drifts with its potential burden of contaminants. (Used throughout.)

Reference Repository Design–The Enhanced Design Alternative II, as described in the baseline design (Wilkins and Heath 1999), is used as the reference design for FEP identification. However, departures from the baseline due to the potential occurrence of FEPs are also addressed (see above). (Used throughout.)

Past Analyses and Mining Effects–Processes described in past documents (e.g., Barr et al. 1996) and in mining effects (e.g., Brady and Brown 1993) apply, as augmented by the effects of WP heat. (Used throughout.)

Degradation–As the potential repository and Yucca Mountain evolve, the properties of EBS components such as ground support, backfill, and drip shields, which are subjected to "processes," depart from their original design characteristics. By assumption, it is presumed that any such departure degrades the function of the component, and design lifetimes and safety factors are selected on the basis of that premise. (Used throughout.)

The design philosophy currently assumes no credit for favorable alterations to the repository system (e.g., encasement of WPs in calcium carbonate precipitated from incoming water). (Used throughout.)

Degradation During The Preclosure Period–Degradation that occurs during the preclosure period would be detected and "fixed." Thus, the FEPS identified are mostly those that occur during the postclosure period. (Used in Section 6.5.1.)

Process Start Point–The starting point of the EBS processes is assumed to be the entry of water into the emplacement drift. (Used throughout.)

Water data, including timing, rate, temperature, chemistry, etc., are assumed to be developed in the unsaturated zone and near field environment PMRs. (Used throughout.)

Common Mode Effect On Flow–Water flow to the emplacement drift will increase due to common mode events and the resulting degradation. (Used in Section 6.8.)

Consequences of Excavation-Related Effects–The consequences of excavation-related effects are assumed to be less than those of the disturbed rock zone that will form as a result of stress relief. (Used throughout.)

6. ANALYSIS

6.1 ANALYSIS APPROACH

This analysis of EBS FEPs consists of several dependent elements: (1) identification of a FEPs "Basis," a collection of EBS FEPs, as well as consequences of processes that need to be accounted for; (2) construction of a number of figures that detail the EBS and how the EBS interacts with the flow system; (3) development of a logic diagram (generalized event tree) to organize and connect the components of the EBS figures and add missing elements; and (4) development of a fault tree focused on "common mode" failures to systematically identify those modes. Steps (1) through (4) are described below. The screening of FEPs and their allocation to AMRs is presented following identification of the individual FEPs.

The analysis approach described above is not dependent on the FEPs that have so far been identified in the Database. Attachment I identifies these FEPs to permit reference and the initial screening presented in Attachment III. The purpose is to ensure that all FEPs that have their origin in other sources are addressed. The screening results are provided as input to the abstracting AMR, and upon further confirmation, will be included in the Database.

6.2 DEFINITIONS

In order to identify FEPs germane to degradation of the EBS design and performance, it is necessary to define the terms EBS, degradation, and common mode degradation.

6.2.1 Engineered Barrier System

The EBS considered in this AMR refers to the emplacement drift system, which includes the host rock surrounding the drift cavity, the environment inside the drift, the ground support system, the waste emplacement equipment, the backfill, the drip shield structure, and the invert. The waste package and supporting structure, as well as the material of the drip shield, are analyzed as part of the Waste Package PMR. The elements of the waste form contained in the WP are analyzed as part of the Waste Form PMR. The thermally perturbed zone of the host rock or "altered zone" is discussed in the Unsaturated Zone and Near Field Environment PMRs (all of these PMRs are in preparation).

The EBS is assumed to extend as far into the rock as the reach of the ground support system (approximately 5 m if rock bolts are used). The environment around and inside the potential repository will evolve during the regulatory period, driven by the changing heat load and mechanical adjustments of the surrounding rock. Processes and events farther away, but still in the immediate vicinity, influence the behavior of the EBS by altering the amount of water available to seep into the drifts, the pathways by which it reaches the drifts, and the pathways by which it exits the drifts with its potential burden of contaminants.

6.2.2 Degradation

As the potential repository and Yucca Mountain evolve, the properties of EBS components such as ground support, backfill, and drip shields, which are subjected to "processes," depart from their original design characteristics. By assumption, it is presumed that any such departure degrades the function of the component, and design lifetimes and safety factors are selected on the basis of that premise. The design philosophy currently assumes no credit for favorable alterations to the repository system (e.g., encasement of WPs in calcium carbonate precipitated from incoming water). Therefore, degradation is defined as occurring for all components.

6.2.3 Common Mode Degradation

The potential repository is designed so that there is defense-in-depth, that is, a number of components can individually fail to perform without compromising repository performance. However, it is sometimes possible to identify failure modes in engineered structures that compromise all of the critical components simultaneously, thus producing "common mode failures." To allow for this possibility in the EBS, in addition to examining the degradation of individual components, it is necessary to search for single events or processes that have the potential of causing multiple-component degradations and, ultimately, increasing the possible dose release.

Usually, "common mode failure" describes the failure of several critical, redundant components due to a single event that simultaneously affects all critical components. A detailed discussion of "common cause" and "common mode" failures and their implications can be found in *Reliability and Risk Analysis – Methods and Nuclear Power Applications* (McCormick 1981, p. 88f) or equivalent text. In this analysis, "common mode degradation," or "common mode" will be used to describe: (1) the degradation or failure of several critical components due to a single event; (2) processes initiated by a single event; or (3) a single process that compromises several critical components and accelerates the potential release rate. An example is movement of a fault that passes through the potential repository. This event could (1) suddenly cause a local ground support collapse that damages a WP and exposes it to water contact, (2) provide a pathway for water influx that would accelerate corrosion and mobilization, and (3) provide an exit for possible radionuclide transport.

6.3 BASIS

To develop a basis for EBS FEPs, a number of performance factors (issues, concerns, and advice from the principal investigators) relevant to degradation of the EBS have been considered. These factors influence the degradation of the EBS components and could induce their eventual failure. Some of these are FEPs in their own right, while others are the consequences of processes involving more fundamental FEPs or are summaries of FEPs. Table 1 lists the factors and advice considered, and identifies the associated and potentially degrading effects. The potential repository baseline design (Wilkins and Heath 1999) was assumed as the reference for identifying FEPs and degradation scenarios.

The "Basis" listed in Table 1 is effectively a book mark, or reference consideration, that reminds the analysts of issues, concerns, and advice perceived to be important by the principal investigators of FEPs in other areas and which need to be accounted for as the FEPs are developed for the EBS.

6.4 CONCEPTUAL FIGURES

To clarify the importance and context of the FEPs, and to illustrate some of the principal FEPs, several figures have been constructed to illustrate the potential degradation of principal elements of the EBS. It is noted that Figures 1 through 6 represent hypothetical, but possible, degradation scenarios considered for the purpose of analysis rather than design. In addition, certain expected and important physical behaviors, namely floor buckling and stress-adjustment fracturing, are also shown. (Such behaviors and their analyses are discussed in publications such as *Rock Mechanics for Underground Mining* (Brady and Brown 1993), *Fundamentals of Rock Mechanics* (Jaeger and Cook 1979), and articles such as "Impacts of Seismic Activity on Long-Term Repository Performance at Yucca Mountain" (Gauthier et al. 1996). The ground support system has been omitted from the figures for clarity.

Figure 1 presents the principal elements of the EBS and a conceptualization of floor buckling in the form of a downward displacement. The "sag" is accompanied by the relative movement of two overlapping segments of the drip shield. This relative movement opens a gap, allowing flow of the backfill to the inside of the drip shield. If the drip shield was diverting water from either of the displaced segments at the time, that water is likely to be focused into the invert at the location of the displacement, as suggested in the figure detail. Figure 1 also shows the residual condensate zones that could form due to cooling in the postclosure period. It shows rockfall atop the backfill, drift alteration, and a possible water flow area from the drift crown down a drift wall to the bottom of the invert. Fractures associated with stress-adjustment (thermo-mechanical and mechanical) are represented as a few fractures that are radially and concentrically distributed around the drift.

Figure 2 presents the same principal elements as in Figure 1, but shows the floor buckling in a local rise of the floor. The detail of the overlapping drip shield segments offers an alternative opening of the overlap for entrance of the backfill (and water, if available). In Figure 3, two additional cross-sectional views, A and B, emphasize different details of the flow. Detail A shows flow from the drift wall down the drip shield to the invert, condensate under the drip shield, and fracture drainage. Drift wall deformation is shown because the ground support system is expected to fail when the temperature has decreased sufficiently to create the condensate flow. Detail B shows flow through the backfill to the drip shield and the invert, condensate under the drip shield, and fracture drainage. The discontinuous, locally saturated flow along the path is fed by fluid arriving at the saturated sites from flow through the backfill, perpendicular (in three-dimension) to the cross-section.

Possible effects of rockfall on the displacement of the drip shield are shown in cross-section in Figures 4 and 5. Here, rock falling on the backfill distorts the drip shield (Figure 4) and displaces the drip shield (Figure 5) so that it contacts the WP and a rail section. As a result, rapid contact corrosion of the affected drip shield, the rail, and the WP would be expected.

In Figure 6, an engineered drain (not in the current baseline design; see Wilkins and Heath 1999) has been hypothetically added to the drift floor of Figure 3. This drain is shown as intersecting several fractures, including a concentric stress-relief fracture. The figure shows both unsaturated flow from the drain (flow plume) and fracture flow.

Figures 1 through 6 give conceptual illustrations of most of the important EBS FEPs. Table 2 lists the FEPs illustrated and the corresponding figure numbers. Most of the additional or new FEPs included in the more inclusive list of EBS FEPs developed in this AMR can be developed from the above list and the figures by considering aspects and details of design, water chemistry, heat and corrosion mechanisms, etc. The remainder can be traced to the "Basis" of Table 1.

6.5 LOGIC DIAGRAM (EVENT TREE)

Integration of the FEPs, to provide context to their occurrence, is developed in the form of a generalized event tree (flow diagram or logic diagram). The components used are often of a summary or top-level nature and are intended to cover the key elements of water movement without providing overwhelming details of important supporting processes (e.g., various chemical interactions). Figures 1 through 6 provide a visual context for some components of the EBS and how they might function. The tree provides an operational context to ensure that all of the processes affecting the physical components in the EBS are addressed.

6.5.1 Context

The EBS FEPs, with the exception of three categories (ventilation, seals, and igneous activities; see Section 6.6.2), can be organized into a "context" of occurrence. This context assists in the elucidation and analysis of their importance in the degradation of the EBS. Context allows the investigator some perspective on which of the elements (i.e., FEPs) are controlling, which are developed (i.e., consequences), and which are of secondary importance.

This analysis includes the drip shield and backfill, which would be installed just prior to closure and decommissioning of the potential repository and, therefore, applies to the long-term degradation of the EBS after closure. It is presumed that degradation that occurrs during the preclosure period would be detected during preclosure inspection and remedied before closure.

The starting point of the EBS processes is assumed to be the entry of water into the emplacement drift. Water data, including timing, rate, temperature, chemistry, etc., are assumed to be developed in the unsaturated zone and near field environment PMRs. The flow in the drift evolves under the influence of the changing thermal output from the WPs. (This evaluation is discussed in the Multiscale Thermohydrologic AMR, currently in preparation; see Attachment II.)

6.5.2 Water Availability Conditions

Three conditions concerning the availability of water (contact water, mobilization water, and exit water) control the EBS FEPs and degradation modes.

6.5.2.1 Contact Water

First, there must be sufficient water available to reach the WP and to effect a breach of the WP by some corrosion mechanism. The water can be available as liquid or vapor, and corrosion can be by any number of mechanisms dependent on temperature, water chemistry, and water phase.

For this first condition, two different sources of water (infiltrate and condensate) and three different flow types (streaming flow, drip, and Philip's drip) are identified. **Infiltrate water** is defined as water that has entered at the surface and infiltrated through the rock to reach the repository. **Condensate water**, described here as the component "Return Flow," is defined as water that has been transported as vapor and has condensed in the rock, in the drift, or on the drip shield. The distinction is made on the grounds that the expected volumetric contributions, and their timing and chemistry, may be sufficiently different to be significant to degradation models (i.e., corrosion of the WPs). **Streaming flow** is a continuous flow of fluid, and **drip** is its intermittent or interrupted state. Drip is the currently expected condition, if it occurs at all. **Philip's drip** is a consequence of a drift of certain dimensions and shape intercepting a homogeneous, isotropic phreatic zone in such a way that it produces saturated conditions at the crown of the drift. This third flow type is esoteric, has been derived analytically, and is not currently supported experimentally nor expected to compete in volume with drip from infiltrate or condensate (Philip et al. 1989).

6.5.2.2 Mobilization Water

Second, there must be sufficient liquid water available to mobilize contaminants from the breached WP and move them through the invert. A WP failure (breach), by itself, does not assure mobilization for some mechanisms of corrosion; vapor corrosion or microbial corrosion could have provided the breach. Waste temperature becomes an important constraint on the volume of water required to mobilize contaminants if the waste temperature would otherwise be above the vaporization temperature of water.

For this second condition, sufficient fluid must arrive at the breached WP to mobilize contaminants and move them through the invert. If the drip shield is intact, then the water source for liquid water moving through the breached WP must be limited to either condensation on the interior surface of the drip shield, or a rise of liquid in the invert sufficient to reach the breached WP. If the drip shield is not intact (e.g., due to physical displacement, gap, or corrosion), then water entering the drift could flow to the WP directly without being diverted by the drip shield. When ordering these possibilities (represented by a number of FEPs and several figures) independently on a volumetric basis, one might expect, first, a compromised drip shield, then, a rise of water level in the invert, and, last, condensation on the interior of the drip shield.

6.5.2.3 Exit Water

Third, there must be an exit from the EBS, either through the drift wall or the drift floor. The exit could be through fractures associated with thermo-mechanical effects and the existing fracture networks, or it could be matrix flow through the host rock. The functioning of the exit, which affects the residence time of mobilized contaminants in the EBS, also influences the mode by which the exit water takes contaminants away from the EBS.

For this third condition, exit from the EBS is defined as the escape of contaminants from the EBS. If fracture flow provides the primary path from the drift, fractures must be open and hydraulically active. Plugging, by fines or by mineralogical alterations (in a hot, wet environment), becomes a performance factor as does fracture closure by thermo-mechanical effects during the thermal period and the formation of new fracture sets as the repository cools. If matrix flow provides the primary path of escape from the EBS, then ponding, if any, and the residence time of contaminants in the drift become performance factors.

6.5.3 FEP Tree (Logic Diagram)

The above conditions, the factors and effects bases (Table 1), and the perspective provided in Figures 1 through 6 (Table 2), are expressed in the construction of the FEP logic tree, herein referred to as "tree," shown in Figure 7. This figure is presented in totality and then as (magnified) segments (Figures 7a through 7f) for clarity. In this figure, the root event is assumed to be the arrival of water at the EBS. The process ends when the water exits the EBS.

The tree in Figure 7 was constructed to track water flow, and is based on flow to the drift occurring from two different sources: infiltrate and condensate ("Return Flow"). Only the Return Flow (condensate) branch is expanded, though the other branch (infiltrate) can be expanded similarly. These two possible sources are distinguished because different flow rates, volumes, water chemistries, temperatures, times of arrival, and locations are expected to be determined by their occurrence. All of these factors are considered important to modeling WP breach and contaminant mobilization.

The tree recognizes three flow types: drip, streaming flow, and Philip's drip. The last is included only for completeness, and is otherwise disregarded as being included in drip. Drip and streaming flow are only volumetrically different and are separated to recognize that flow may be distributed or may be well focused. Each intersection of the tree "branches" is an "OR" gate (any branch is possible); comments and FEPs are included in ovals where they may apply.

6.6 ENGINEERED BARRIER SYSTEM FEATURES, EVENTS, AND PROCESSES

6.6.1 Features, Events, and Processes Set

A set of EBS FEPs has been identified, based on: (1) the baseline design of the potential repository (Wilkins and Heath 1999), (2) the EBS FEPs basis in Table 1, (3) the conceptual figures (Figures 1 through 6), (4) the context described in Section 6.5.1, (5) the water availability conditions, and (6) the logic tree as developed. This FEP set is identified in Table 3.

The FEPs in Table 3 are categorized by whether they are features, events, or processes. If a FEP corresponds to one or more FEPs currently identified in the YMP FEP Database, the Database identifying numbers are also indicated (e.g., 2.1.06.07.00). FEPs that are not in the database are referred to as "new" and are identified by a number in the format "ebsxx." All of the "new" FEPs are described in Attachment IV. In some cases, Table 3 has both "new" and database numbers for the same FEP. In such cases, the "new" description is to be considered an input for the database update. Any FEPs with neither "new" nor database numbers are subset or detail FEPs that are to be considered in conjunction with the corresponding main FEP. The remaining information in Table 3 is explained in Section 6.7.

6.6.2 Deferred and Not Applicable FEPs

This section addresses three FEP categories that are part of the EBS FEP Basis (Table 1), but are not considered in the figures or in the logic tree. These FEPs are identified in Table 3 as "Deferred" or "N/A for EBS FEPs." Deferred FEPs are typically related to, and dependent upon, design solutions. For these FEPs, the applicable design areas are identified. Not applicable (N/A) FEPs are related to the EBS, but are considered to be in the domain of other FEP analysis areas (PMRs). A reference to the applicable PMR is proposed for these FEPs. Three such FEP categories need to be specified in more detail and are discussed below.

Ventilation, or the forced circulation of air through the drifts, is expected to continue until closure. This movement of air is expected to remove heat and moisture from the rock surrounding the drifts and, therefore, sets the initial conditions for the functioning of the EBS. For this latter reason, ventilation is the topic of another EBS AMR. Forced ventilation will cease after closure and is not part of the considerations of long-term behavior of the EBS. Therefore, no EBS FEPs for long-term releases are identified as resulting from ventilation. Ventilation is discussed in more detail in the ANSYS thermal calculations (CRWMS M&O 1999d).

Seals for plugging the openings produced during excavation and drilling operations are expected to be constructed to control the movement of water. No specific sealing requirements have been identified for the EBS; however, it is expected that seals would be emplaced in the ramps, ventilation shafts, and boreholes in the near field and away from the EBS. No seal-related FEPs have been identified for the EBS. Seals are discussed in more detail in the *Repository Seals Requirements Study* (CRWMS M&O 1997).

Igneous activity refers to the interaction of an ascending magma dike and the repository drifts, and includes the possible formation of a vent and an associated contaminated cinder cone with an ash plume. This is the topic of a PMR and several supporting AMRs (in preparation). The occurrence of the event and its consequences appear to be secondary to the EBS design. This topic and the FEPs it engenders are left to the PMR addressing volcanism and are not considered here. Igneous activity is discussed in more detail in *Scenarios Constructed for Basaltic Igneous Activity at Yucca Mountain and Vicinity* (Barr et al. 1993) and in the Disruptive Events PMR, now in preparation.

6.7 FEATURE, EVENT, AND PROCESS SCREENING AND REFERENCE ANALYSIS MODEL REPORTS

One of the objectives of this AMR is to perform an initial screening of the EBS FEPs that are currently in the Database to determine which should be excluded from further consideration in TSPA. The initial screening results will be provided to the abstracting AMR (E0110, see Attachment II) for confirmation or update. The sections below describe the initial screening process and the allocation of FEPs to EBS AMRs.

6.7.1 Screening Database Features, Events, And Processes

It should be noted that the FEPs in Attachment I that are subject to screening are listed in the current version of the Database. The set of FEPs from the Database (Attachment I) that are based on designs other than Enhanced Design Alternative II served as a point of departure to identify and screen FEPs reported in various AMRs, including this analysis. Additional EBS design-specific FEPs were identified in this analysis. New FEPs or screening arguments more relevant to this EBS for previously identified and screened FEPs, from this analysis and other AMRs, are to be provided as input to the abstracting AMR (E0110, see Attachment II), and from that AMR to the Database. The FEP screening approach taken in this AMR was to examine each FEP to confirm that it is "applicable to the EBS" as defined in Section 6.2.1, and to determine whether it should be "Included" in or "Excluded" from further TSPA consideration (based on probability or consequences). A screening rationale is provided for each FEP. For a FEP that is "Included," a check was performed to confirm that it is also included among the EBS FEPs that are independently identified in Table 3.

Attachment III provides the screening arguments for the FEPs in Attachment I (those currently in the Database). The Database FEP numbers in Table 3 correspond to FEPs that are EBS FEPs, and which could not be excluded in Attachment III.

In summary, Table 3 lists the FEPs that have been identified and which could not be excluded in this AMR. Table 3 indicates whether a FEP relates to one or more Database FEPs that were screened (i.e., could not be excluded) in Attachment III, or whether it is a new FEP that is described in Attachment IV. A FEP with no reference to a new or a database FEP is a detail or a subset to a main FEP, and needs to be evaluated and documented in the abstracting AMR (E0110, see Attachment II).

6.7.2 Reference Engineered Barrier System Analysis Model Reports

Table 3 references one or more EBS AMR for each FEP in the table, with two exceptions: (1) FEPs that can appropriately be dealt with as part of future design efforts rather than in the analyses currently supporting the Site Recommendation; and (2) FEPs that are dealt with in PMRs that are directly related to the EBS PMR. These PMRs are WP, Waste Form, Unsaturated Zone, Near Field Environment, and Disruptive Events (all in preparation).

Attachment II identifies three categories of AMRs: supportive AMRs, process AMRs, and abstraction AMRs. Supportive AMRs provide data to Process AMRs, which are abstracted in the abstraction AMRs. The EBS PMR draws from the information in the process and abstraction AMRs. Table 3 references only process model AMRs (E0050, E0090, E0100, E0120), with the exception of the abstracting AMR (E0110), which summarizes FEPs in various chemical analyses directly, without abstracting them from a process model. Each of the referenced AMRs is expected to address the FEPs listed in its column in Table 3.

6.8 COMMON MODES

To cause a common mode degradation, an event or process must occur which compromises the function of several key components as a direct result of an event or process that has the potential of affecting the release of contaminants from the EBS. The common mode degradation of the EBS can be local (i.e., affecting only a few adjacent or distributed WPs), or it can be "nonlocal" (i.e., affecting a large part of or all of the repository).

As an example, consider the failure of the ground support system due to one or more of the following events or processes: seismic event, fault movement in the potential repository, thermo-mechanical movement in a shear zone, thermo-mechanical response producing floor buckling (and drift movement), corrosion of ground support (e.g., bolted steel sets), thermal-hydrologic-mechanical-chemical alteration of the Topopah Spring basal vitrophyre (propagating to the drifts as floor heave), and volcanic events.

Such a ground support failure may result in events or processes with possible cascade effects that could displace backfill and the drip shield, and could directly damage the WP and its support, including the invert. Damage to the WP, which does not penetrate the WP but which accelerates corrosion, should also be considered as a common mode degradation, with delay. Release of contaminants, however, cannot occur unless the event or process causing failure of the ground support also includes sufficient water flow to assure the mobilization of contaminants from the WPs.

There are subsets of events and processes that affect part of the EBS components which might also be considered as common mode degradations. An example is a seismic event which propagates down drifts causing relative movement of WPs and the backfill-loaded drip shield, leading to contact corrosion, and for which there is incidental failure of the ground support.

A primitive fault tree for common mode degradation has been constructed in Figure 8 to aid in identifying the components associated with common mode degradation (see ovals in Figure 8). If a common mode exists, then it is expected to appear as a basic event occurring on every (or almost every) branch. This fault tree starts from the top with the release "fault" and progressively asks about changes that must occur to reach a "basic" initiating event. Branches are connected by "AND" gates, which require all branches immediately below the gate to occur in order to apply, or "OR" gates, which require any branch below the gate to occur.

Three requirements are identified in the tree as principal branches: (1) there must be enhanced water flow to the WPs, (2) there must be waste mobilization, and (3) there must be enhanced drainage to transport contaminants away. It is an implicit assumption that whatever the common mode, locally increased water flow to the drift will occur. Such a local increase of water flow means a local decrease elsewhere, as constrained by the water budget. As the fault tree is currently expanded, one branch, "water-mobilized contaminants," occurs for all releases. How this might be affected by local increases in water flow into the potential repository is ignored because it would require details of the water chemistry that are irrelevant to that point of the tree. This branch is connected by an "AND" gate to "Penetrated WPs," which is a requirement for any mobilization.

This construction of the fault tree (in Figure 8) shows that three basic events are shared for each of the principal branches. These are "Thermo-Mechanical Stress Alteration," "Thermal-Mechanical-Chemical-Hydrologic coupled processes" related to the Topapah Spring basal vitrophyre (TPSbv) layer, and "Seismic Event." The last occurs in two forms, "local" and "nonlocal," to distinguish faulting that intercepts a drift from the effects of ground motion caused by the seismic event. Figure 8 identifies several common mode degradations for further evaluation in a TSPA context.

Table 4 summarizes the common mode events or processes for the EBS, based on Figure 8. In general, common mode analysis requires the assessment of combined effects of FEPs that are typically analyzed within more than one discipline. The common modes in Table 4 are identified as input for assessment in a total system context.

7. CONCLUSIONS

A list of FEPs that are pertinent to the EBS has been identified (Table 3) with one or more references to EBS AMRs or other PMRs. Some of the FEPs correspond to FEPs currently identified in the database. Excluded database FEPs have also been identified (Attachment III), as are the common mode degradations (Table 4). Table 5 integrates the "new" and Database FEPs based on Table 3 and Attachments III and IV. The FEPs identified as "Deferred" and "N/A for the EBS FEPs" are listed in Tables 6 and 7, respectively.

Tables 4 through 7 constitute the input from this AMR to the abstracting AMR (E0110, see Attachment II). The abstracting AMR function is to address the accuracy and uncertainty and final screening of EBS FEPs (from this and other EBS AMRs) and to provide input to TSPA, the EBS PMR, and the YMP FEP Database.

All references, input, and assumptions in this analysis were used for information only. No data-associated TBVs are identified.

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ATTACHMENTS

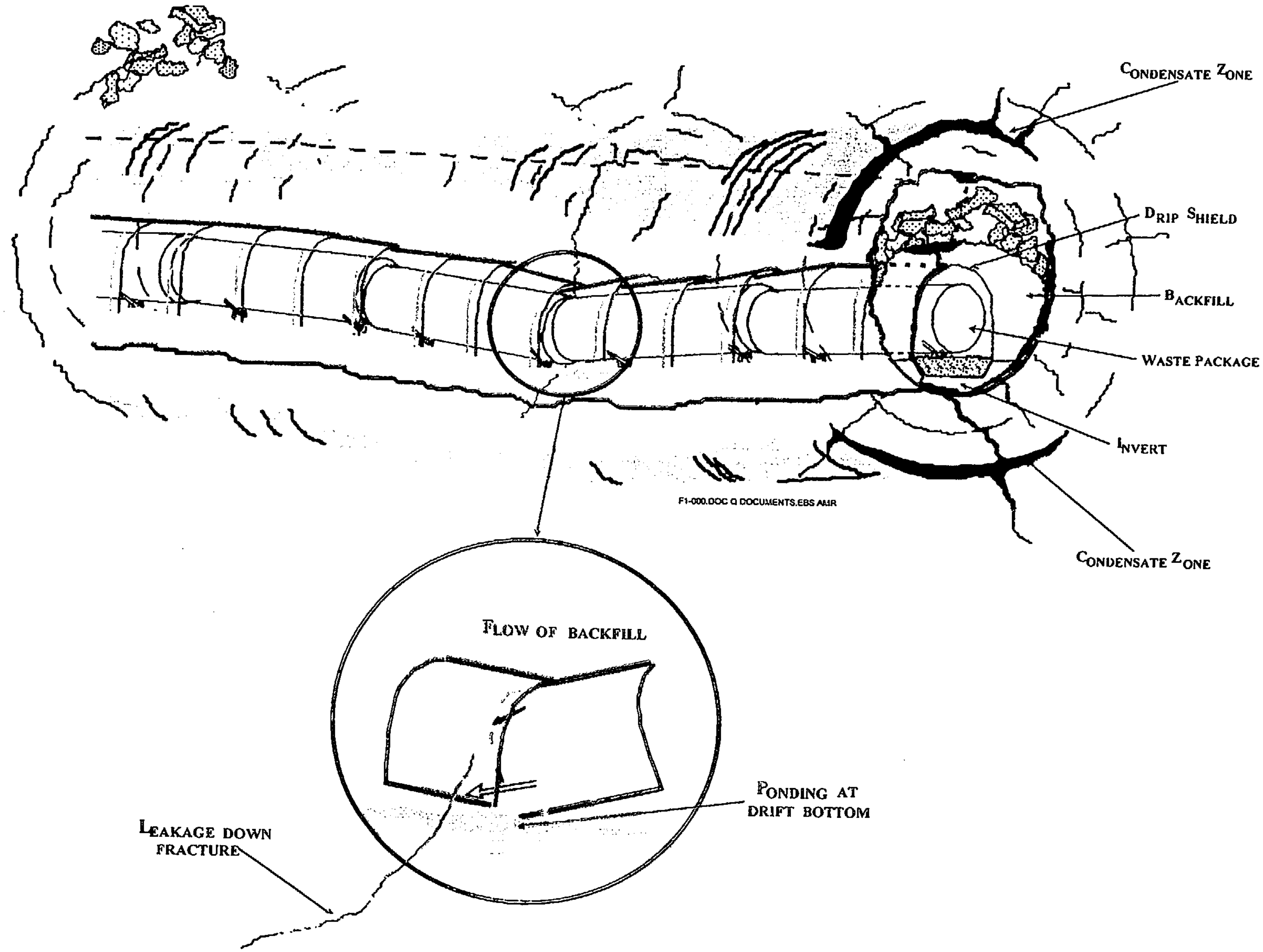
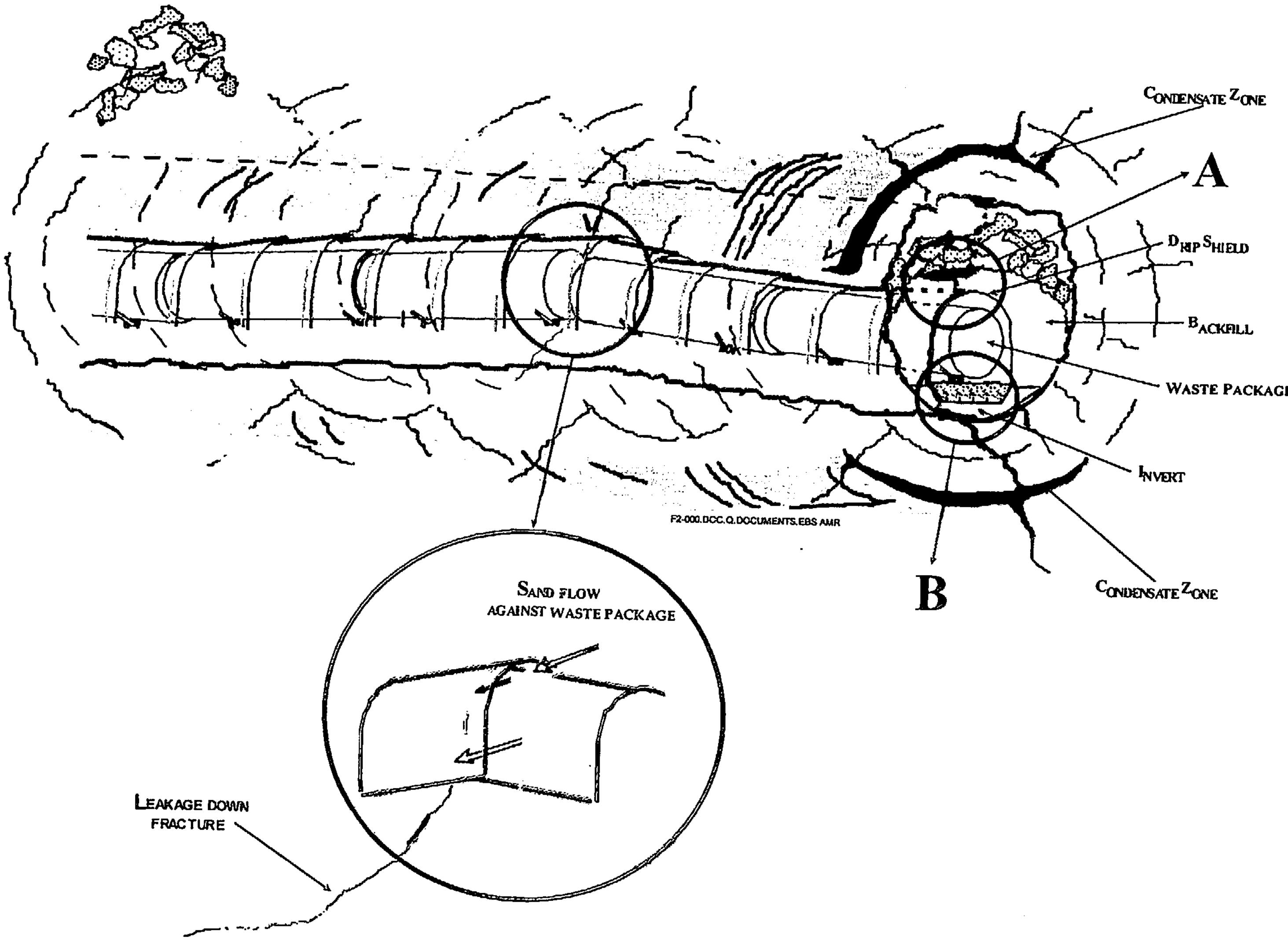


Figure 1. Floor Heave with Downward Displacement



NOTE: Several selected degradation regions are circled and magnified for emphasis in Figure 3.

Figure 2. Floor Heave with Upward Displacement

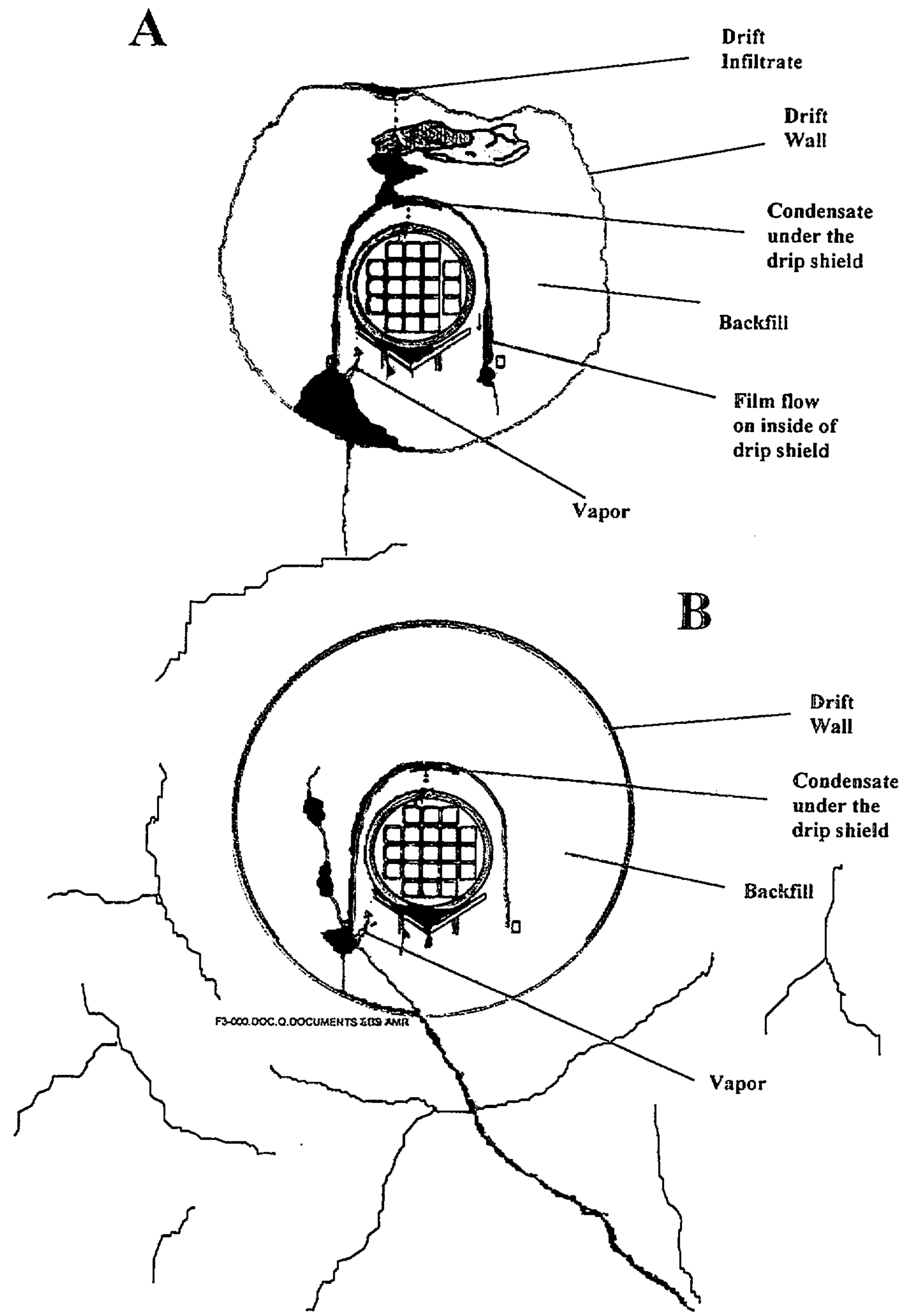


Figure 3. Cross-Sections of the Drift Depicting the Degradation in Regions A and B of Figure 2

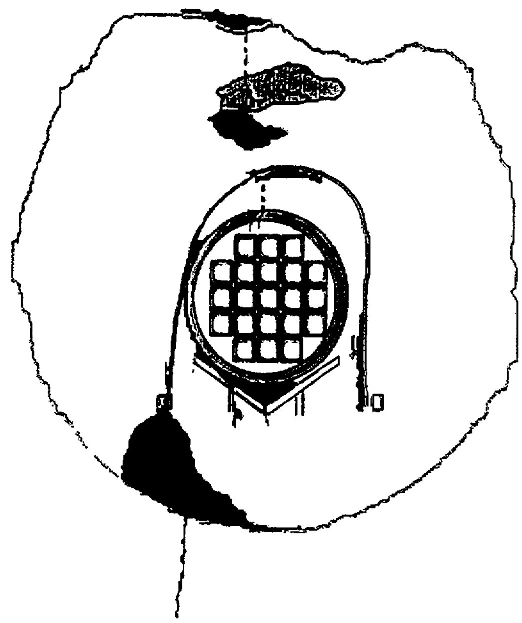


Figure 4. Cross-Section of the Drift with an Intact Drip Shield Distorted by Rockfall Sufficient to Contact a Waste Package

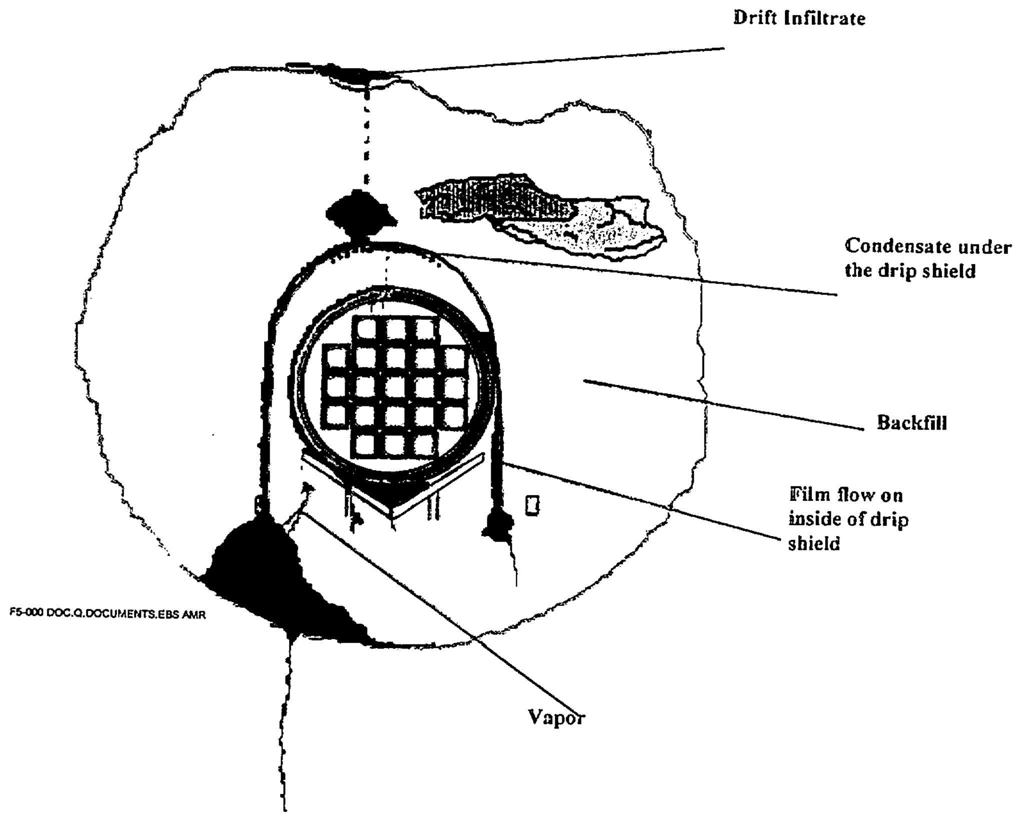


Figure 5. Cross-Section of the Drift with an Intact Drip Shield Displaced Laterally by Rockfall Sufficient to Contact a Waste Package

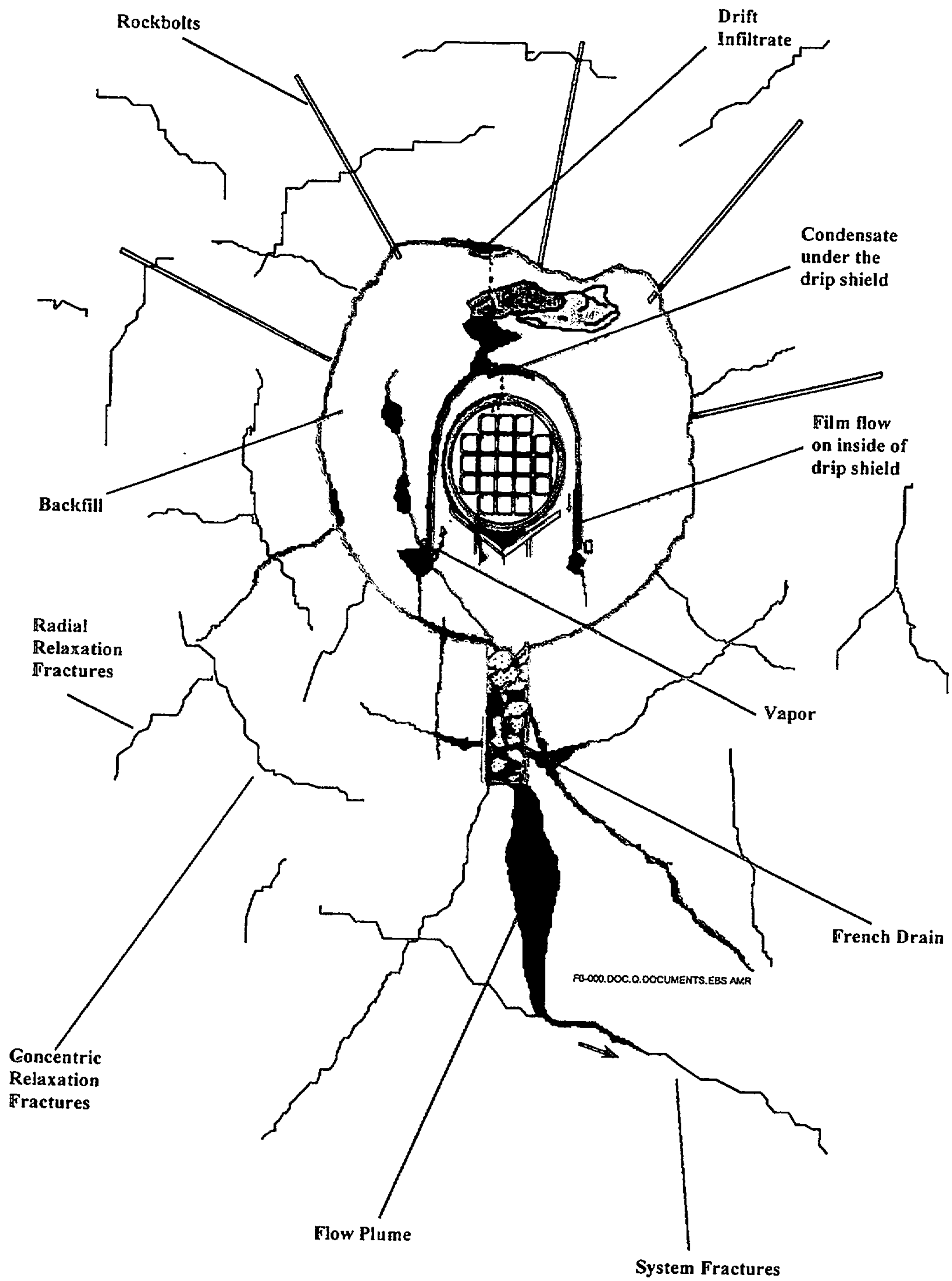


Figure 6. Cross-Section of the Drift with Hypothetical Engineered Floor Drainage (Included to Illustrate Possible Drainage Effect)

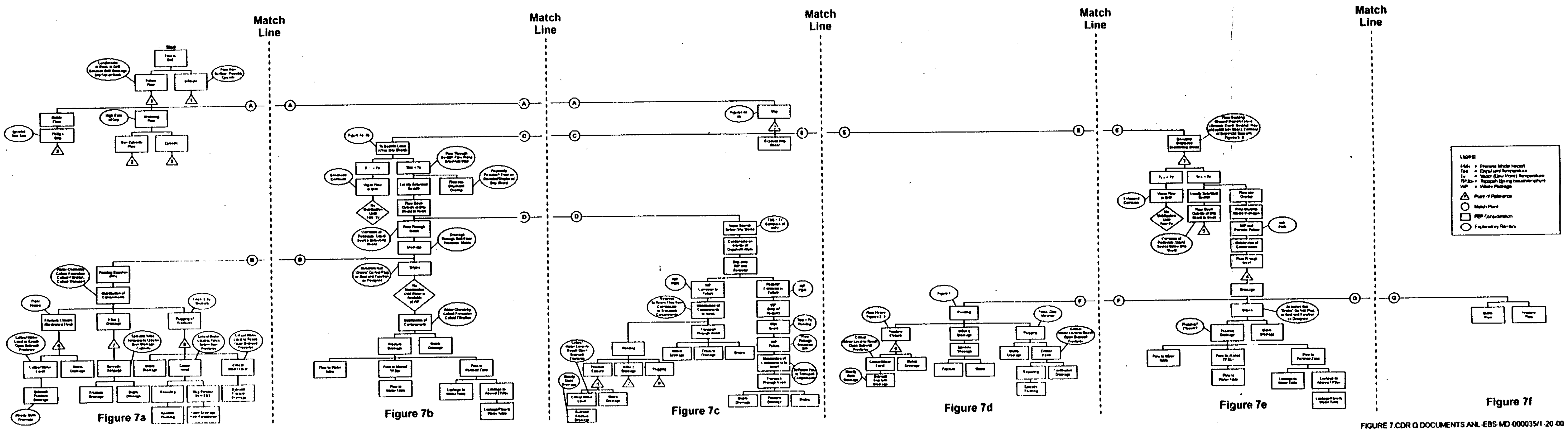


Figure 7. EBS FEP Tree. (FEPs Are Identified for the Expected Behavior)

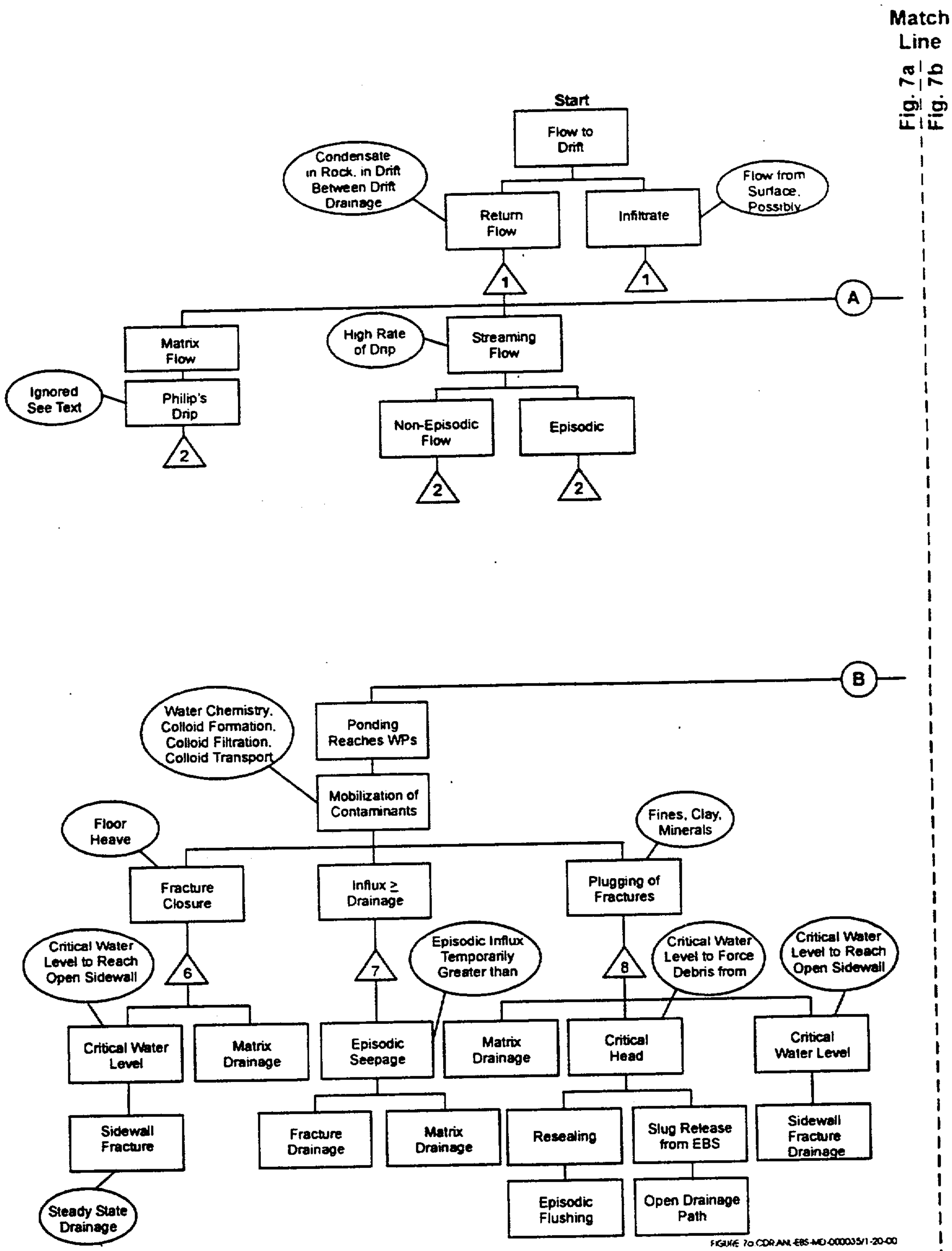


Figure 7a. Part 7a of Figure 7
(See Legend in Figure 7f)

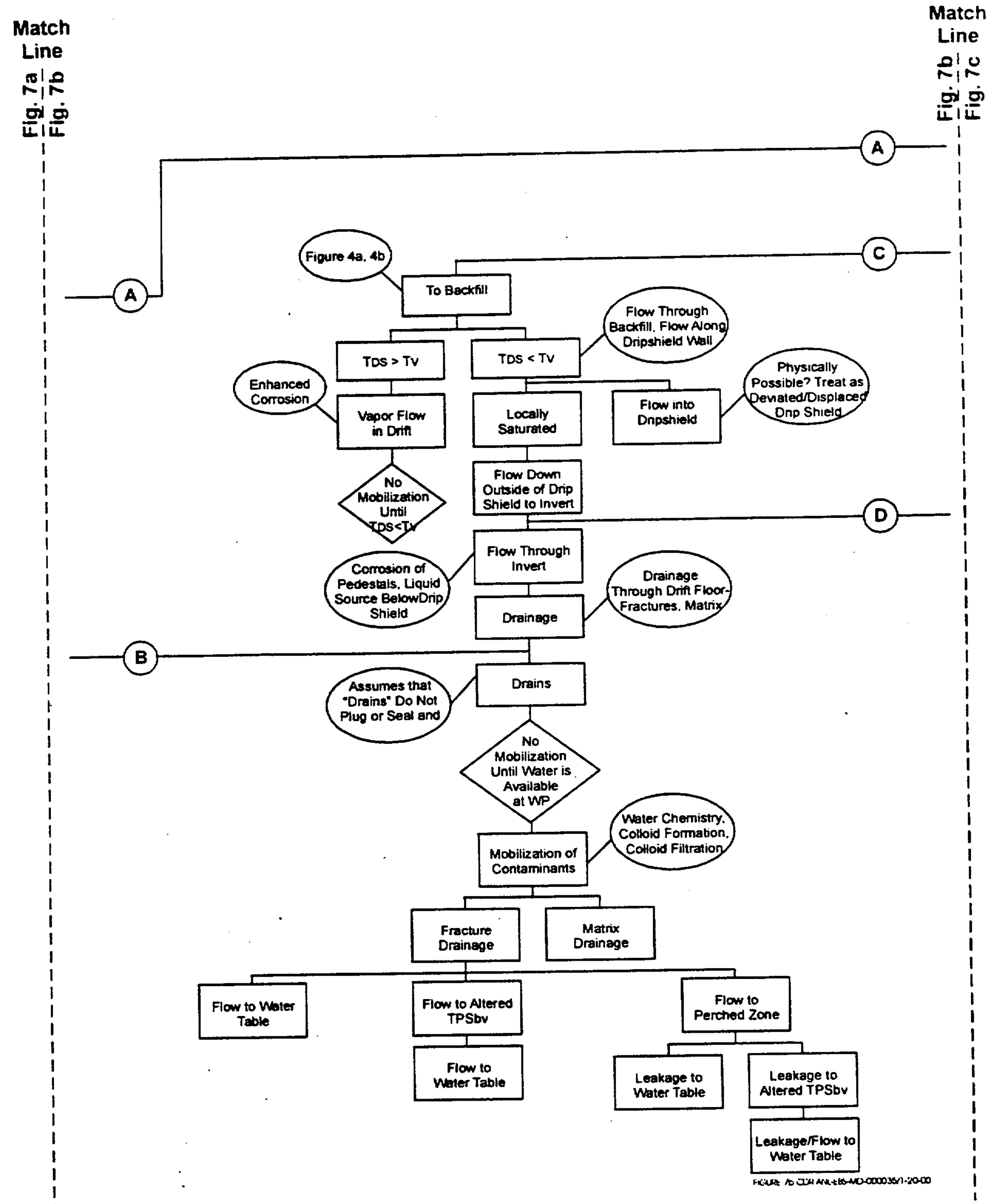


Figure 7b. Part 7b of Figure 7
(See Figure Legend in Figure 7f)

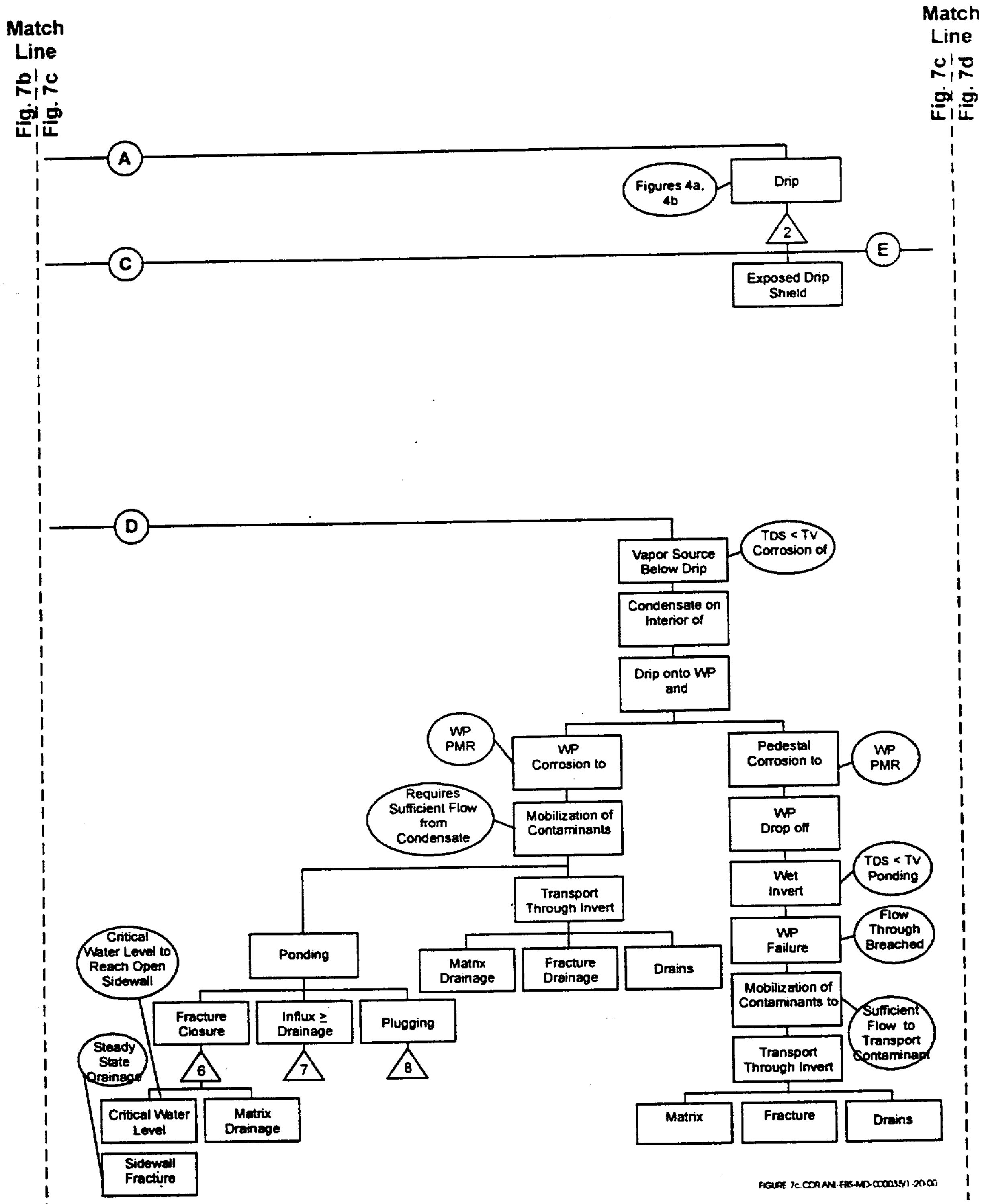


Figure 7c. Part 7c of Figure 7
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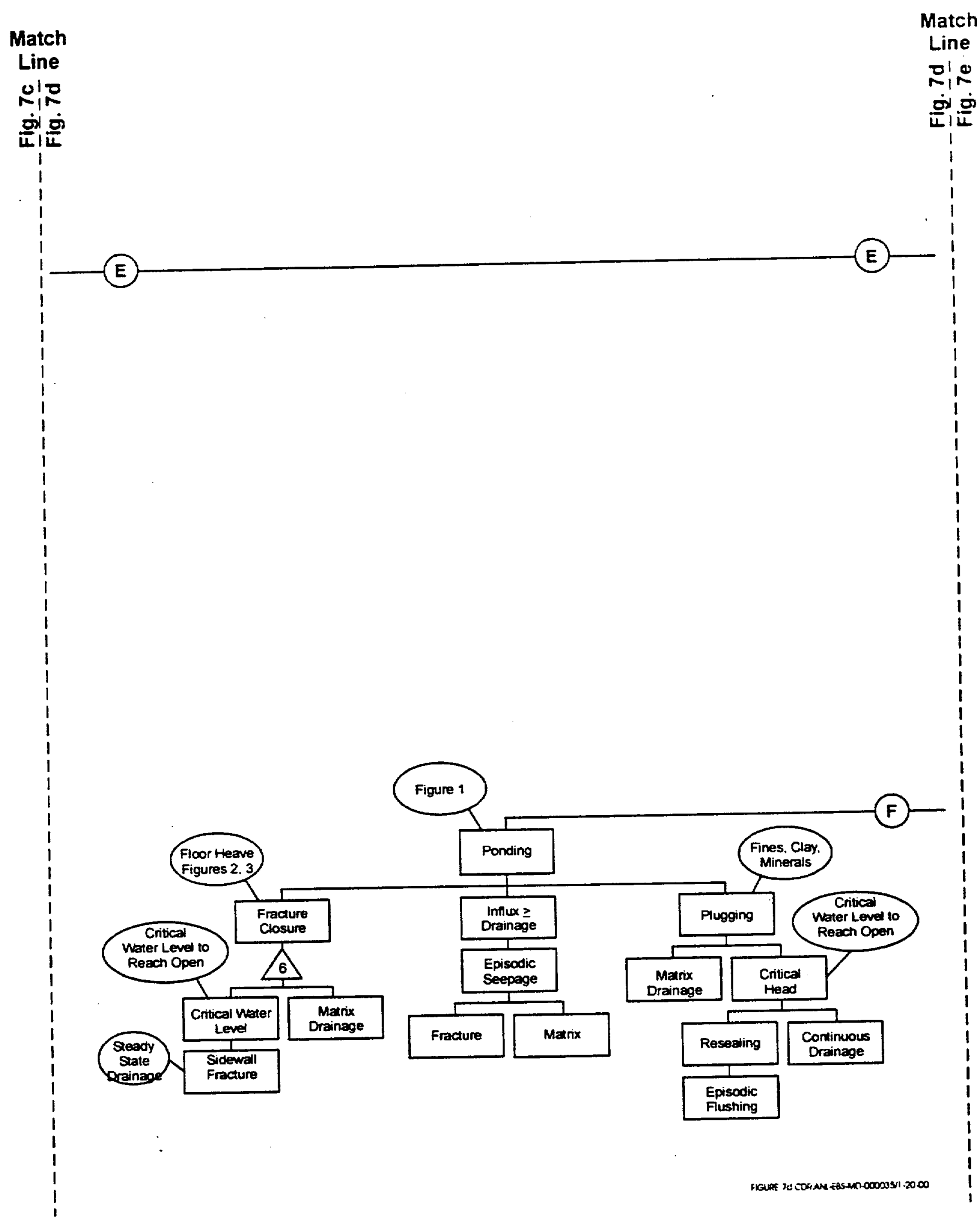


Figure 7d. Part 7d of Figure 7
(See Legend in Figure 7f)

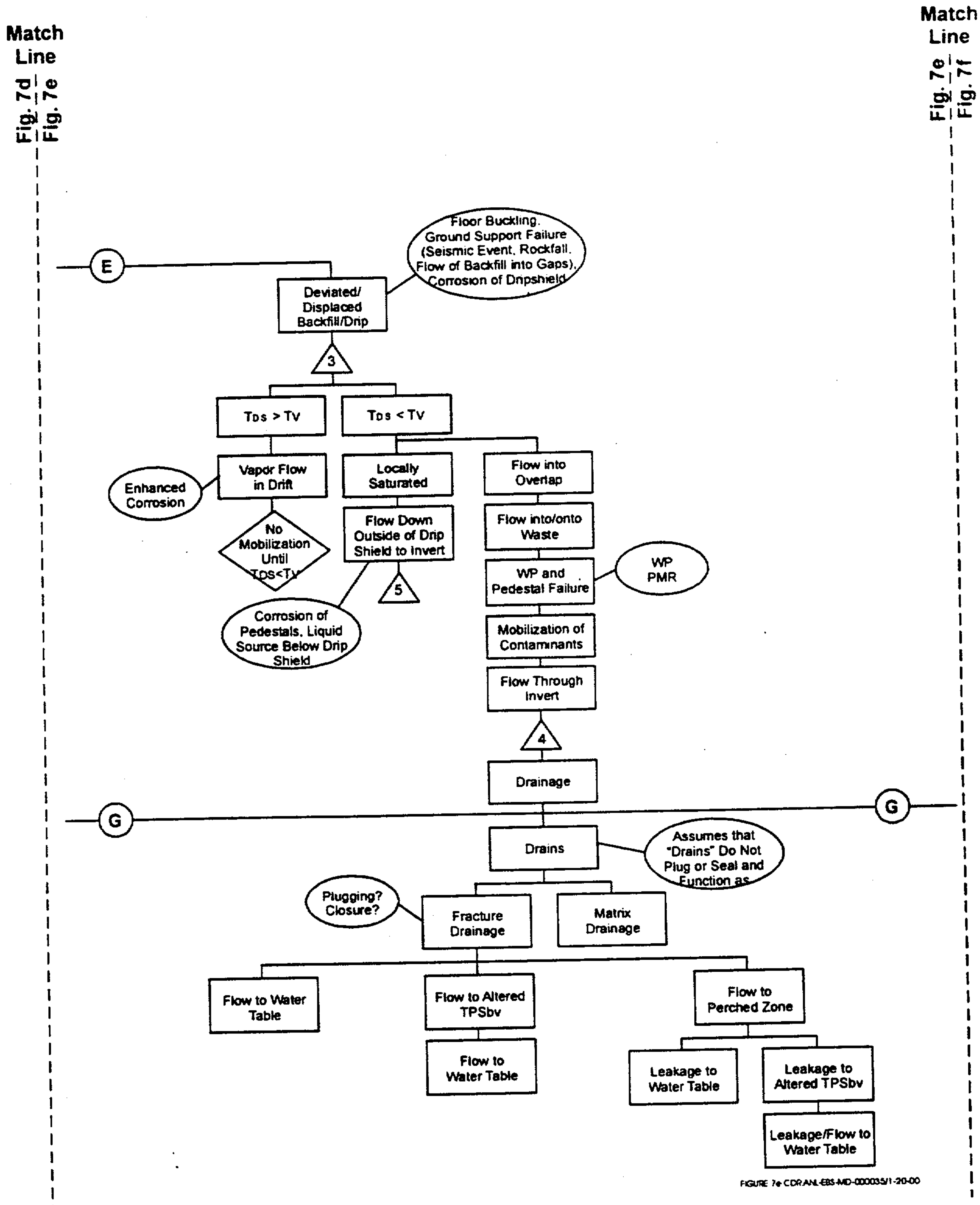


Figure 7e. Part 7e of Figure 7
(See Legend in Figure 7f)

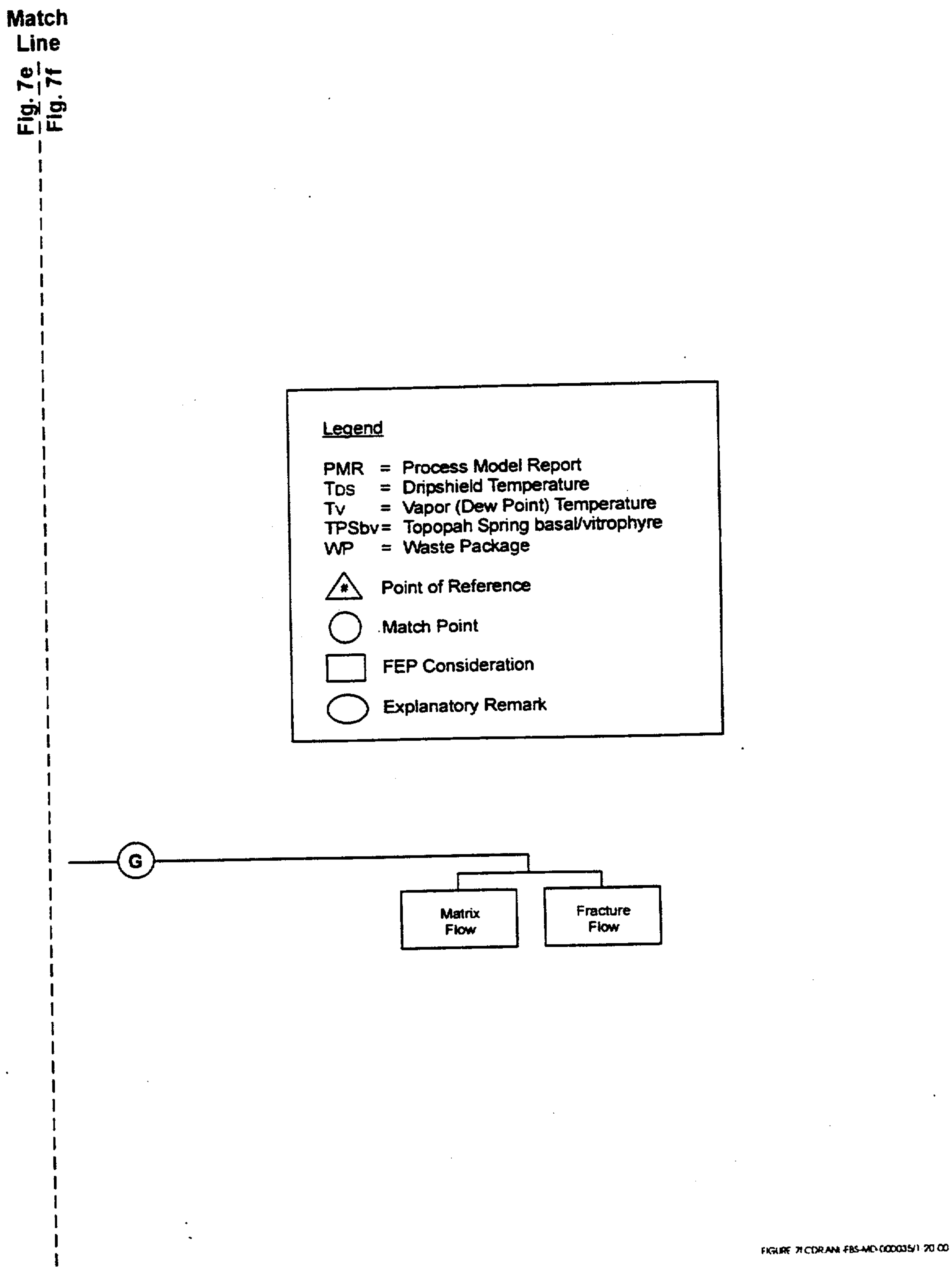


Figure 7f. Part 7f of Figure 7

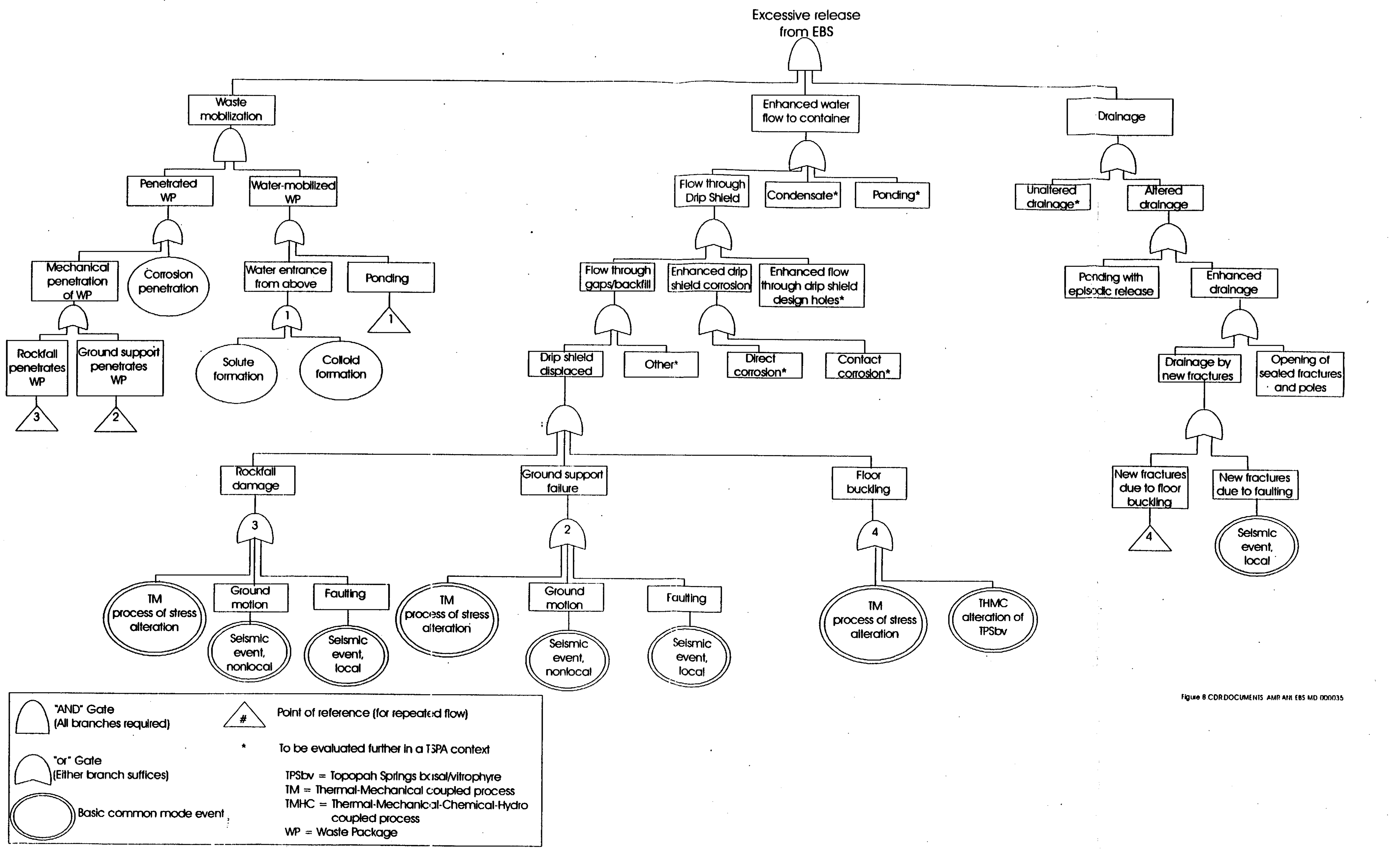


Figure 8. Common Mode Degradation Tree

Table 1. Basis for Engineered Barrier System Feature, Event, and Process Identification

	Performance Factor	Alternative Effects or Processes	Remarks
1.	Flow Types	Weeps	Locally-saturated flow, presumed to be fracture flow
		Drip	Water drops from the drift crown or fracture openings
		Matrix flow	Classical unsaturated flow through the matrix (Richard's equation.)
2.	Water Sources	Infiltrate	Fracture and matrix flow of water entering from the surface
		Condensate	Condensate formed in rock and in drift, accumulated because of thermal-hydrologic processes
		Condensate under the Drip Shield (DS)	Condensation of water vapor beneath the drip shield from water in the invert
3.	Chemistry	Rock/water interactions for condensate	Alters solutes for corrosion processes
		Rock/water interactions for infiltrate	Alters solutes for corrosion processes
		Rock/water interactions for waste package effluent	Interaction of dissolved and colloidal contaminants with invert and drift floor for transport
		Rock/water interactions of fines and minerals in fractures along flow pathways	Interactions may plug fractures
		Colloids	Stability in the invert, filtration and alteration in the exit transport
4.	Heat	Thermo-mechanical interaction, stress -evolution	Rotation of least principal stress, fracture closure, thermal expansion of rock, residual drift size
		Thermo-chemical interaction, transport and sorption	Temperature rate and phase dependencies
		Thermo-chemical interaction, corrosion of ground support, pedestals, rails, etc.	Temperature rate dependencies
5.	Drift Alteration	Floor heave (buckling)	Buckling due to mechanical stress relief and to thermo-mechanical coupling
		Ground support failure	Failure due to mechanical stress relief and thermo-mechanical coupling
		Rockfall	
		Stopping up fracture zones	Localized rockfall affecting water intrusion
		Invert movement	Associated with floor and wall movement

Table 1. Basis for Engineered Barrier System Feature, Event, and Process Identification (Continued)

	Performance Factor	Alternative Effects or Processes	Remarks
6.	Pathways	Infiltrate entering the EBS	Fracture and matrix flow of surface water
		Condensate entering the EBS	Condensate in the rock and in the drift provides a local water source.
		Movement around the drip shield	Drip shield functions as designed
		Movement through the drip shield	Drip shield fails in some locations
		Movement under the drip shield in the invert	Condensate flows along drip shield inner wall and drips
		Movement through the invert	Water chemistry changes, affects consequences of ponding.
		Flow/transport exiting in open fractures	Fracture exits in the drift floor
		Flow/transport exiting in plugged fractures	Fracture exits are plugged by fines, clays, mineral alterations, etc.
		Flow/transport exiting as matrix flow	Idealized transport in porous media.
7.	Corrosion	Chemical properties of infiltrate and condensate	Rock/water interactions would be expected to provide different water constituents for these different sources.
		Corrosion of the drip shield	Direct corrosion (water contact) and contact corrosion (with waste packages or rails).
		Corrosion of pedestals	Pedestal failure puts waste package on or in invert.
		Corrosion of ground support	Failure of rockbolts, wire mesh, and steel sets affects drift stability.
8.	Mobilization of Contaminants	Fuel/waste form effects on mobilization	Effects on solubility, speciation, colloid formation, stability
		Interaction with invert	Alteration of solute phases, sorption
		Interaction with drift floor	Alteration of solute phases, sorption
		Interaction with fractures and fracture plugging	Mineral alterations (e.g., reaction with fines), possible ponding
9.	Transport	Through invert	Alteration of solute phases, sorption
		Along drift floor	Alteration of solute phases, sorption
		Through drift floor	Fracture and matrix flow/transport including plugging
		Ponding and localization of flow	Ponding, episodic release, solubility limited transport

Table 1. Basis for Engineered Barrier System Feature, Event, and Process Identification (Continued)

	Performance Factor	Alternative Effects or Processes	Remarks
10.	Ventilation	Mine – water removal/dryout	Establishes initial conditions
		Mine – heat removal	Establishes initial conditions
		Mountain – Background	Heat driven – postclosure affects temperature, moisture, exchange with atmosphere
		Mountain – Chimney effects	Chimney behavior of fault zones
11.	Seals	Ramps	Not in the waste emplacement drifts
		Shafts	Undefined in the EBS
		Drifts	Undefined purpose
12.	Drains	Location	Floor, lower ribs
		Design	Rock filled, intercepts likely locations of stress-relief fractures
		Functional lifetime	Probably not needed during the thermal period (no liquid water)
		Plugging and other failure modes	Thermo-mechanical compression, fines, mineralogical changes

Table 2. Engineered Barrier System Features, Events, and Processes Reference Figures

FEPs	Figures
Features: All of the principal components of the EBS except "Ground Support"	Figures 1 through 6
Events: Rockfall	Figures 1 through 6
Processes:	
Condensate zone formation	Figures 1, 2
Dryout	Figures 1, 2
Floor buckling	Figures 1, 2
Condensation	
In drift	All
Beneath drip shield	Figures 3, 4, 5, 6
Flow along drip shield wall	
Outside	Figures 3A, B, 4, 5, 6
Inside	Figures 3A, 4, 6
Flow through backfill	
Unsaturated zone/ saturated zone flow along drip shield	Figures 1, 2, 3A, 4, 5, 6
Unsaturated zone/ saturated zone flow through backfill	Figures 3A, 4, 5, 6
Movement of backfill through gaps and separations in drip shield	Figures 1, 2
Fluid Flow into gaps and separations in drip shield	
Unsaturated zone flow in relocated backfill	Figures 1, 2
Saturated zone flow through openings	Figures 1, 2
Drainage	
Through invert	Figures 3, 4, 5, 6
Through drift floor	Figures 1, 2, 3A, 4, 5, 6
Matrix flow	Figure 6
Fracture flow	Figure 6
Through drift walls	Figures 1, 2
Through engineered drains (if such are used)	Figure 6
Drip Shield Movement Relative to Waste Packages/Rails	Figures 1, 2
Flow of backfill through gaps and separations.	Figures 1, 2

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
F	FEATURES										
F1	Drip Shield			ebs2 2.1.06.07.00			X				
		a	Drip Shield design (geometry, materials, clearances, etc.)	Deferred						WP, SS	
		b	Drip Shield supports	ebs3			X				
F2	Ground Support			ebs21 2.1.06.02.00			X				
		a	Steel sets design	Deferred						SS	
		b	Wire mesh and Rockbolts	ebs21			X				
		c	Rockbolts and grout	ebs22 2.1.06.01.00				X			
F3	Backfill			ebs4 2.1.04.02.00			X				
		a	Backfill design	Deferred						SS	
		b	Material type, size, backfill weld	2.1.04.05.00			X	X			
F4	Invert			ebs5			X				
		a	Invert design	Deferred							
F5	Drains (if used)			ebs23			X				
		a	Drain design, location	Deferred						SS	
F6	Emplacement Equipment			Deferred						SS	
		a	Rails	ebs7			X				
		b	Pedestal	ebs8			X				

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References (Continued)

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
E	EVENTS										
E1	Rockfall			2.1.07.01.00, 2.1.07.02.00			X				
		a	Distortion of drip shield	ebs6			X				
		b	Mesh impact on backfill	2.1.04.04.00			X				
E2	Seismic Event			ebs11			X				
		a	Waste package displacement	Deferred						WP	
		b	Drip shield displacement	Deferred						WP, SS	
		c	Rockfall	Deferred						SS, WP	
		d	Establish new flow pathways	N/A for EBS FEPs							UZ, NFE
		e	Ground motion	ebs9			X				
E3	Ground Support Failure			ebs12			X				
		a	By seismic effects	Deferred						SS	
		b	By thermo-mechanical processes	2.1.11.07.00				X			
		c	By corrosion	Deferred						SS	
E4	Mechanical Damage to Waste Package (after drip shield emplacement)			N/A for EBS FEPs							WP

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References (Continued)

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
P	PROCESSES										
P1	Condensate Zone Formation			N/A for EBS FEPs					X		UZ, NFE
P2	Dryout of Rock			2.1.08.11.00					X		
P3	Between Drift Drainage			N/A for EBS FEPs							NFE
P4	Thermo-Mechanical Evolution of Repository Block			N/A for EBS FEPs, ebs13 2.1.04.04.00, 2.1.07.06.00, 2.1.08.08.00, 2.1.11.01.00, 2.1.11.05.00, 2.1.11.07.00, 2.1.11.09.00					X		UZ, NFE
		a	Heating w/thermal expansion and relaxation	N/A for EBS FEPs							UZ, NFE
		b	Floor buckling	2.1.07.06.00			X		X		UZ, NFE
		c	Fracture sealing and opening	N/A for EBS FEPs							UZ, NFE
		d	Ground support loading/unloading	Deferred						SS	

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References (Continued)

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
P5	Shear Fracture/Fault Movement and Relaxation			ebs14					X		
		a	Establishes flow pathways in and out	N/A for EBS FEPs							UZ, NFE
		b	Distorts drip shield and rails	Deferred						WP, SS	
P6	Condensation			N/A for EBS FEPs							UZ, NFE
		a	In drift	2.1.08.04.00			X				
		b	Beneath drip shield	ebs15, 2.1.06.06.00			X				
P7	Thermo-chemical Alteration of the Topopah Spring Basal Vitrophyre		Contributes to floor heave	N/A for EBS FEPs							UZ, NFE
P8	Reflux			N/A for EBS FEPs							UZ
		a	Reflux heat pipe	N/A for EBS FEPs							UZ
		b	Reflux drainage of condensate zone	ebs16			X				
		c	Reflux autocatalytic drainage of condensate zone	N/A for EBS FEPs							UZ
P9	Flow Along Drip Shield Wall			2.1.08.01.00			X				
		a	Outside drip shield wall	ebs24			X				
		b	Inside drip shield wall	ebs17			X				

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References (Continued)

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
P10	Flow Through Backfill			ebs18 2.1.04.01.00, 2.1.08.01.00			X				
		a	Flow through backfill	ebs18			X				
		b	Flow along drip shield	ebs18			X				
P11	Movement of Backfill Through Gaps and Separations in Drip Shield			ebs19 2.1.04.04.00			X				
P12	Fluid Flow into Gaps and Separations in Drip Shield			ebs20 2.1.06.06.00			X				
		a	Flow in relocated backfill	ebs20			X				
		b	Flow through openings	ebs20			X				
P13	Microbial Activity			ebs25, 2.1.10.01.00, 2.1.11.08.00, 2.1.12.04.00	X						
		a	In invert (alteration of water chemistry)	See P13	X						
		b	In backfill (alteration of water chemistry)	See P13	X						
		c	Under drip shield	See P13	X						
P14	Alteration of Infiltrate Chemistry (Non-Microbial)			2.1.04.02.00, 2.1.09.01.00				X			
		a	In backfill	See P14				X			
		b	In invert	See P14				X			

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References (Continued)

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
P15	Rockbolt/Grout Corrosion			ebs26 2.1.06.01.00, 2.1.06.02.00, 2.1.09.02.00, 2.1.12.05.00				X			
		a	Altering flow path	ebs26				X			
		b	Altering fluid chemistry	ebs26 2.1.12.05.00				X			
P16	Wire Mesh Corrosion		Altering fluid chemistry	2.1.09.02.00				X			
P17	Drainage with Transport			2.1.08.06.00, 2.1.08.07.00		X					
		a	Through invert	2.1.08.05.00, 2.1.08.07.00		X	X				
		b	Through backfill	2.1.04.09.00		X	X				
		c	Matrix flow through drift floor	Included in other FEPs		X	X				
		d	Fracture flow through drift floor	Included in other FEPs		X	X				
		e	With sealing and plugging	ebs27		X	X				
		f	Through drift walls	Included in other FEPs		X	X				
		g	Through constructed drains (if used)	ebs28		X	X				
		h	Ponding	ebs29		X	X				
		i	Controls on ponding	ebs28			X				

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References (Continued)

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
P18	Drip Shield and Waste Package Corrosion			N/A for EBS FEPs	X						WP
		a	Direct aqueous corrosion	ebs32	X						
		b	Contact corrosion	N/A for EBS FEPs	X						WP
		c	Microbial corrosion	ebs25	X						
		d	Flow of backfill through corroded elements	ebs30			X				
		e	Fluid flow through corroded elements to waste packages	ebs31, 2.1.06.06.00			X				
P19	Drip Shield Movement Relative to Waste Packages/Rails			ebs10			X				
		a	Thermo-mechanically induced distortion	N/A for EBS FEPs			X				WP
		b	Pedestal collapse	ebs1 2.1.06.05.00			X				
		c	Relative seismic motion	ebs11			X				
		d	Loading distortion	ebs6			X				

Table 3. Engineered Barrier System Features, Events, and Processes Identification and Analysis Model Report References (Continued)

FEP Category		Sub/secondary FEP		"New" or Database Reference FEP Number	Relevant EBS AMRs (see Attachment II)					Reference Design Area[a]	Reference PMR[b]
					E0110	E0050	E0090	E0100	E0120		
P20	Alteration of Temperature-Dependent Chemical Activity			2.1.04.02.00, 2.1.09.05.00, 2.1.09.06.00, 2.1.09.08.00, 2.1.09.12.00, 2.1.09.19.00, 2.1.11.04.00, 2.1.11.09.00, 2.1.12.03.00, 2.2.08.04.00	X			X			
		a	Reactions w/ invert materials	See P20				X			
		b	Solute alteration (phase changes and sorption)	See P20				X			
		c	Colloid formation enhanced by engineered materials	2.1.09.14.00, 2.1.09.16.00, 2.1.09.17.00, 2.1.09.18.00, 2.1.09.19.00	X			X			
P21	Ventilation		Water removal, Heat removal, Efflorescence (mineral deposition because of evaporation)	1.1.02.02.00 Deferred (see Section 6.6.2)						SS	
P22	Seal Degradation		Thermo-mechanical alteration, Chemical, Separation from rock wall	Deferred (see Section 6.6.2)						SS	
P23	Igneous Processes		Interaction of EBS with propagating dike, interaction of magmatic intrusion with waste packages, drip shield, and backfill	N/A for EBS FEPs (see Section 6.6.2)							DE

NOTE: SS=Subsurface; WP=Waste Package; UZ=Unsaturated Zone; NFE=Near Field Environment; DE=Disruptive Events

[a] = Reference Design Area for "Deferred" FEPs; [b] = Reference PMR is for "N/A" FEPs

Table 4. Summary of Common Modes Identified in Figure 8

Common Mode	Description	Remarks
Distal seismic event	Local, disruptive ground motion is produced by an earthquake occurring outside the potential repository	Likelihood estimated in the Probabilistic Seismic Hazard Assessment (CRWMS M&O 1998)
Proximal seismic event	Faulting or movement on an existing fault occurs through the potential repository	Likelihood estimated in the Probabilistic Seismic Hazard Assessment (CRWMS M&O 1998)
Thermo-chemical alteration of the Topopah Spring basal vitrophyre	Thermo- chemical alteration of glasses to clays and zeolites, in this unit beneath the potential repository, accompanied by volume increases which appear at the nearest free surface, namely the drift floors.	Mechanism established experimentally and reported to the U.S. Department of Energy (DOE 1996)
Local igneous event	A basaltic intrusion intersects potential repository drifts and may reach the surface. EBS design and performance is of little significance for this occurrence.	Likelihood estimated in Probabilistic Volcanic Hazards Assessment (CRWMS M&O 1996)
Thermo-mechanical stress alteration	Stress alteration, increase, and relaxation during repository life causes massive failure of ground support, initiating a sequence of associated failures	Unknown; thought to be limited by gradual and local failure of ground support

Table 5. Engineered Barrier System FEPs and Degradation Modes

FEP Category		FEP Number	FEP Name	FEP Description
FEATURES				
F1	Drip Shield	ebs2	Drip shield	Liquid water contact with the waste package is believed to affect the rate of corrosion of the metals, exposing the waste. The drip shield is intended to reduce direct liquid contact with the containers.
		ebs 3	Drip shield supports	Failure of the drip shield supports allows the drip shield to make contact with the waste package or with the rails. Since the drip shield is made of Ti, the rails of steel, and the waste packages of a high-nickel alloy, contact could result in contact corrosion possibly affecting the integrity of the waste package.
		2.1.06.07.00	Effects and degradation of drip shield	The drip shield will affect the amount of water reaching the waste package. Behavior of the drip shield in response to rockfall, ground motion, and physical, chemical degradation processes should be considered. Effects of the drip shield on the disposal region environment (for example, changes in relative humidity and temperature below the shield) should be considered for both intact and degraded conditions. Degradation processes specific to the chosen material should be identified and considered. For example, oxygen embrittlement should be considered for titanium drip shields.
F2	Ground Support	ebs 21	Ground support – Wire mesh and rockbolts	The expected life of ground support after the operational phase of the repository is unknown. Failure of ground support allows rockfall and development of a chimney or enlarged drift and filling of fracture or fault zones.
		ebs 22	Ground support – rockbolts and grout	The issues are that ground support introduces materials (Fe, grout, etc.) into the facility, which affects water chemistry. All ground support eventually fails, allowing rockfall, altering drift size and properties, and affecting flow pathways.
		2.1.06.01.00	Degradation of cementitious materials in drift	Degradation of cementitious material used for any purposes in the disposal region may affect long-term performance through both chemical and physical processes. Degradation may occur by physical, chemical, and microbial processes.
		2.1.06.02.00	Effects of rock reinforcement materials	Degradation of rock bolts, wire mesh, and other materials used in ground control may affect the long-term performance of the repository.
F3	Backfill	ebs 4	Backfill	Crushed rock is placed to protect the waste package, or the drip shield and waste package from rockfall, failure of ground support, and possibly as a Richard's barrier for flow. Location of backfill, the size, and material type, all affect water chemistry (and the corrosion rates for drip shield and waste packages, dissolution rates for waste), and thermal properties (and waste temperatures and cladding failure). Suggestions for material type currently include sand, crushed limestone, marble, and crushed tuff. The last is the subject of investigation.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
		2.1.04.02.00	Physical and chemical properties of backfill	The physical and chemical properties of the backfill may affect groundwater flow, waste package and drip shield durability, and radionuclide transport in the waste disposal region.
		2.1.04.05.00	Backfill evolution	Properties of the backfill may change through time, due to processes such as silica cementation, alteration of minerals, thermal effects, and physical compaction. These changes could then affect the movement of water and radionuclides in the backfill.
F4	Invert	ebs5	Invert	The invert materials, currently expected to be crushed rock, form the bed for the rails and will be the resting place for the waste package after the support pedestals fail. The invert is part of the flow pathway from the waste to the drift bottom and exit from the drift. The invert is also part of the flow pathway for water deflected by the drip shield from the waste packages. Water can accumulate in the invert, acting as a water vapor source for corrosion or possibly ponding. Accordingly, invert materials affect water chemistry for transport.
F5	Drains (if used)	ebs23	Drains (if used)	Water accumulation in the drift would wet the invert materials, possibly pond, and provide a continuing source of water vapor beneath the drip shield and backfill for interaction with waste packages and their supports.
F6	Operational Equipment	ebs7	Rails	Rails represent a material, steel, added to the repository which is not necessary to long-term isolation, but which may have an impact on corrosion of the drip shield and on water chemistry for transport. If the Ti drip shield and the steel rails are in contact, contact corrosion is expected, which could affect the long-term ability of the drip shield to divert water from the waste package. Such contact would be expected locally as a result of a seismic disturbance, rockfall, or ground support failure.
		ebs8	Pedestal	The pedestal may be distorted or rack because of floor heave (thermo-mechanical stress adjustment) and ground motion (seismic event), or may fail due to corrosion. Failure by any mode will drop the waste package onto or into the invert.
	EVENTS			
E1	Rockfall	ebs6	Rockfall loading distortion of drip shield	Contact corrosion, compromising the drip shield or the waste package develops as a result of displacement or distortion of the drip shield.
		2.1.04.04.00	Mechanical effects of backfill	Backfill may alter the mechanical evolution of the drift environment by providing resistance to rock creep and rock fall, by changing the thermal properties of the drift, or by other means. Impacts of the evolution of the properties of the backfill itself should be considered.
		2.1.07.01.00	Rockfall (large block)	Rockfall may occur that are large enough to mechanically tear or rupture waste packages.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
		2.1.07.02.00	Mechanical degradation or collapse of drift	Partial or complete collapse of the drifts, as opposed to discrete rockfall, could occur as a result of seismic activity, thermal effects, stresses related to excavation, or possibly other mechanisms. Drift collapse could affect stability of the engineered barriers and waste packages. Drift collapse may be localized as stopping at faults or other geologic features. Rockfall of small blocks may produce rubble throughout part or all of the drifts.
E2	Seismic Event	ebs9	Ground motion	Ground motion, generated by seismic events, provides accelerations to components of the repository, including the waste packages, drip shield, backfill, surrounding rock, and ground support. These accelerations cause relative motion of the components and could generate ground support failure, rockfall, and damage to waste packages and drip shields.
		ebs11	Relative seismic motion	Ground motion in the potential repository generates waste package displacement, relative displacement between waste package, drip shield, and rails, and ground support failure, and rockfall.
E3	Ground Support Failure	ebs12	Ground support failure	Failure of ground support, for whatever reason, allows rockfall, displacement of backfill and waste packages, and development of new flow pathways. Possible cases include ground motion, thermo-mechanical stress adjustment and corrosion.
		2.1.11.07.00	Thermally-induced stress changes in waste and EBS	Thermally induced stress changes in the waste and EBS may affect performance of the potential repository. Relevant processes include rockfall.
PROCESSES				
P2	Dryout of Rock	2.1.08.11.00	Resaturation of repository	Water content in the potential repository will increase following the peak thermal period.
P4	Thermo-mechanical Evolution of Repository Rock	ebs13	Thermo-mechanical evolution of a repository block	Thermo-mechanical coupling, which alters the stress state of the rock surrounding the repository, affects floor buckling, fracture sealing and openings to the EBS, and loading and unloading of ground support.
		2.1.04.04.00[a]	Mechanical effects of backfill	See E1
		2.1.07.06.00	Floor buckling	Buckling, or heave, of the drift floor occurs in response to changing stress. Floor buckling may affect the performance of components of the EBS such as the drip shield, the invert, and the pedestal. Effects may include movement of EBS components, and changes in the topography of the surface of the drift floor and invert that may affect water flow.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
		2.1.08.08.00	Induced hydrological changes in the waste and EBS	Thermal, chemical, and mechanical processes related to the construction of the potential repository and the emplacement of waste may induce changes in the hydrologic behavior of the system.
		2.1.11.01.00	Heat output / temperature in waste and EBS	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, hydrologic effects, and the possibility of exothermal reactions. Considerations of the heat generated by radioactive decay should take different properties of different waste types, including U.S. Department of Energy spent nuclear fuel, into account.
		2.1.11.05.00	Differing thermal expansion of repository components	Thermally-induced stresses could alter the performance of the waste or EBS. For example, thermal stresses could create pathways for preferential fluid flow in the backfill or through the drip shield.
		2.1.11.07.00*	Thermally-induced stress changes in waste and EBS	See P1
		2.1.11.09.00	Thermal effects on liquid or two-phase fluid flow in the waste and EBS	Temperature differentials may result in convective flow in the waste and EBS.
P5	Shear Fracture/Fault Movement and Relaxation	ebs14	Shear fracture/ fault movement and relaxation	Fractures that might otherwise be closed during the thermal period, because of compression from thermal expansion, are maintained as open pathways because of shear movement. Movement also allows distortion of the drift and the relative location of drip shield, rails, and waste packages, with possible contact being established.
P6	Condensation	ebs15	Condensation beneath drip shield	Condensation on the inner surface of the drip shield circumvents its performance and provides water to drip onto the waste package and its supporting pedestal. Enhanced corrosion of waste package and pedestal becomes possible.
		2.1.06.06.00	Effects and degradation of drip shield	The drip shield will affect the amount of water reaching the waste package. Behavior of the drip shield in response to rockfall, ground motion, and physical, chemical degradation processes should be considered. Effects of the drip shield on the disposal region environment (for example, changes in relative humidity and temperature below the shield) should be considered for both intact and degraded conditions. Degradation processes specific to the chosen material should be identified and considered. For example, oxygen embrittlement should be considered for titanium drip shields.
		2.1.08.04.00	Condensation forms on backs of drifts	Emplacement of waste in drifts creates a large thermal gradient across the drifts. Moisture condenses on the roof and flows downward through the backfill.
P8	Reflux	ebs16	Reflux drainage of condensate zone	Condensate zones could contain a substantial amount of mobile water able to flow back into the drifts, perhaps as a single extended episode.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
P9	Flow Along Drip Shield Wall	ebs17	Flow along drip shield (inside) wall	Water vapor is available from water otherwise diverted from the waste packages, which flows down the drip shield and enters the invert, where it may accumulate.
		ebs24	Flow along drip shield (outside) wall	Since the segmented drip shield will see liquid water, the concerns are the effectiveness of the diversion (i.e., will liquid flow pass through the overlaps) and the corrosion resistance of the drip shield material to the water chemistry in the impinging water.
		2.1.04.01.00	Preferential pathways in the backfill	Preferential pathways for flow and diffusion may exist within the backfill and may affect long-term performance of the waste packages. Backfill may not preclude hydrological, chemical, and thermal interactions between waste packages within a drift.
		2.1.08.01.00	Increased unsaturated water flux at the repository	An increase in the unsaturated water flux at the potential 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.
P10	Flow Through Backfill	ebs18	Flow through backfill	Flow through the backfill reacts chemically with the backfill. This chemically altered water then interacts with the drip shield and rails to eventually reach the invert.
		2.1.04.01.00*	Preferential pathways in the backfill	See P9
		2.1.08.01.00*	Increased unsaturated water flux at the repository	See P9
P11	Movement of Backfill Through Gaps and Separations in Drip Shield	ebs19	Movement of backfill through gaps and separations in drip shield	The continuity of the drip shield and its ability to deflect liquid water could be compromised as a result of movement produced by thermo-mechanical or seismic processes.
		2.1.04.04.00*	Mechanical effects of backfill	See E1
P12	Fluid Flow Into Gaps and Separations in Drip Shield	ebs20	Fluid flow into gaps and separations in drip shield	The ability of the drip shield to deflect liquid water could be compromised as a result of the movement of liquid water through gaps or spaces which develop between drip shield segments.
		2.1.06.06.00*	Effects and degradation of drip shield	See P7
P13	Microbial Activity	ebs25	Microbial activity	The concern is microbially accelerated corrosion and mobilization occurring in the warm, moist environment of the EBS.
		2.1.10.01.00	Biological activity in waste and EBS	Biological activity in the waste and EBS may affect disposal-system performance by altering degradation processes such as corrosion of the waste packages and waste form (including cladding), by affecting radionuclide transport through the formation of colloids and biofilms, and by generating gases.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
		2.1.11.08.00	Thermal effects: chemical and microbiological changes in the waste and EBS	Temperature changes may affect chemical and microbial processes in the waste and EBS.
		2.1.12.04.00	Gas generation (CO2, CH4, H2S) from microbial degradation	Microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials, will produce mainly CO2, but also other gases. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions (temperature, pressure, geochemical conditions), and the substrates present.
P14	Alteration of Infiltrate Chemistry (Non-Microbial)	2.1.04.02.00[a]	Physical and chemical properties of backfill	See F3
		2.1.09.01.00	Properties of the potential carrier plume in the waste and EBS	When unsaturated flow in the drifts 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.
P15	Rockbolt/Grout Corrosion	ebs26	Rockbolt/grout corrosion	The corrosion and alteration changes the flow path for water entrance and alters the chemistry of the water following those flow paths.
		2.1.06.01.00[a]	Degradation of cementitious materials in drift	See F2
		2.1.06.02.00[a]	Effects of rock reinforcement materials	See F2
		2.1.09.02.00	Interaction with corrosion products	Corrosion products produced during degradation of the metallic portions of the EBS and waste package may affect the mobility of radionuclides. Sorption/desorption and co-precipitation/dissolution processes may occur.
		2.1.12.05.00	Gas generation from concrete	Production of gases from the aging and degradation of concrete may occur through radiolysis of water in the cement pore spaces and microbial growth on concrete.
P16	Wire Mesh Corrosion	2.1.09.02.00[a]	Interaction with corrosion products	See P15
P17	Drainage With Transport	ebs27	Drainage with transport – sealing and plugging	Normal functioning of drainage in the drifts is not established, so how drainage will change if fractures are plugged is unclear. Suggestions include ponding until fractures in the wall are reached by the water level or until there is sufficient head to clear the fractures.
		ebs28	Drainage – through constructed drains	Water accumulation would be possible in a drift, particularly in a region of floor buckling, if normal drainage is blocked. Such blockage could occur if fines and debris are deposited in fractures or as sediment along the drift floor. Excess water could allow more rapid corrosion and contaminant mobilization. The conundrum here is that rapid draining of water sooner might also mean rapid draining of contaminated water later.
		ebs29	Drainage with transport – ponding	Water could accumulate in the invert in sufficient amounts to flood the waste package, enhancing corrosion and eventual mobilization. Criticality could be a possible consequence.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
		2.1.04.09.00	Radionuclide transport through backfill	Radionuclide transport in the drift environment may be affected by the presence of backfill. Transport of both dissolved and colloidal species, advective and diffusive effects and sorption processes should be considered.
		2.1.08.05.00	Flow through invert	Flow through invert results in transport of contaminants to the unsaturated zone
		2.1.08.06.00	Wicking in waste and EBS	Capillary rise, or wicking, is a potential mechanism for water to move through the waste and engineered barrier system.
		2.1.08.07.00	Pathways for unsaturated flow and transport in the waste and EBS	Unsaturated flow and radionuclide transport may occur along preferential pathways in the waste and EBS. Physical and chemical properties of the EBS and waste form, in both intact and degraded states, should be considered in evaluating pathways.
P18	Drip Shield Corrosion	ebs25[a]	Microbial Activity	See P13
		ebs30	Drip shield corrosion – flow of backfill through corroded elements	The continuity of the drip shield and its ability to deflect liquid water could be compromised as a result of holes produced by corrosion.
		ebs31	Drip shield corrosion – fluid flow through corroded elements to waste packages	Deflection of liquid water away from the waste packages depends on continuity of the drip shield and the absence of penetrations.
		ebs32	Corrosion of waste packages	Corrosion may contribute to waste package failure. Corrosion is most likely to occur at locations where water drips on the waste packages, but other mechanisms should be considered.
		2.1.06.06.00[a]	Effects and degradation of drip shield	See P7
P19	Drip Shield Movement Relative to Waste Package/ Rails	ebs1	Pedestal collapse	The waste package, as a result of pedestal collapse, lies on or in the invert and could be in contact with the drip shield and the rails, and be exposed to contact corrosion. While bedded in the invert, the waste package is more likely to see local ponding and the enhanced corrosion and mobilization which might accompany it.
		ebs6[a]	Rockfall loading distortion of drip shield	See E1
		ebs10	Drip shield movement relative to waste packages/rails	Contact of the Ti drip shield with the waste package or with the steel rails will cause contact corrosion. In the former case, corrosion of the waste package will be enhanced, while in the latter case, that of the drip shield will be accelerated. Presumably, the fate of the rails is inconsequential.
		ebs11[a]	Relative seismic motion	See E2
		2.1.06.05.00	Degradation of invert and pedestal	Degradation of the materials used in the invert and the pedestal supporting the waste package may occur by physical, chemical, or microbial processes, and may affect the long-term performance of the repository.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
P20	Alteration of Temperature-Dependent Chemical Activity	2.1.04.02.00*	Physical and chemical properties of backfill	See F3
		2.1.09.05.00	In-drift sorption	Sorption of radionuclides within the waste and EBS may affect the aqueous concentrations.
		2.1.09.06.00	Reduction-oxidation potential in waste and EBS	The redox potential in the waste and EBS influences the oxidation of barrier and waste-form materials and the solubility of radionuclide species. Local variations in the redox potential can occur.
		2.1.09.08.00	Chemical gradients / enhanced diffusion in waste and EBS	The existence of chemical gradients within the disposal system, induced naturally or resulting from repository material and waste emplacement, may influence the transport of contaminants of dissolved and colloidal species.
		2.1.09.12.00	Rind (altered zone) formation in waste, EBS, and adjacent rock	Thermo-chemical processes involving precipitation, condensation and redissolution alter the 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.
		2.1.09.14.00	Colloid formation in waste and EBS	Colloids in the waste and EBS may affect radionuclide transport. Different types of colloids may exist initially ormay form during the evolution of the system by a variety of mechanisms. This FEP aggregates all types of colloids into a single category.
		2.1.09.16.00	Formation of pseudo-colloids (natural) in waste and EBS	Pseudo-colloids are colloidal sized assemblages (between approximately 1 nanometer and 1 micrometer in diameter) of nonradioactive material that has radionuclides bound to it. Pseudo-colloids include microbial colloids, mineral fragments, and humic and fulvic acids. This FEP addresses radionuclide-bearing colloids formed from host-rock materials and all interactions of the waste and EBS with the host rock environment except corrosion. Pseudo-colloids formed from corrosion of the waste form and EBS are discussed in FEP 2.1.09.17.00 Microbial colloids are discussed in FEP 2.1.09.18.00.
		2.1.09.17.00	Formation of pseudo-colloids (corrosion products) in waste and EBS	Pseudo-colloids are colloidal sized assemblages (between approximately 1 nanometer and 1 micrometer in diameter) of nonradioactive material that has radionuclides bound to it. Pseudo-colloids include microbial colloids, mineral fragments, and humic and fulvic acids. This FEP addresses pseudo-colloids such as iron oxyhyrdroxides formed from corrosion and degradation of the metals in the waste form and EBS. Radionuclide-bearing colloids formed from host-rock materials and all interactions of the waste and EBS with the host rock environment except corrosion are discussed in FEP 2.1.09.16.00. Microbial colloids are discussed in FEP 2.1.09.18.00.
		2.1.09.18.00	Microbial colloid transport in the waste and EBS	This FEP addresses the formation and transport of microbial colloids in the waste and EBS. Pseudo-colloids formed from corrosion and degradation of the metals in the waste form and EBS are discussed in FEP 2.1.09.16.00. Radionuclide-bearing colloids formed from host-rock materials and all interactions of the waste and EBS with the host rock environment except corrosion are discussed in FEP 2.1.09.17.00.

Table 5. Engineered Barrier System FEPs and Degradation Modes (Continued)

FEP Category		FEP Number	FEP Name	FEP Description
		2.1.09.19.00	Colloid transport and sorption in the waste and EBS	Interactions between radionuclide-bearing colloids and the waste and EBS may result in retardation of the colloids during transport by sorption mechanisms.
		2.1.11.04.00	Temperature effects / coupled processes in waste and EBS	This FEP broadly encompasses all coupled-process effects of temperature changes within the waste and EBS.
		2.1.11.09.00[a]	Thermal effects on liquid or two-phase fluid flow in the waste and EBS	See P4
		2.1.12.03.00	Gas generation (H2) from metal corrosion	Gas generation can affect the mechanical behavior of the host rock and engineered barriers, chemical conditions, and brine flow, and, as a result, the transport of radionuclides. Gas generation due to oxic corrosion of waste packages, cladding, structural materials will occur at early times following closure of the repository. Anoxic corrosion may follow the oxic phase, if all oxygen is depleted. The formation of a gas phase around the canister may even exclude water from the iron thus inhibiting further corrosion.
		2.2.08.04.00	Redissolution of precipitates directs more corrosive fluids to waste packages	Redissolution of precipitates which have plugged pores as a result of evaporation of ground water in the hot zone, produces a pulse of fluid reaching the waste packages when gravity-driven flow resumes, which is more corrosive than the original fluid in the rock.
P21	Ventilation	1.1.02.02.00	Effects of pre-closure ventilation	The duration of pre-closure ventilation acts together with waste package spacing (as per design) to control the extent of the boiling front.

NOTE: [a] = repeated FEP

Table 6. EBS-Related FEPs Recommended for "Deferral" as Design-Dependent FEPs

FEP #	FEP Name	Reference Design Area
A. Database FEPs ("Deferred" in Attachment III)		
1.1.07.00.00	Repository design	SS
1.1.08.00.00	Quality control	SS
1.1.12.01.00	Accidents and unplanned events during operation	SS
1.1.13.00.00	Retrievability	SS
B. FEPs Categories ("Deferred" in Table 3)		
F1a	Drip shield design	WP, SS
F2a	Ground Support—Steel sets design	SS
F3a	Backfill design	SS
F4a	Invert design	SS
F5a	Drain design, location	SS
F6	Emplacement Equipment	SS
E2a	Seismic Event—Waste package displacement	WP
E2b	Seismic Event—Drip shield displacement	SS, WP
E2c	Seismic Event—Rockfall	SS, WP
E3a	Ground Support Failure—By seismic events	SS
E3c	Ground Support Failure—By corrosion	SS
P4d	Ground Support Loading/Unloading	SS
P5b	Distorts drip shield and rails	WP, SS
P21	Ventilation	SS
P22	Seal Degradation	SS

NOTES: SS = Subsurface; WP = Waste Package

Table 7. EBS-Related FEPs Recommended for Analysis in Other PMRs

A. Database FEPs (N/A for EBS FEPs in Attachment III)		
YMP FEP Database Number	FEP Name	Reference PMR
1.2.04.03.00	Igneous intrusion into repository	DE
2.1.03.10.00	Waste package healing	WP
2.1.03.12.00	Waste package failure (long-term)	WP
2.1.07.03.00	Movement of waste packages	WP
2.1.07.05.00	Creeping of metallic materials in the EBS	WP
2.1.12.02.00	Gas generation (He) from fuel decay	WF
2.1.12.07.00	Radioactive gases in waste and EBS	WF
2.1.12.08.00	Gas explosions	WF, DE
2.1.13.01.00	Radiolysis	WF
2.1.13.02.00	Radiation damage in waste and EBS	WF

B. FEPs Categories (N/A for EBS FEPs in Table 3)		
FEP Number	FEP Name	Reference PMR
E2d	Seismic Event - Establish New Flow Pathway	UZ, NFE
E4	Mechanical Damage to Waste Package	WP
P1	Condensate Zone Formation	UZ, NFE
P5a	Establish Flow Pathways In and Out	UZ, NFE
P6	Condensation	UZ, NFE
P7	Thermo-Chemical Alteration of the Topopah Spring Basal Vitrophyre	UZ, NFE
P8	Reflux	UZ
P8c	Reflux—Autocatalytic Drainage of Condensate Zone	UZ
P18	Drip Shield and Waste Package Corrosion	WP
P18b	Contact Corrosion	WP
P19a	Thermo-Mechanical Induced Distortion	WP
P23	Igneous Processes	DE

NOTES: DE = Distruptive Events; NFE = Near Field Environment; UZ = Unsaturated Zone;
WF = Waste Form; WP = Waste Package;

ATTACHMENT I

ENGINEERED BARRIER SYSTEM FEATURES, EVENTS, AND PROCESSES DATABASE SUBSET

Table I-1 identifies FEPs that were initially identified in the YMP FEP Database (in preparation) for EBS analysis. The FEP identification number (ID in Table I-1), name, and number are based on input received via the AP-3.14Q transmittal (CRWMS M&O 1999a). This information is based on a preliminary draft of the Database, and is used in this AMR as reference only. The full description and screening of the FEPs is contained in Attachment III of this AMR.

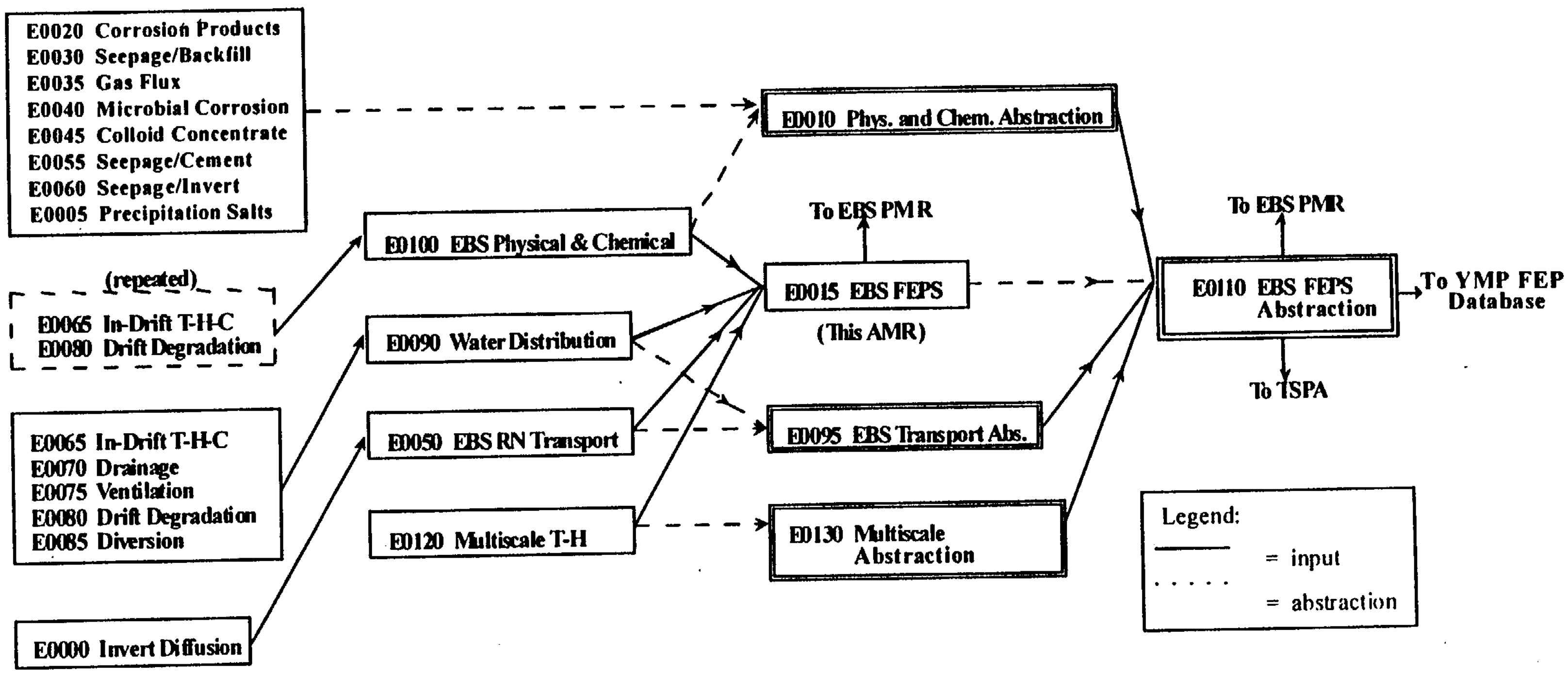
Table I-1. Engineered Barrier System Features, Events, and Processes Database Subset

ID	YMP FEP Database Number	FEP Name
35	1.1.02.00.00	Excavation/ construction
41	1.1.02.01.00	Site flooding (during construction and operation)
43	1.1.02.02.00	Effects of pre-closure ventilation
45	1.1.02.03.00	Undesirable materials left
49	1.1.03.01.00	Error in waste or backfill emplacement
68	1.1.07.00.00	Repository design
77	1.1.08.00.00	Quality control
95	1.1.12.01.00	Accidents and unplanned events during operation
102	1.1.13.00.00	Retrievability
170	1.2.04.03.00	Igneous intrusion into repository
674	2.1.03.10.00	Container healing
685	2.1.03.12.00	Container failure (long-term)
689	2.1.04.01.00	Preferential pathways in the backfill
693	2.1.04.02.00	Physical and chemical properties of backfill
704	2.1.04.03.00	Erosion or dissolution of backfill
706	2.1.04.04.00	Mechanical effects of backfill
709	2.1.04.05.00	Backfill evolution
713	2.1.04.06.00	Properties of bentonite
749	2.1.04.07.00	Buffer characteristics
755	2.1.04.08.00	Diffusion in backfill
756	2.1.04.09.00	Radionuclide transport through backfill
775	2.1.06.01.00	Degradation of cementitious materials in drift
779	2.1.06.02.00	Effects of rock reinforcement materials
781	2.1.06.03.00	Degradation of the liner
782	2.1.06.04.00	Flow through the liner
784	2.1.06.05.00	Degradation of invert and pedestal
786	2.1.06.06.00	Effects and degradation of drip shield
788	2.1.06.07.00	Effects at material interfaces
790	2.1.07.01.00	Rockfall (large block)
795	2.1.07.02.00	Mechanical degradation or collapse of drift
804	2.1.07.03.00	Movement of containers
809	2.1.07.04.00	Hydrostatic pressure on container
812	2.1.07.05.00	Creeping of metallic materials in the EBS
818	2.1.07.06.00	Floor buckling
821	2.1.08.01.00	Increased unsaturated water flux at the repository
823	2.1.08.02.00	Enhanced influx (Philip's drip)
825	2.1.08.04.00	Condensation forms on backs of drifts
826	2.1.08.05.00	Flow through invert
829	2.1.08.06.00	Wicking in waste and EBS

830	2.1.08.07.00	Pathways for unsaturated flow and transport in the waste and EBS
840	2.1.08.08.00	Induced hydrological changes in the waste and EBS
841	2.1.08.09.00	Saturated groundwater flow in waste and EBS
847	2.1.08.11.00	Resaturation of repository
851	2.1.09.01.00	Properties of the potential carrier plume in the waste and EBS
866	2.1.09.02.00	Interaction with corrosion products
888	2.1.09.05.00	In-drift sorption
893	2.1.09.06.00	Reduction-oxidation potential in waste and EBS
899	2.1.09.07.00	Reaction kinetics in waste and EBS
901	2.1.09.08.00	Chemical gradients / enhanced diffusion in waste and EBS
918	2.1.09.11.00	Waste-rock contact
919	2.1.09.12.00	Rind (altered zone) formation in waste, EBS, and adjacent rock
921	2.1.09.13.00	Complexation by organics in waste and EBS
934	2.1.09.14.00	Colloid formation in waste and EBS
946	2.1.09.15.00	Formation of true colloids in waste and EBS
947	2.1.09.16.00	Formation of pseudo-colloids (natural) in waste and EBS
953	2.1.09.17.00	Formation of pseudo-colloids (corrosion products) in waste and EBS
955	2.1.09.18.00	Microbial colloid transport in the waste and EBS.
956	2.1.09.19.00	Colloid transport and sorption in the waste and EBS.
958	2.1.09.20.00	Colloid filtration in the waste and EBS
962	2.1.09.21.00	Suspensions of particles larger than colloids
966	2.1.10.01.00	Biological activity in waste and EBS
979	2.1.11.01.00	Heat output / temperature in waste and EBS
993	2.1.11.03.00	Exothermic reactions in waste and EBS
995	2.1.11.04.00	Temperature effects / coupled processes in waste and EBS
1002	2.1.11.05.00	Differing thermal expansion of repository components
1008	2.1.11.07.00	Thermally-induced stress changes in waste and EBS
1011	2.1.11.08.00	Thermal effects: chemical and microbiological changes in the waste and EBS
1012	2.1.11.09.00	Thermal effects on liquid or two-phase fluid flow in the waste and EBS
1015	2.1.11.10.00	Thermal effects on diffusion (Soret effect) in waste and EBS
1020	2.1.12.01.00	Gas generation
1026	2.1.12.02.00	Gas generation (He) from fuel decay
1032	2.1.12.03.00	Gas generation (H2) from metal corrosion
1037	2.1.12.04.00	Gas generation (CO2, CH4, H2S) from microbial degradation
1043	2.1.12.05.00	Gas generation from concrete
1044	2.1.12.06.00	Gas transport in waste and EBS
1053	2.1.12.07.00	Radioactive gases in waste and EBS
1056	2.1.12.08.00	Gas explosions
1062	2.1.13.01.00	Radiolysis
1072	2.1.13.02.00	Radiation damage in waste and EBS
1084	2.1.13.03.00	Mutation
1216	2.2.07.06.00	Episodic / pulse release from repository
1333	2.2.08.04.00	Redissolution of precipitates directs more corrosive fluids to containers

ATTACHMENT II

ENGINEERED BARRIER SYSTEM ANALYSIS MODEL REPORTS IDENTIFICATION AND FEATURES, EVENTS, AND PROCESSES FLOW



NOTE: Full titles of AMRs and document numbers are given in Table II-1.

Figure II-1. Engineered Barrier System Analysis and Model Reports and Features, Events, and Processes Flow

Table II-1. Engineered Barrier System Analysis Model Report Identification

AMR Title	ID	Document ID Number
Invert Diffusion Properties Model	E0000	ANL-EBS-MD-000031
Physical and Chemical Environment Abstraction	E0010	ANL-EBS-MD-000046
Engineered Barrier System-Features, Events, and Processes and Degradation Modes Analysis	E0015	ANL-EBS-MD-000035
In-Drift Corrosion Products	E0020	ANL-EBS-MD-000041
Seepage/Backfill Interaction	E0030	ANL-EBS-MD-000039
In-Drift Gas Flux and Composition	E0035	ANL-EBS-MD-000040
In-Drift Microbial Communities	E0040	ANL-EBS-MD-000038
In-Drift Colloids and Concentrations	E0045	ANL-EBS-MD-000042
Engineered Barrier System Radionuclide Transport Model	E0050	ANL-EBS-MD-000034
Seepage/Cement Interaction	E0055	ANL-EBS-MD-000043
Seepage/Invert Interaction	E0060	ANL-EBS-MD-000044
In-Drift Thermal-Hydrologic-Chemical Model	E0065	ANL-EBS-MD-000026
Water Drainage Model	E0070	ANL-EBS-MD-000029
Ventilation Model	E0075	ANL-EBS-MD-000030
Drift Degradation Analysis	E0080	ANL-EBS-MD-000027
Water Diversion Model	E0085	ANL-EBS-MD-000028
Water Distribution and Removal Model	E0090	ANL-EBS-MD-000032
Engineered Barrier System Radionuclide Transport Abstraction	E0095	ANL-WIS-PA-000001
Physical and Chemical Environment Process Model	E0100	ANL-EBS-MD-000033
In-Drift Precipitates Salts Analysis	E0105	ANL-EBS-MD-000045
Engineered Barrier System Degradation Modes and Features, Events, and Processes Degradation Modes Abstraction	E0110	ANL-WIS-PA-000002
Multiscale Thermohydrologic Model	E0120	ANL-EBS-MD-000049
Abstraction of Near Field Environment Drift Thermodynamic and Percolation Flux	E0130	ANL-EBS-HS-000003

ATTACHMENT III

DATABASE INITIAL SCREENING OF ENGINEERED BARRIER SYSTEM FEATURES, EVENTS, AND PROCESSES

EBS FEPs

FEP Number	1.1.02.00.00
FEP Name	Excavation/construction
FEP Description	This category contains FEPs related to the excavation of the underground regions of the potential 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 due to explosives residue.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Excavation-related effects on the properties of the engineered and natural barriers are excluded from the TSPA modeling on the basis of low consequence. A zone of disturbed rock that will form around the excavations as a result of stress relief is included in the analysis. However, boring and blasting will be designed to have minimal impact, and the consequences of excavation-related effects are assumed to be less than those of the disturbed rock zone that will form as a result of stress relief. Various changes in the groundwater chemistry and geochemical alteration of the rock may occur during excavation, operation, and backfilling, These changes may be due to introduced construction or excavation materials and/or influx of water.

FEP Number	1.1.02.01.00
FEP Name	Site flooding (during construction and operation)
FEP Description	Flooding of the site during construction and operation could introduce water into the underground tunnels, which could affect the long-term performance of the repository. This is a specific example of an accident or unplanned event discussed under FEP 1.1.12.01.00.
Screening	Exclude
Exclude Basis	This is primarily a design issue
Rationale	The possibility of flooding was considered in the location of the entry ramps and surface buildings. As a result of this, the current design makes flooding of the underground areas, which would require redirection of runoff (e.g., down ramps), highly unlikely. In general, operational issues are outside the scope of the TSPA. It is noted that a single flooding event would be unlikely to have long-term impact on repository performance. Water entering ramps would drain rapidly into fractured rock. Consequently, little, if any, flood water would reach the emplacement drifts.

FEP Number	1.1.02.02.00
FEP Name	Effects of pre-closure ventilation
FEP Description	The duration of pre-closure ventilation acts together with waste package spacing (as per design) to control the extent of the boiling front.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	1.1.02.03.00
FEP Name	Undesirable materials left
FEP Description	During construction and operation there might be possibilities for leaving unwanted material in the vicinity of the radioactive waste. The materials can be of different kinds and can to some extent affect many long-term processes in the potential repository from canister corrosion to transport mechanisms of radionuclides.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Materials introduced during the preclosure construction and operation phase of the potential repository may, if not controlled, have a conceivably unconstrained impact on groundwater chemistry within the EBS, thereby impacting corrosion processes, radionuclide transport, etc.

FEP Number 1.1.03.01.00

FEP Name Error in waste or backfill emplacement

FEP Description Deviations from the design and/or errors in waste and backfill emplacement could affect long-term performance.

Screening Exclude

Exclude Basis Probability

Rationale Waste and backfill will be emplaced according to potential repository design. Alternative emplacement designs, with and without backfill have been considered, but the TSPA assumes a single emplacement strategy. Within this single emplacement strategy, the impact of uncertainties in such parameters as environmental conditions and the impact of allowable tolerances in design parameters is explicitly accounted for in the TSPA. Deviations beyond those considered are excluded on the basis of the repository quality control program.

In general, the TSPA is based on the premise that the potential repository will be constructed, operated, and closed according to design. Deviations from design during the operational period are the subject of an extensive quality control program, and are outside the scope of the long-term performance assessment.

FEP Number 1.1.07.00.00

FEP Name Repository design

FEP Description This category contains FEPs related to the design of the potential repository, and the ways in which the design contributes to long-term performance. Changes to or deviations from the specified design may affect the long-term performance of the disposal system.

Screening Include/Defer

Exclude Basis

Rationale Design activity (Subsurface).

FEP Number	1.1.08.00.00
FEP Name	Quality control
FEP Description	This category contains FEPs related to quality assurance and control procedures and tests during the design, construction, and operation of the potential repository, as well as the manufacture of the waste forms, waste packages, and engineered features. Lack of quality control could result in material defects, faulty waste package fabrication, and faulty or non-design-standard construction, all of which may lead to reduced effectiveness of the engineered barriers.
Screening	Include/Defer
Exclude Basis	
Rationale	Quality control activity (Subsurface).

FEP Number	1.1.12.01.00
FEP Name	Accidents and unplanned events during operation
FEP Description	The long-term performance of the disposal system might be seriously affected by unplanned or improper activities that take place during construction, operation, and closure of the repository.
Screening	Include/Defer
Exclude Basis	
Rationale	Design/Operations activity (Subsurface).

FEP Number	1.1.13.00.00
FEP Name	Retrievability
FEP Description	This category contains FEPs related to design, emplacement, operational, or administrative measures that might be applied or considered in order to enable or ease retrieval of wastes. There may be a requirement to retrieve all or part of the waste stored in the repository; for example, to recover valuable fissile materials or to replace defective waste packages.
Screening	Include/Defer
Exclude Basis	
Rationale	Design activity (Subsurface).

FEP Number	1.2.04.03.00
FEP Name	Igneous intrusion into repository
FEP Description	Magma from an igneous intrusion may flow into the drifts and extend over a portion of the potential repository site, forming a sill. The sill could be limited to the drifts or a continuous sill could form along the plane of the repository, bridging between adjacent drifts.
Screening	Not applicable to EBS FEPs
Exclude Basis	
Rationale	The ex-container EBS has no allocated performance against igneous intrusion.

FEP Number	2.1.03.10.00
FEP Name	Waste package healing
FEP Description	Pits and holes in waste packages could be partially or fully plugged by chemical or physical reactions during or after their formation, affecting corrosion processes and water flow and radionuclide transport through the breached waste package. Passivation by corrosion products is a potential mechanism for waste package healing.
Screening	Not applicable to EBS FEPs
Exclude Basis	
Rationale	The EBS as defined in this analysis does not include the waste package. It is noted that excluding this FEP results in a conservative estimate of performance, i.e., once corrosion has penetrated a waste package, there is a permanent pathway for water to enter.

FEP Number	2.1.03.12.00
FEP Name	Waste package failure (long-term)
FEP Description	Waste packages and drip shields have a potential to fail over long periods of times by a variety of mechanisms, including general corrosion, stress corrosion cracking, pit corrosion, hydride cracking, microbially-mediated corrosion, internal corrosion, and mechanical impacts.
Screening	Not applicable to EBS FEPs
Exclude Basis	
Rationale	The waste package and drip shield are not analyzed as part of the EBS process models. The EBS determines the environment within which the waste package/drip shield must function, not the effects of that environment on the waste package/drip shield performance.

FEP Number	2.1.04.01.00
FEP Name	Preferential pathways in the backfill
FEP Description	Preferential pathways for flow and diffusion may exist within the backfill and may affect long-term performance of the waste packages. Backfill may not preclude hydrological, chemical, and thermal interactions between waste packages within a drift.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.04.02.00
FEP Name	Physical and chemical properties of backfill
FEP Description	The physical and chemical properties of the backfill may affect groundwater flow, waste package and drip shield durability, and radionuclide transport in the waste disposal region.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.04.03.00
FEP Name	Erosion or dissolution of backfill
FEP Description	Solid material in buffer or backfill is carried away by flowing groundwater, either by erosion of particulate matter or by dissolution.
Screening	Exclude
Exclude Basis	Probability
Rationale	Backfill material at Yucca Mountain will not be highly soluble, and no significant loss due to dissolution is anticipated. Flow rates in the unsaturated environment of the potential repository will be too low to cause erosion (refer to the Physical and Chemical Environment AMR (currently in preparation); see Attachment II).

FEP Number	2.1.04.04.00
FEP Name	Mechanical effects of backfill
FEP Description	Backfill may alter the mechanical evolution of the drift environment by providing resistance to rock creep and rock fall, by changing the thermal properties of the drift, or by other means. Impacts of the evolution of the properties of the backfill itself should be considered.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.04.05.00
FEP Name	Backfill evolution
FEP Description	Properties of the backfill may change through time, due to processes such as silica cementation, alteration of minerals, thermal effects, and physical compaction. These changes could then affect the movement of water and radionuclides in the backfill.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.04.06.00
FEP Name	Properties of bentonite
FEP Description	This category contains FEPs specific to the properties of bentonite buffers. Because the Yucca Mountain design does not include bentonite backfill, all FEPs in this category are irrelevant to the YMP TSPA.
Screening	Exclude
Exclude Basis	Not applicable to baseline design
Rationale	No use of bentonite is planned for Yucca Mountain.

FEP Number	2.1.04.07.00
FEP Name	Buffer characteristics
FEP Description	This category contains FEPs specific to repository designs that include chemical buffering agents in the waste disposal region. The Yucca Mountain design does not include buffering agents, and all FEPs in this category are irrelevant to the YMP TSPA.
Screening	Exclude
Exclude Basis	Not applicable to baseline design
Rationale	There is no buffer used in the current design at Yucca Mountain.

FEP Number	2.1.04.08.00
FEP Name	Diffusion in backfill
FEP Description	Diffusion processes in backfill may affect waste package performance and radionuclide transport.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Diffusion processes are insignificant compared to convective flow transport as discussed in E0095.

FEP Number	2.1.04.09.00
FEP Name	Radionuclide transport through backfill
FEP Description	Radionuclide transport in the drift environment may be affected by the presence of backfill. Transport of both dissolved and colloidal species, advective and diffusive effects and sorption processes should be considered.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.06.01.00
FEP Name	Degradation of cementitious materials in drift
FEP Description	Degradation of cementitious material used for any purposes in the disposal region may affect long-term performance through both chemical and physical processes. Degradation may occur by physical, chemical, and microbial processes.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.06.02.00
FEP Name	Effects of rock reinforcement materials
FEP Description	Degradation of rock bolts, wire mesh, and other materials used in ground control may affect the long-term performance of the repository.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.06.03.00
FEP Name	Degradation of the liner
FEP Description	Degradation of materials used to line the drifts may occur by physical, chemical, or microbial processes, and may affect long-term performance.
Screening	Exclude
Exclude Basis	Not applicable to baseline design
Rationale	No liner is planned for the potential repository (other than the steel mesh for ground support). Thus, this FEP is not relevant to the YMP design.

FEP Number	2.1.06.04.00
FEP Name	Flow through the liner
FEP Description	Groundwater flow may occur through the liner.
Screening	Exclude
Exclude Basis	Not applicable to baseline design
Rationale	No liner is planned for the potential repository (other than the steel mesh for ground support). Thus, this FEP is not relevant to the YMP design.

FEP Number	2.1.06.05.00
FEP Name	Degradation of invert and pedestal
FEP Description	Degradation of the materials used in the invert and the pedestal supporting the waste package may occur by physical, chemical, or microbial processes, and may affect the long-term performance of the repository.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.06.06.00
FEP Name	Effects and degradation of drip shield
FEP Description	The drip shield will affect the amount of water reaching the waste package. Behavior of the drip shield in response to rockfall, ground motion, and physical, chemical degradation processes should be considered. Effects of the drip shield on the disposal region environment (for example, changes in relative humidity and temperature below the shield) should be considered for both intact and degraded conditions. Degradation processes specific to the chosen material should be identified and considered. For example, oxygen embrittlement should be considered for titanium drip shields.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.06.07.00
FEP Name	Effects at material interfaces
FEP Description	Physical and chemical effects that occur at the interfaces between materials in the drift, such as at the contact between the backfill and the drip shield, may affect the performance of the system.
Screening	Include
Exclude Basis	
Rationale	While this is directed at buffer and backfill, its generalization is included implicitly (and in some cases explicitly) in modeling of corrosion, rind development, precipitation in rock walls, etc.

FEP Number	2.1.07.01.00
FEP Name	Rockfall (large block)
FEP Description	Rockfall may occur that are large enough to mechanically tear or rupture waste packages.
Screening	Include
Exclude Basis	
Rationale	Large-block rockfall is a possibility in the drifts. Such blocks could be loosed during the thermal period when thermal expansion causes considerable compressive forces and reorientation of the least principal stress.

FEP Number	2.1.07.02.00
FEP Name	Mechanical degradation or collapse of drift
FEP Description	Partial or complete collapse of the drifts, as opposed to discrete rockfall, could occur as a result of seismic activity, thermal effects, stresses related to excavation, or possibly other mechanisms. Drift collapse could affect stability of the engineered barriers and waste packages. Drift collapse may be localized as stopping at faults or other geologic features. Rockfall of small blocks may produce rubble throughout part or all of the drifts.
Screening	Include
Exclude Basis	
Rationale	Changing stress state, either from fault (tectonic) adjustment or from seismic waves arriving from distal sources produces rockfall and liner failure. Such displacement of surrounding rocks into the tunnels and attendant growth of the tunnel (possibly by chimneying) is categorized as tunnel failure. A distinction is made between the thermal and post-thermal states because the thermally induced compression around the drifts is expected to require higher ground accelerations in order to induce tunnel failure than for the post-thermal relaxing environment.

FEP Number	2.1.07.03.00
FEP Name	Movement of waste packages
FEP Description	Waste packages may move as a result of seismic activity, degradation of the invert or pedestal, rockfall, fault displacement, or other processes.
Screening	Not applicable for EBS FEPs
Exclude Basis	
Rationale	The waste package is not analyzed as part of the EBS process models.

FEP Number	2.1.07.04.00
FEP Name	Hydrostatic pressure on waste package
FEP Description	Waste packages emplaced in the saturated zone will be subjected to hydrostatic pressure in addition to stresses associated with the evolution of the waste and barrier system.
Screening	Exclude
Exclude Basis	Probability
Rationale	A potential repository at Yucca Mountain locates waste above the water table, in a fractured, porous medium. Thus, the pressure is approximately atmospheric. Consequently, this FEP is not relevant for the YMP design, which callsfor emplacement in the unsaturated zone.

FEP Number	2.1.07.05.00
FEP Name	Creeping of metallic materials in the EBS
FEP Description	Metals used in the waste package or drip shield may deform by creep processes in response to deviatoric stress.
Screening	Not applicable for EBS FEPs
Exclude Basis	
Rationale	The waste package and drip shield are not analyzed as part of the EBS process models.

FEP Number	2.1.07.06.00
FEP Name	Floor buckling
FEP Description	Buckling, or heave, of the drift floor occurs in response to changing stress. Floor buckling may affect the performance of components of the EBS such as the drip shield, the invert, and the pedestal. Effects may include movement of EBS components, and changes in the topography of the surface of the drift floor and invert that may affect water flow.
Screening	Include
Exclude Basis	
Rationale	The stress state around the drift changes in response to mechanical stress relief (because opening the drift produces a free surface) and thermo-mechanical stresses developed due to waste package heat generation. An expected response of these stresses is buckling, or heave, of the drift floor that produces local basins and hillocks relative to the original surface. Waste packages and their supporting pedestals will be disturbed. This is expected to produce a durable alteration of the potential repository system.

FEP Number	2.1.08.01.00
FEP Name	Increased unsaturated water flux at the repository
FEP Description	An increase in the unsaturated water flux at the potential 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.
Screening	Include
Exclude Basis	
Rationale	Climate is expected to change. As a surrogate for that change, three climate states with different infiltration fluxes have been considered in TSPA modeling.

FEP Number	2.1.08.02.00
FEP Name	Enhanced influx (Philip's Drip)
FEP Description	An opening in unsaturated rock alters the hydraulic potential, affecting local saturation around the opening and redirecting flow. Some of the flow is directed to the opening where it is available to seep into the opening.
Screening	Exclude
Exclude Basis	Probability and consequences
Rationale	See Section 6.5.2.1 of this report.

FEP Number	2.1.08.04.00
FEP Name	Condensation forms on backs of drifts
FEP Description	Emplacement of waste in drifts creates a large thermal gradient across the drifts. Moisture condenses on the roof and flows downward through the backfill.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.08.05.00
FEP Name	Flow through invert
FEP Description	Flow through invert results in transport of contaminants to the unsaturated zone.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.08.06.00
FEP Name	Wicking in waste and EBS
FEP Description	Capillary rise, or wicking, is a potential mechanism for water to move through the waste and engineered barrier system.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.08.07.00
FEP Name	Pathways for unsaturated flow and transport in the waste and EBS
FEP Description	Unsaturated flow and radionuclide transport may occur along preferential pathways in the waste and EBS. Physical and chemical properties of the EBS and waste form, in both intact and degraded states, should be considered in evaluating pathways.
Screening	Include
Exclude Basis	
Rationale	The details of internal pathways providing release from a waste pacakge are subsumed in an integrated release distribution.

FEP Number	2.1.08.08.00
FEP Name	Induced hydrological changes in the waste and EBS
FEP Description	Thermal, chemical, and mechanical processes related to the construction of the potential repository and the emplacement of waste may induce changes in the hydrologic behavior of the system.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time. Consequences to EBS performances are bounded by assuming fracture plugging below the drift in the Water Distribution and Removal AMR (see Attachment II), presently in preparation.

FEP Number	2.1.08.09.00
FEP Name	Saturated groundwater flow in waste and EBS
FEP Description	Saturated flow and radionuclide transport may occur along preferential pathways in the waste and EBS. Physical and chemical properties of the EBS and waste form, in both intact and degraded states, should be considered in evaluating pathways.
Screening	Exclude
Exclude Basis	Probability
Rationale	This FEP addresses processes for a potential repository sited in the saturated zone. For Yucca Mountain, leaching and transport starts in the unsaturated zone (with attendant peculiarities of locally saturated flows and unsaturated flow) and the saturated zone controls transport, but only in part (because of the problem of mixing).

FEP Number	2.1.08.11.00
FEP Name	Resaturation of repository
FEP Description	Water content in the potential repository will increase following the peak thermal period.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.09.01.00
FEP Name	Properties of the potential carrier plume in the waste and EBS
FEP Description	When unsaturated flow in the drifts is reestablished following the peak thermal period, water will have chemical and physical characteristics influenced by the near field host rock and EBS. Water chemistry may be strongly affected by interactions with cementitious materials.
Screening	Include
Exclude Basis	
Rationale	When the flow system reestablishes itself through the potential repository, because of repository temperature and introduced materials (e.g., ground support materials) the flow system will include the characteristics of the repository (pH, Temperature, dissolved constituents, etc.). It is into this reestablished flow system called the carrier plume that radioactive contaminants will be added as waste packages fail.

FEP Number	2.1.09.02.00
FEP Name	Interaction with corrosion products
FEP Description	Corrosion products produced during degradation of the metallic portions of the EBS and waste package may affect the mobility of radionuclides. Sorption/desorption and co-precipitation/dissolution processes may occur.
Screening	Include
Exclude Basis	
Rationale	Interaction of contaminants with corrosion products is expected to control mobilization and speciation of the contaminants (e.g., Fe, oxyhydroxides, and colloids).

FEP Number	2.1.09.05.00
FEP Name	In-drift sorption
FEP Description	Sorption of radionuclides within the waste and EBS may affect the aqueous concentrations.
Screening	Include
Exclude Basis	
Rationale	Sorption of radionuclides on other materials within the EBS may delay release to the environment, provided that these materials are not suspended in groundwater. Excluding this FEP is conservative. However, EBS materials will corrode and form colloids that may irreversably sorb some radionuclides and increase the total aqueous concentration. The increase in concentration is bounded in the Physical and Chemical Environment AMR (see Attachment II), presently in preparation.

FEP Number	2.1.09.06.00
FEP Name	Reduction-oxidation potential in waste and EBS
FEP Description	The redox potential in the waste and EBS influences the oxidation of barrier and waste-form materials and the solubility of radionuclide species. Local variations in the redox potential can occur.
Screening	Include
Exclude Basis	
Rationale	Redox potential in the waste and engineered barrier system is included in TSPA modeling of the waste form and waste package. Redox potential in the drift environment has been considered in analysis of the potential for criticality.

FEP Number	2.1.09.07.00
FEP Name	Reaction kinetics in waste and EBS
FEP Description	Chemical reactions, such as radionuclide dissolution/precipitation reactions and reactions controlling the reduction-oxidation state, may not reach equilibrium in the drift and waste environment.
Screening	Exclude
Exclude Basis	Consequences
Rationale	The assumption of chemical equilibrium for determining radionuclide concentration is conservative because equilibrium solubility limits exceed reach radionuclide concentrations determined in waste form degradation measurements. (This subject is addressed in the Waste Form PMR, in preparation.)

FEP Number	2.1.09.08.00
FEP Name	Chemical gradients / enhanced diffusion in waste and EBS
FEP Description	The existence of chemical gradients within the disposal system, induced naturally or resulting from repository material and waste emplacement, may influence the transport of contaminants of dissolved and colloidal species.
Screening	Include
Exclude Basis	
Rationale	In Yucca Mountain, the establishment of carrier plumes, each with the signature of the potential repository (with respect to temperature and chemistry-including hyperalkalinity), means that there are persistent chemical gradients which identify the boundaries of the plumes. Sorption and reaction of contaminants with host rock occur within these plumes, at least until they become well-mixed with connate waters. It appears that the chemistry of the plumes is important, in contrast to the chemical gradients across their boundaries.

FEP Number	2.1.09.11.00
FEP Name	Waste-rock contact
FEP Description	Waste and rock are placed in contact by mechanical failure of the drip shields and waste packages. Reactions between uranium, rock minerals, and water in contact with both precipitate uranium, leading spent fuel to dissolve more rapidly than if constrained by the equilibrium solubility of uranium.
Screening	Exclude
Exclude Basis	Consequences
Rationale	This FEP applied to emplacement of waste packages vertically in boreholes in the drift floor. Current design is horizontal in-drift emplacement using large waste packages. Eventual contact with rock is expected as a result of drift collapse (rockfall). The rock-water interactions and the Fe of the waste package is expected to be more controlling on U solubility than the interactions suggested in this FEP.

FEP Number	2.1.09.12.00
FEP Name	Rind (altered zone) formation in waste, EBS, and adjacent rock
FEP Description	Thermo-chemical processes involving precipitation, condensation and redissolution alter the properties of the waste, EBS, and adjacent rock These alterations form a rind, or altered zone, with hydrologic, thermal and mineralogic properties different from the current conditions.
Screening	Include
Exclude Basis	
Rationale	The thermo-chemical-hydrologic processes which will produce a rind are known to occur, the questions are, at what rate and to what depth. For the post-thermal period, rockfall is expected to drop the altered zone (rind) into the open drifts.

FEP Number	2.1.09.13.00
FEP Name	Complexation by organics in waste and EBS
FEP Description	The presence of organic complexants in water in the waste and EBS could augment radionuclide transport by providing a transport mechanism, in addition to simple diffusion and advection of dissolved material. Organic complexants may include materials found in natural groundwater such as humates and fulvates, or materials introduced with the waste or engineered materials.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Complexation of radionuclides with organic species has been excluded from the TSPA on the basis of negligible consequences for two reasons. First, this mechanism would be most significant if it could alter the form of the dissolved radionuclides thereby reducing the likelihood of sorption in the invert. However, since sorption is presently ignored in the TSPA (see FEP 2.1.09.05.00) the transport of radionuclides is already maximized, and the neglect of complexation has no impact on the calculated release rate. Second, complexation in the immediate vicinity of the waste form could increase the rate of radionuclide release if the release rate is concentration limited. However, because of the low concentration of organics in the Yucca Mountain repository this is expected to be negligible.

FEP Number	2.1.09.14.00
FEP Name	Colloid formation in waste and EBS
FEP Description	Colloids in the waste and EBS may affect radionuclide transport. Different types of colloids may exist initially or may form during the evolution of the system by a variety of mechanisms. This FEP aggregates all types of colloids into a single category.
Screening	Include
Exclude Basis	
Rationale	See separate FEPs for natural pseudo-colloids (FEP 2.1.09.16.00), and pseudo-colloids formed from corrosion products (FEP 2.1.09.17.00).

FEP Number	2.1.09.15.00
FEP Name	Formation of true colloids in waste and EBS
FEP Description	True colloids are colloidal-size assemblages (between approximately one nanometer and 1 micrometer in diameter) of radionuclide-containing compounds. They may form in the waste and EBS during waste-form degradation and radionuclide transport. True colloids are also called radionuclide intrinsic colloids (or actinide intrinsic colloids, for those including actinide elements).
Screening	Exclude
Exclude Basis	Consequences
Rationale	The formation of true colloids is expected to occur as part of the waste form degradation process (and is discussed in the Waste Form Degradation FEPs Analysis, in preparation). Additional colloid formation within the EBS is excluded in the TSPA on the basis of negligible consequences. This is because the EBS radionuclide transport analysis does not consider any retardation mechanisms. Thus, the rate of radionuclide transport is already maximized.

FEP Number	2.1.09.16.00
FEP Name	Formation of pseudo-colloids (natural) in waste and EBS
FEP Description	Pseudo-colloids are colloidal sized assemblages (between approximately 1 nanometer and 1 micrometer in diameter) of nonradioactive material that has radionuclides bound to it. Pseudo-colloids include microbial colloids, mineral fragments, and humic and fulvic acids. This FEP addresses radionuclide-bearing colloids formed from host-rock materials and all interactions of the waste and EBS with the host rock environment except corrosion. Pseudo-colloids formed from corrosion of the waste form and EBS are discussed in FEP 2.1.09.17.00 Microbial colloids are discussed in FEP 2.1.09.18.00.
Screening	Include
Exclude Basis	
Rationale	Colloidal particles are formed from the rock by alteration under thermal, mechanical and chemical stresses imposed by the potential repository. Normally well-retarded radioelements such as plutonium and americium sorb to the colloids.

FEP Number	2.1.09.17.00
FEP Name	Formation of pseudo-colloids (corrosion products) in waste and EBS
FEP Description	Pseudo-colloids are colloidal sized assemblages (between approximately 1 nanometer and 1 micrometer in diameter) of nonradioactive material that has radionuclides bound to it. Pseudo-colloids include microbial colloids, mineral fragments, and humic and fulvic acids. This FEP addresses pseudo-colloids such as iron oxyhyrdroxides formed from corrosion and degradation of the metals in the waste form and EBS. Radionuclide-bearing colloids formed from host-rock materials and all interactions of the waste and EBS with the host rock environment except corrosion are discussed in FEP 2.1.09.16.00. Microbial colloids are discussed in FEP 2.1.09.18.00.
Screening	Include
Exclude Basis	
Rationale	Corrosion products such as Fe oxyhydroxides are available to form the nucleus for this mechanism.

FEP Number	2.1.09.18.00
FEP Name	Microbial colloid transport in the waste and EBS.
FEP Description	This FEP addresses the formation and transport of microbial colloids in the waste and EBS. Pseudo-colloids formed from corrosion and degradation of the metals in the waste form and EBS are discussed in FEP 2.1.09.16.00. Radionuclide-bearing colloids formed from host-rock materials and all interactions of the waste and EBS with the host rock environment except corrosion are discussed in FEP 2.1.09.17.00.
Screening	Include
Exclude Basis	
Rationale	Microbial transport of contaminants, as colloids or as incorporated material, in the flow system is possible. The extent and importance of microbial transport remain to be experimentally determined.

FEP Number	2.1.09.19.00
FEP Name	Colloid transport and sorption in the waste and EBS.
FEP Description	Interactions between radionuclide-bearing colloids and the waste and EBS may result in retardation of the colloids during transport by sorption mechanisms.
Screening	Include
Exclude Basis	
Rationale	Colloids, their formation, transport, sorption, filtration and interaction with the surrounding rock, have been identified as possibly important to mobilization of contaminants in Yucca Mountain.

FEP Number	2.1.09.20.00
FEP Name	Colloid filtration in the waste and EBS
FEP Description	Filtration processes may affect transport of radionuclide-bearing colloids in the waste and EBS.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Transport of colloids within the EBS (within the tunnel) conservatively excludes consideration of colloid filtration. In this way, transport of radionuclides into the unsaturated zone is maximized.

FEP Number	2.1.09.21.00
FEP Name	Suspensions of particles larger than colloids
FEP Description	Ground water flow through the waste could remove radiouclide-bearing particles by a rinse mechanism. Particles of radionuclide bearing material larger than colloids could be then be transported in water flowing through the waste and EBS by suspension.
Screening	Exclude
Exclude Basis	Probability
Rationale	Observations documented in the Physical and Chemical Environment AMR (see Attachment II), presently in preparation, show little difference in total suspended solids in pumped groundwater samples with and without filtration. Little, if any, material with particle sizes greater than 200 mm was present. The flow velocity near a pumping well is much higher than unperturbed groundwater flow velocity, and should lead to more suspended solids. Accordingly, there is very little probability of transporting larger than colloid-size particles through the groundwater system or the unsaturated zone.

FEP Number	2.1.10.01.00
FEP Name	Biological activity in waste and EBS
FEP Description	Biological activity in the waste and EBS may affect disposal-system performance by altering degradation processes such as corrosion of the waste packages and waste form (including cladding), by affecting radionuclide transport through the formation of colloids and biofilms, and by generating gases.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.11.01.00
FEP Name	Heat output / temperature in waste and EBS
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, hydrologic effects, and the possibility of exothermal reactions. Considerations of the heat generated by radioactive decay should take different properties of different waste types, including U.S. Department of Energy spent nuclear fuel, into account.
Screening	Include
Exclude Basis	
Rationale	Decay heat is a major issue in repository design, particularly at Yucca Mountain where high loading densities and high temperatures (>200 C) are intended to be part of the waste isolation scheme.

FEP Number	2.1.11.03.00
FEP Name	Exothermic reactions in waste and EBS
FEP Description	Exothermic reactions liberate heat and will alter the temperature of the disposal system and affect the properties of the potential repository and surrounding materials. Hydration of concrete used in the underground environment is an example of a possible exothermic reaction.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Hydration of concrete will be complete long before closure, while the system is actively being ventilated. Therefore, no significant effect on postclosure thermal performance is expected. This subject is addressed in the EBS Physical and Chemical Environment AMR (see Attachment II), presently in preparation.

FEP Number	2.1.11.04.00
FEP Name	Temperature effects / coupled processes in waste and EBS
FEP Description	This FEP broadly encompasses all coupled-process effects of temperature changes within the waste and EBS.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number 2.1.11.05.00

FEP Name Differing thermal expansion of repository components

FEP Description Thermally-induced stresses could alter the performance of the waste or EBS. For example, thermal stresses could create pathways for preferential fluid flow in the backfill or through the drip shield.

Screening Include

Exclude Basis

Rationale The details of differential effects in a potential repository at Yucca Mountain, such as distribution of stress and strain associated with different waste package thermal outputs, are subsumed in the grosser effects of liner failure, and ubiquitous rockfall.

FEP Number 2.1.11.07.00

FEP Name Thermally-induced stress changes in waste and EBS

FEP Description Thermally induced stress changes in the waste and EBS may affect performance of the potential repository. Relevant processes include rockfall.

Screening Include

Exclude Basis

Rationale Repository heat at Yucca Mountain will drive the mechanical and chemical evolution of the potential repository and the mountain, producing durable changes. Thermal expansion (and thermo-mechanical coupling) is expected to rotate the least principal stress, currently NNW-SSE, to vertical and after cooling thermal contraction will rotate it back. Durable changes to the fracture flow systems are anticipated.

FEP Number	2.1.11.08.00
FEP Name	Thermal effects: chemical and microbiological changes in the waste and EBS
FEP Description	Temperature changes may affect chemical and microbial processes in the waste and EBS.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number	2.1.11.09.00
FEP Name	Thermal effects on liquid or two-phase fluid flow in the waste and EBS
FEP Description	Temperature differentials may result in convective flow in the waste and EBS.
Screening	Include
Exclude Basis	
Rationale	Could not be excluded at this time.

FEP Number 2.1.11.10.00

FEP Name Thermal effects on diffusion (Soret effect) in waste and EBS

FEP Description The Soret effect is a diffusion process caused by a thermal gradient. In liquids having both light and heavy molecules (or ions), the heavier molecules tend to concentrate in the cold region. Temperature differences in the waste and EBS may result in a component of diffusive solute flux that is proportional to the temperature gradient.

Screening Exclude

Exclude Basis Probability

Rationale Diffusion through the invert may limit the release rate of radionuclides, provided that advective flow is reduced to zero. If advection occurs, diffusion will not affect the steady-state mass release rate. If advection does not occur, bounding values of diffusion coefficients developed in the In-drift Diffusion Properties Model AMR (see Attachment II), presently in preparation, are used.

FEP Number 2.1.12.01.00

FEP Name Gas generation

FEP Description Gas may be generated in the potential repository by a variety of mechanisms. Gas generation might lead to pressurization of the repository, produce multiphase flow, and affect radionuclide transport. This FEP aggregates all types of gas generation into a single category.

Screening Exclude

Exclude Basis Consequences

Rationale Barometric pressure changes of a few mm Hg at the surface of Yucca Mountain propagate rapidly to the potential repository level, indicating free gas-plume pressure communication through the mountain (see the Unsaturated Zone PMR, presently in preparation). Also, current closure plans do not include a requirement to seal against gas exchanges, and the ramps/drifts/other underground openings will provide even greater gas permeabillity.

FEP Number	2.1.12.02.00
FEP Name	Gas generation (He) from fuel decay
FEP Description	Helium gas production may occur by alpha-decay in the fuel. He production might cause local pressure buildup in cracks in the fuel and in the void between fuel and cladding, leading to cladding failure.
Screening	Not applicable for EBS FEPs
Exclude Basis	
Rationale	Fuel and cladding performance are not part of the EBS process models.

FEP Number	2.1.12.03.00
FEP Name	Gas generation (H2) from metal corrosion
FEP Description	Gas generation can affect the mechanical behavior of the host rock and engineered barriers, chemical conditions, and brine flow, and, as a result, the transport of radionuclides. Gas generation due to oxic corrosion of waste packages, cladding, structural materials will occur at early times following closure of the repository. Anoxic corrosion may follow the oxic phase, if all oxygen is depleted. The formation of a gas phase around the canister may even exclude water from the iron thus inhibiting further corrosion.
Screening	Include
Exclude Basis	
Rationale	The potential repository in the unsaturated zone in Yucca Mountain is expected to be connected to the atmosphere and to be operating under oxidizing conditions. Gas generated by metal corrosion will interact with the waste packages or escape from the drifts. This topic is addressed in the Physical and Chemical Environment AMR (see Attachment II), presently in preparation.

FEP Number	2.1.12.04.00
FEP Name	Gas generation (CO2, CH4, H2S) from microbial degradation
FEP Description	Microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials, will produce mainly CO2, but also other gases. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions (temperature, pressure, geochemical conditions), and the substrates present.
Screening	Include
Exclude Basis	
Rationale	Microbial gas generation in Yucca Mountain is expected to use waste packages and waste as the growth substrate (e.g. Fe-philic bacteria) with H2, CH4, CO2, etc. as the gases produced. Temperature is expected to run from ambient to about 200 C. The matter of microbial corrosion of waste packages is the topic of a study plan at Lawrence Livermore National Laboratory. This topic is also addressed in the Physical and Chemical Environment AMR (see Attachment II), presently in preparation.

FEP Number	2.1.12.05.00
FEP Name	Gas generation from concrete
FEP Description	Production of gases from the aging and degradation of concrete may occur through radiolysis of water in the cement pore spaces and microbial growth on concrete.
Screening	Include
Exclude Basis	
Rationale	At Yucca Mountain, decomposition of concrete includes radiolysis, microbial decomposition and thermal decomposition. In addition, the potential repository location in the unsaturated zone reduces the dominance of aqueous corrosion.

FEP Number	2.1.12.06.00
FEP Name	Gas transport in waste and EBS
FEP Description	Gas in the waste and engineered barrier system could affect the long-term performance of the disposal system. Radionuclides may be transported as gases or in gases, gas bubbles may affect flow paths, and two-phase flow conditions may be important.
Screening	Exclude
Exclude Basis	Consequences
Rationale	This FEP addresses the phenomena of (1) gaseous-phase radionuclide transport, which is not relevant to the EBS, and (2) two-phase flow effects on liquid transport, which is applicable to the EBS, but its effect is not expected to be significant and, hence, is excluded. The Water Distribution and Removal AMR (see Attachment II), presently in preparation, indicates that even with a capillary backfill, such as Overton sand, and estimated maximum infiltration rates, the backfill remains unsaturated, and gas will be transmitted freely. Hence, no effect on gas saturation in the EBS is expected from gas generation within the drift. In saturated repository sites, backfill, such as bentonite, could be used to provide a low-permeability region around the waste packages. Such a region could be breached by gas-pressure buildup. However, this is not applicable to Yucca Mountain.

FEP Number	2.1.12.07.00
FEP Name	Radioactive gases in waste and EBS
FEP Description	Radioactive gases may exist or be produced in the potential repository. These gases may subsequently escape from the repository. Typical radioactive gases include 14C (in 14CO2 and 14CH4) produced during microbial degradation, tritium, fission gases (Ar, Xe, Kr), and radon.
Screening	Not applicable for EBS FEPs
Exclude Basis	
Rationale	The EBS is not expected to restrict the release of radioactive gases.

FEP Number	2.1.12.08.00
FEP Name	Gas explosions
FEP Description	Explosive gas mixtures could collect in the sealed repository. An explosion in the potential repository could have radiological consequences if the structure of the repository were damaged or near-field processes enhanced or inhibited.
Screening	Not applicable for EBS FEPs
Exclude Basis	
Rationale	Gases are not expected to build up in the potential repository, due to the high gas permeability in the surrounding fractured rock. See 2.1.12.01.

FEP Number	2.1.13.01.00
FEP Name	Radiolysis
FEP Description	Alpha, beta, gamma and neutron irradiation of water can cause disassociation of molecules, leading to gas production and changes in chemical conditions (Eh, pH, concentration of reactive radicals).
Screening	Not applicable for EBS FEPs
Exclude Basis	
Rationale	Radiation is largely attenuated by the waste package; radiolysis will be significant within the waste package.

FEP Number	2.1.13.02.00
FEP Name	Radiation damage in waste and EBS
FEP Description	Strong radiation fields could lead to radiation damage to the waste forms and waste packages.
Screening	Not applicable for EBS FEPs
Exclude Basis	
Rationale	Radiation is largely attenuated by the waste package; radiolysis will be significant within the waste package.

FEP Number	2.1.13.03.00
FEP Name	Microbial mutation
FEP Description	Radiation fields could cause mutation of microorganisms, leading to unexpected chemical reactions and impacts.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Mass balance arguments in the Physical and Chemical Environment AMR (see Attachment II), presently in preparation, show that the consequences of microbial effects, with or without mutation, are not significant.

FEP Number	2.2.07.06.00
FEP Name	Episodic / pulse release from repository
FEP Description	Episodic release of radionuclides from the potential repository and radionuclide transport in the unsaturated zone may occur both because of episodic flow into the repository, and because of other factors including intermittent failures of waste packages.
Screening	Exclude
Exclude Basis	Consequences
Rationale	Bounding concentrations of radionuclides, including colloids, are developed in the Physical and Chemical Environment AMR (see Attachment II), presently in preparation. Concentration enhancement by colloids would be most likely to occur during episodic flow. By assuming that colloid enhancement occurs continuously for the average influx rate, a conservative bound is obtained, and episodic release need not be considered explicitly.

FEP Number	2.2.08.04.00
FEP Name	Redissolution of precipitates directs more corrosive fluids to waste packages
FEP Description	Redissolution of precipitates which have plugged pores as a result of evaporation of ground water in the hot zone, produces a pulse of fluid reaching the waste packages when gravity-driven flow resumes, which is more corrosive than the original fluid in the rock.
Screening	Include
Exclude Basis	
Rationale	Reestablishment of flow will occur through the mode with the highest permeability, fractures through which flow persisted or which were easily unplugged. Plugged pores are least likely to reopen because there is no flow to dissolve the precipitates. Flow is likely to have chemistry associated with redissolution; however, it is still likely that the chemistry of the fluids will be driven by interaction with drift liner, dissolved constituents such as Fe, and the residual temperature of the potential repository.

ATTACHMENT IV

Table IV-1. Engineered Barrier System Features, Events, and Processes to be Included in the Yucca Mountain Site Characterization Project Feature, Event, and Process Database

FEP ebs #[a]	FEP Name	Issues(s)	Inclusion Argument
1	Pedestal Collapse	The waste package, as a result of pedestal collapse, lies on or in the invert and could be in contact with the drip shield and the rails, and be exposed to contact corrosion. While bedded in the invert, the waste package is more likely to see local ponding and the enhanced corrosion and mobilization which might accompany it.	Pedestal collapse could result from corrosion, seismically produced ground motion, or thermo-mechanical stress adjustment of the drift. It is an expected event in the repository life.
2	Drip Shield	Liquid water contact with the waste package is believed to affect the rate of corrosion of the metals, exposing the waste. The drip shield is intended to reduce direct liquid contact with the containers.	This feature is a baseline design feature (Wilkins and Heath 1999). It is intended to reduce direct contact of liquids with the waste package.
3	Drip Shield Supports	Failure of the drip shield supports allows the drip shield to make contact with the waste package or with the rails. Since the drip shield is made of Ti, the rails of steel, and the waste packages of a high-nickel alloy, contact could result in contact corrosion possibly affecting the integrity of the waste package.	Drip shield supports are part of the Engineered Barrier System design and their long-term failure must be considered.
4	Backfill	Crushed rock is placed to protect the waste package, or the drip shield and waste package from rockfall, failure of ground support, and possibly as a Richard's barrier for flow. Location of backfill, the size, and material type, all affect water chemistry (and the corrosion rates for drip shield and waste packages, dissolution rates for waste), and thermal properties (and waste temperatures and cladding failure). Suggestions for material type currently include sand, crushed limestone, marble, and crushed tuff. The last is the subject of investigation.	Backfill is a design feature which affects waste package lifetime, cladding failure, waste mobilization, and contaminant transport both indirectly (e.g., temperature) and directly (e.g., water chemistry). It is part of the disposal system and must be accounted for in some respect.
5	Invert	The invert materials, currently expected to be crushed rock, form the bed for the rails and will be the resting place for the waste package after the support pedestals fail. The invert is part of the flow pathway from the waste to the drift bottom and exit from the drift. The invert is also part of the flow pathway for water deflected by the drip shield from the waste packages. Water can accumulate in the invert, acting as a water vapor source for corrosion or possibly ponding. Accordingly, invert materials affect water chemistry for transport.	The invert is a design feature. It forms part of the flow pathway for liquid flow and for liquid transport, and its properties, affect water chemistry for transport. It forms part of the analysis of transport.
6	Rockfall Loading Distortion of Drip Shield	Contact corrosion, compromising the drip shield or the waste package develops as a result of displacement or distortion of the drip shield.	Enhanced corrosion would shorten the waste package life. Corrosion mechanisms need to be examined to establish their relative importance to waste package lifetime.
7	Rails	Rails represent a material, steel, added to the repository which is not necessary to long-term isolation, but which may have an impact on corrosion of the drip shield and on water chemistry for transport. If the Ti drip shield and the steel rails are in contact, contact corrosion is expected, which could affect the long-term ability of the drip shield to divert water from the waste package. Such contact would be expected locally as a result of a seismic disturbance, rockfall, or ground support failure.	Rails represent an added material whose presence directly affects another component, the drip shield, and indirectly affects water chemistry. These interactions need to be included in accounting for the waste package environment.

Table IV-1. Engineered Barrier System Features, Events, and Processes to be Included in the Yucca Mountain Site Characterization Project Feature, Event, and Process Database (Continued)

FEP ebs #[a]	FEP Name	Issues(s)	Inclusion Argument
8	Pedestal	The pedestal may be distorted or rack because of floor heave (thermo-mechanical stress adjustment) and ground motion (seismic event), or may fail due to corrosion. Failure by any mode will drop the waste package onto or into the invert.	The pedestal is a design feature. Its lifetime and performance influence corrosion of the waste package. The pedestal needs to be accounted for or discounted in analyses.
9	Ground Motion	Ground motion, generated by seismic events, provides accelerations to components of the repository, including the waste packages, drip shield, backfill, surrounding rock, and ground support. These accelerations cause relative motion of the components and could generate ground support failure, rockfall, and damage to waste packages and drip shields.	Ground motion is an expected phenomenon and is considered in the baseline design of both underground and surface components. Seismic hazard assessment is tasked to provide standard earthquake engineering inputs to support design.
10	Drip Shield Movement Relative to Waste Packages/Rails	Contact of the Ti drip shield with the waste package or with the steel rails will cause contact corrosion. In the former case, corrosion of the waste package will be enhanced, while in the latter case, that of the drip shield will be accelerated. Presumably, the fate of the rails is inconsequential.	Rockfall is expected to occur over the life of the repository. Some of that rockfall could be massive enough to cause displacement of the drip shield. The lifetimes of the waste packages are affected directly by corrosion or indirectly by reduced protection from the drip shield.
11	Relative Seismic Displacement	A seismic event in the potential repository generates relative displacements between waste package, drip shield, and rails, and ground support failure, and rockfall.	Since distant earthquakes producing local ground motion are assured events, the effects of such ground motion need to be accounted for in the EBS.
12	Ground Support Failure	Failure of ground support, for whatever reason, allows rockfall, displacement of backfill and waste packages, and development of new flow pathways. Possible cases include ground motion, thermo-mechanical stress adjustment and corrosion.	Ground support eventually fails. The rate of failure in a heated repository is unknown. Failure of ground support could initiate a chain of events which, by compromising the waste packages, allow early release.
13	Thermo-Mechanical Evolution of a Repository Block	Thermo-mechanical coupling, which alters the stress state of the rock surrounding the repository, affects floor buckling, fracture sealing and openings to the EBS, and loading and unloading of ground support.	Thermo-mechanical coupling which affects the flow of water into and out of the EBS directly alters the likelihood of contaminant transport.
14	Shear Fracture/ Fault Movement and Relaxation	Fractures that might otherwise be closed during the thermal period, because of compression from thermal expansion, are maintained as open pathways because of shear movement. Movement also allows distortion of the drift and the relative location of drip shield, rails, and waste packages, with possible contact being established.	Open fractures provide pathways for focus of water and release of contaminants, and need to be accounted for. Contact corrosion reduces drip shield and waste package performance.
15	Condensation Beneath Drip Shield	Condensation on the inner surface of the drip shield circumvents its performance and provides water to drip onto the waste package and its supporting pedestal. Enhanced corrosion of waste package and pedestal becomes possible.	The waste package and pedestal are not protected by the drip shield from this water source. The contribution to corrosion and mobilization of this source needs to be assessed.
16	Reflux Drainage of Condensate Zone	Condensate zones could contain a substantial amount of mobile water able to flow back into the drifts, perhaps as a single extended episode.	All water sources for significant amount of water reaching the EBS should be included in analyses.
17	Flow along Drip Shield (inside) Wall	Water vapor is available from water otherwise diverted from the waste packages, which flows down the drip shield and enters the invert, where it may accumulate.	The segmented drip shield is part of current baseline design. How it will work as engineered is subject to experimentation. Tests are presently in progress.

Table IV-1. Engineered Barrier System Features, Events, and Processes to be Included in the Yucca Mountain Site Characterization Project Feature, Event, and Process Database (Continued)

FEP ebs #[a]	FEP Name	Issues(s)	Inclusion Argument
18	Flow Through Backfill	Flow through the backfill reacts chemically with the backfill. This chemically altered water then interacts with the drip shield and rails to eventually reach the invert.	Flow through the backfill is likely to affect corrosion of the drip shield and, after reaction, also affect flow and transport exiting the drift.
19	Movement of Backfill Through Gaps and Separations in Drip Shield	The continuity of the drip shield and its ability to deflect liquid water could be compromised as a result of movement produced by thermo-mechanical or seismic processes.	Use of a drip shield requires some estimate of its behavior and confidence in that behavior.
20	Fluid Flow into Gaps and Separations in Drip Shield	The ability of the drip shield to deflect liquid water could be compromised as a result of the movement of liquid water through gaps or spaces which develop between drip shield segments.	Use of a drip shield requires some estimate of its behavior and confidence in that behavior.
21	Ground Support – Wire Mesh and Rockbolts	The expected life of ground support after the operational phase of the repository is unknown. Failure of ground support allows rockfall and development of a chimney or enlarged drift and filling of fracture or fault zones.	Failure of ground support is included; it is an expected phenomenon. All ground support fails eventually. The thermal environment of a repository puts the ground support under stress, which departs from the usual mine environment.
22	Ground Support – Rockbolts and Grout	The issues are that ground support introduces materials (Fe, grout, etc.) into the facility, which affects water chemistry. All ground support eventually fails, allowing rockfall, altering drift size and properties, and affecting flow pathways.	Introduced materials, such as steel rock bolts and grout, are expected to produce chemical changes in water chemistry. These changes may affect corrosion rates and will influence solubilities for contaminants. Failure of ground support, which allows rockfall and concomitant changes to drift geometry, affects the waste packages both directly by loading and indirectly by altering flow paths.
23	Drains (if used)	Water accumulation in the drift would wet the invert materials, possibly pond, and provide a continuing source of water vapor beneath the drip shield and backfill for interaction with waste packages and their supports.	Engineered drains are included for consideration. They are not currently part of the baseline design. Utility of a drain is not clear, because an engineered drain must survive the thermal period when presumably no water is available, and work properly after the thermal period is past. A drain which rapidly removes water reaching the drift floor, when prevention of waste package corrosion and mobilization of contaminants are the concerns, also rapidly removes contaminants from the drift once they are mobilized. Currently no trade-off studies are available.
24	Flow Along Drip Shield (outside) Wall	Since the segmented drip shield will see liquid water, the concerns are the effectiveness of the diversion (i.e., will liquid flow pass through the overlaps) and the corrosion resistance of the drip shield material to the water chemistry in the impinging water.	The segmented drip shield is part of current baseline design. How it will work as engineered, is subject to experimentation. Tests are presently in progress.
25	Microbial Activity	The concern is microbially accelerated corrosion and mobilization occurring in the warm, moist environment of the EBS.	All mechanisms for corrosion and mobilization need to be assessed.
26	Rockbolt/Grout Corrosion	The corrosion and alteration changes the flow path for water entrance and alters the chemistry of the water following those flow paths.	Flow pathways control, in part, the rate and frequency of water entering a drift.

Table IV-1. Engineered Barrier System Features, Events, and Processes to be Included in the Yucca Mountain Site Characterization Project Feature, Event, and Process Database (Continued)

FEP ebs #[a]	FEP Name	Issues(s)	Inclusion Argument
27	Drainage with Transport – Sealing and Plugging	Normal functioning of drainage in the drifts is not established, so how drainage will change if fractures are plugged is unclear. Suggestions include ponding until fractures in the wall are reached by the water level or until there is sufficient head to clear the fractures.	Engineered floor drains are included for consideration; they are not part of the baseline design (Wilkins and Heath 1999). Details of how contaminants leave the drift are important elements in establishing how transport proceeds through the unsaturated zone beneath the repository.
28	Drainage – Through Constructed Drains	Water accumulation would be possible in a drift, particularly in a region of floor buckling, if normal drainage is blocked. Such blockage could occur if fines and debris are deposited in fractures or as sediment along the drift floor. Excess water could allow more rapid corrosion and contaminant mobilization. The conundrum here is that rapid draining of water sooner might also mean rapid draining of contaminated water later.	Engineered floor drains are included for consideration; they are not part of the baseline design (Wilkins and Heath 1999). Drainage, which is a component of the measure of the residence of contaminants in the drift, needs to be carefully examined to resolve the conundrum.
29	Drainage with Transport – Ponding	Water could accumulate in the invert in sufficient amounts to flood the waste package, enhancing corrosion and eventual mobilization. Criticality could be a possible consequence.	Any processes that accelerate corrosion and contaminant mobilization require careful attention. Here, the problem is that contaminants are not transported until they are moved out of the pond. Criticality calculations can be done for this simple geometry.
30	Drip Shield Corrosion – Flow of Backfill Through Corroded Elements	The continuity of the drip shield and its ability to deflect liquid water could be compromised as a result of holes produced by corrosion.	Use of a drip shield requires some estimate of its behavior and confidence in that behavior.
31	Drip Shield Corrosion – Fluid Flow Through Corroded Elements to Waste Packages	Deflection of liquid water away from the waste packages depends on continuity of the drip shield and the absence of penetrations.	Use of a drip shield requires some estimate of its behavior and confidence in that behavior.
32	Corrosion of Drip Shields and Waste Packages	Corrosion may contribute to waste package failure. Corrosion is most likely to occur at locations where water drips on the waste packages, but other mechanisms should be considered.	The time-dependent water distribution relative to waste package corrosion is an important parameter relative to repository performance.

NOTE: [a] The FEP identification numbers are based on Table 3 of this report.