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

2. ☒ Analysis — Check all that apply

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

Describe use:

The analyses in this report provide input to conceptual model development and analysis for waste package and drip shield degradation.

3. ☐ Model — Check all that apply

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

Describe use:

4. Title:
FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation

5. Document Identifier (including Rev. No. and Change No., if applicable):
ANL-EBS-PA-000002 REV 01

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Remarks:

Revision 01

For TSPA-SR

Ahmed M. Monib is responsible for all sections of this document.

Bryan Bullard, Kearn P. Lee, and Michael Riggins aided in the development of the secondary FEP arguments contained in Section 6.2 of this document

2. Analysis or Model Title:

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4. Revision/Change No.	5. Description of Revision/Change
00	Initial Issue
00 ICN 01	Interim Change Notice. Updated for no backfill base case.
01	Revision 01. Updated to include secondary FEP discussions.
	Note: No black vertical lines were used to denote changes from the previous revision, since extensive changes have been made since 00 ICN 01 of this document.

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1. PURPOSE AND SCOPE

1.1 PURPOSE

As directed by a written development plan (CRWMS M&O 2000as), the primary purpose of this Analyses and Models Report (AMR) is to identify and document the analyses and resolution of the primary features, events, and processes (FEPs) affecting the waste package (WP) and drip shield (DS) degradation processes in the repository. Twenty-eight (28) FEPs have been identified as primary FEPs associated with the WP and DS degradation process. This AMR has been prepared to document the FEP inclusion/exclusion process and the screening methodology used in the process. The secondary FEPs and their relationship to their associated primary FEPs are also addressed and discussed herein.

1.2 SCOPE

The scope of this AMR is to identify the treatment of the primary FEPs affecting WP and DS degradation. The FEPs that are deemed potentially important to repository performance are evaluated, either as components of the total system performance assessment (TSPA) or as separate analysis in the Analyses and Models Report. The scope for this activity involves two tasks, namely:

Task 1: Identify, which FEPs are to be considered explicitly in the TSPA (called included FEPs) and in which AMRs these FEPs are addressed,

Task 2: Identify FEPs not to be included in the TSPA (called excluded FEPs) and provide justification for why these FEPs do not need to be a part of the TSPA model.

The analyses documented in this AMR are for the site recommendation (SR) basecase design (CRWMS M&O 2000ab). In this design, a drip shield is placed over the waste package and no backfill is placed over the drip shield (see Design Constraint 2.2.1.1.9 of CRWMS M&O 2000ab). The FEPs have been classified as primary and secondary FEPs and have been assigned to associated Process Model Reports (PMRs). The assignments were based on the nature of the FEPs so that the analysis and resolution for screening decisions reside with the subject-matter experts in the relevant disciplines. This AMR addresses the screening decisions associated with the FEPs for the Waste Package Degradation PMR group.

1.3 OVERVIEW OF FEPs ANALYSIS AND DEVELOPMENT

The overall FEPs identification and selection processes are summarized as follows. The initial set of FEPs has been created for the Yucca Mountain Project (YMP) TSPA by combining lists of FEPs identified as relevant to the YMP. This list consists of FEPs from the Nuclear Energy Agency working group, FEPs from YMP literature and site studies, and FEPs identified during YMP project staff workshops. These FEPs are organized under categories based on Nuclear Energy Agency category headings, which are further broken down into primary FEPs and secondary FEPs. The FEPs have been identified by a variety of methods, including expert judgement, informal elicitation, event tree analysis, stakeholder review, and regulatory stipulation. All potentially relevant FEPs have been included, regardless of origin. This approach has led to considerable redundancy in the FEP list, because the same FEPs are frequently identified by multiple sources, but it also ensures that a comprehensive review of narrowly defined FEPs will be performed.

Each FEP has been identified as either a primary or a secondary FEP (CRWMS M&O 2000al). Primary FEPs are those FEPs for which detailed screening arguments are developed. The classification and description of primary FEPs strives to capture the essence of all the secondary FEPs that map to the primary. Secondary FEPs are either FEPs that are completely redundant or that can be aggregated into a single primary FEP. The primary FEPs have been assigned to associated PMRs. The assignments were based on the nature of the FEPs so that the analysis and resolution for screening decisions reside with the subject-matter experts in the relevant disciplines. The resolution of other than system-level FEPs are documented in AMRs prepared by the responsible PMR groups. This section summarizes the screening decisions associated with the FEPs that are relevant to the waste package and drip shield PMR group.

Of the original list of FEPs, twenty-eight (28) have been identified as primary FEPs in relationship to waste package and drip shield degradation. The secondary FEPs assigned to waste package and drip shield degradation have been examined in detail and found to be addressed fully by the analyses applied to the primary FEPs. The approach used for these analyses is a combination of qualitative and quantitative screening of the primary FEPs. As per direction given by Dyer (Dyer 1999), the analyses are based on the criteria provided by the Nuclear Regulatory Commission (NRC) in proposed 10 Code of Federal Regulations (CFR) Part 63 (64 FR 8640) and by the U.S. Environmental Protection Agency (EPA) in proposed 40 CFR Part 197 (64 FR 46976) to determine whether or not each FEP should be included in the TSPA. For FEPs that are excluded from the TSPA based on the NRC or EPA criteria, the screening argument includes a summary of the basis and results that indicate either low probability or low consequence. As appropriate, screening arguments cite work done outside this activity, such as in other AMRs. For FEPs that are included in the TSPA, the TSPA disposition includes a reference to the AMR that describes how the FEP has been incorporated in the process models or the TSPA abstraction models.

2. QUALITY ASSURANCE

The Quality Assurance (QA) program applies to this analysis. The development of this report is prepared under the activity evaluation conducted for work package numbers *3301213PMA, 3301213PMB, and 33012132MJ.* The technical work plan *Waste Package Degradation Process Model Report for Site Recommendation* (CRWMS M&O 2000as), associated with this activity was prepared per AP-2.21Q, *Quality Determinations and Planning for Scientific, Engineering, and Regulatory Compliance Activities*. The results of this evaluation indicate that the activity is subject to the *Quality Assurance Requirements and Description* (DOE 2000) requirements. The methods used to control the electronic management of data as required by AP-SV.1Q, *Control of the Electronic Management of Information*, was accomplished in accordance with this plan.

This document was prepared in accordance with AP-3.10Q, *Analyses and Models,* and reviewed in accordance with AP-2.14Q, *Review of Technical Products.*

3. COMPUTER SOFTWARE AND MODEL USAGE

No computational software or models were used in the development of the analyses and modeling activities described in this AMR. The analyses and arguments presented herein are based on regulatory requirements, the results from other AMRs, or documented technical literature.

4. INPUTS

4.1 DATA AND PARAMETERS

The technical information used in this AMR as input has been obtained, where possible, from controlled source documents and references using the appropriate document identifiers or records system accession numbers.

A FEPs input list for this study can be found in the FEPs database (CRWMS M&O 2000al), which describes which FEPs are deemed primary/secondary with respect to their effects on the waste package (WP) and drip shield (DS) degradation process in the repository. As stated in the aforementioned development plan, the electronic database contains "a comprehensive list of FEPs potentially relevant to the long-term performance of the repository" and is capable of storing and retrieving information about the treatment of the FEPs in the TSPA.

Three sources have been used as sources of accepted data regarding metal properties. The first two, ASM International 1987 and 1990, are handbooks of metal properties, which contain accepted data. The third source, Haynes International 1988, contains data provided by a manufacturer and is considered accepted data.

Technical data for the waste package material properties have been taken from two data items in the Reference Information Base (RIB): *Physical and Chemical Characteristics of Alloy 22* (MO0003RIB00071.000), and *Physical and Chemical Characteristics of Type 316N Grade* (MO0003RIB00076.000).

4.2 CRITERIA

Technical screening criteria are provided as per U.S. Department of Energy's (DOE) interim guidance (Dyer 1999) as identified by the NRC in proposed 10 CFR Part 63 (64 FR 8640) and by the EPA in proposed 40 CFR Part 197 (64 FR 46976).

The proposed NRC regulations specifically allow the exclusion of FEPs from the TSPA if they are of low probability (less than one chance in 10,000 of occurring in 10,000 years) or if occurrence of the FEP can be shown to have no significant effect on expected annual dose.

4.2.1 Low Probability

The probability criterion as stated in the DOE's interim guidance (Dyer 1999) as identified by the NRC in proposed 10 CFR Section 63.114 (d) (64 FR 8640).

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

The EPA provides essentially the same criterion in proposed 40 CFR Section 197.40(64 FR 46976)

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

Because the probability of any specific event depends strongly on how it is defined, the probability criterion can only be applied on an appropriately broad scale. For example, the probability of seismic events should be evaluated over the entire 10,000-year period, rather than being artificially lowered by defining 10,000 different seismic events each occurring in a different year.

4.2.2 Low Consequence

Criteria for low consequence screening arguments as stated in the DOE's interim guidance (Dyer 1999) as identified by the NRC in proposed 10 CFR Section 63.114(e-f) (64 FR 8640)

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

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

The EPA provides essentially the same criteria in proposed 40 CFR Section 197.40 (64 FR 46976).

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

These criteria allow omitting those FEPs that can be shown to have no significant effect on the expected annual dose. "Significant" is an undefined term in the regulations and the lack of a significant effect must be demonstrated on a case-by-case basis for each FEP. Because the relevant performance measures differ for different FEPs (e.g., effects on performance can be measured in terms of changes in concentrations, flow rates, travel times, and other measures as well as overall expected annual dose), there is no single quantitative test of "significance."

4.3 CODES AND STANDARDS

This AMR was prepared to comply with the DOE interim guidance (Dyer 1999) which directs the use of specified Subparts/Sections of the proposed NRC high-level waste rule, 10 CFR Part 63 (64 FR 8640). Subparts of this proposed rule that are applicable to data include Subpart B, Section 15 (Site Characterization), Subpart E, Section 114 (Requirements For Performance Assessment), Subpart F (Performance Confirmation Program) and Subpart G (Quality Assurance). The subpart applicable to models is also outlined in Subpart E Section 114.

5. ASSUMPTIONS

There are three assumptions made in screening of the waste package FEPs. These assumptions or combinations thereof are used throughout this report.

Assumption 1) As directed by interim guidance (Dyer 1999, Section 114(l)), assume "evolution of the geologic setting consistent with present knowledge of natural processes".

The assumption affects waste package and drip shield FEPs concerned with geologic processes. The assumption implies that existing knowledge of natural processes is sufficient to adequately quantify future states of the system.

Assumption 2) Assume that the repository will be constructed, operated, and closed according to the regulatory requirements applicable to the construction, operation, and closure period and that deviations from design will be detected and corrected.

This assumption is justified based on the conditions specified in proposed 10 CFR Section 63.32, which pertains to construction authorization and which requires

"Periodic or special reports regarding:

(1) Progress of construction;

(2) Any data about the site, obtained during construction, that are not within the predicted limits on which the facility design was based;

(3) Any deficiencies, in design and construction, that, if uncorrected, could adversely affect safety at any future time".

In addition, proposed 10 CFR 63 Subpart F requires that a performance confirmation program be instituted. The focus of the program is confirmation of geotechnical and design parameters (Section 63.132), design testing (Section 63.133) and monitoring and testing waste packages (Section 63.134). In addition, under proposed 10 CFR 63 Subpart G, quality assurance requirements are applied to "site characterization, facility and equipment construction, facility operation, performance confirmation, permanent closure, and decontamination and dismantling of surface facilities". The assumption impacts waste package and drip shield FEPs that are affected by events occurring during the construction, operation, or closure period.

Assumption 3) Assume that the design parameters for the waste package and drip shield can be used to justify an excluded decision.

This assumption is justified based on the conditions specified in proposed 10 CFR 63.32 Subpart G that pertains to quality assurance.

> "Quality assurance includes quality control, which comprises those quality assurance actions related to the physical characteristics of a material, structure, component or system that provide a means to control the quality of the material, structure, component or system to predetermined requirements".

The assumption allows exclusion of FEPs when the design process specifically addresses the issue described by that particular FEP. Note that deviation from a design process despite a set of quality controls is allowed for in the TSPA. One example is the mechanism of "juvenile" failures of the waste package and/or drip shield (see primary FEP 2.1.03.08 and CRWMS M&O 2000p).

If a particular FEP meets the requirements of any of these assumptions, it will be considered to have a low probability of occurrence, even though it is not possible, in the current analysis, to assign a quantitative value to the probability.

6. ANALYSES AND MODELS

The FEPs are classified as either primary or secondary in the YMP FEPs database (CRWMS M&O 2000al). Primary FEPs are those that will require the development and documentation of screening arguments. Secondary FEPs are redundant or are considered a part of another FEP. Of primary concern in this AMR is the addressing and documenting of the screening arguments for the primary FEPs. Of the original list of FEPs, twenty-eight (28) have been identified as primary in relationship to waste package (WP) and drip shield (DS) degradation. The 28 primary FEPs addressed in this AMR are listed in Table 1. The secondary FEPs and their associated primary FEPs are listed in Table 2.

The technical information used in this AMR as input has been obtained, where possible, from controlled source documents and references using the appropriate document identifiers or records system accession numbers.

Based on the determination of importance presented in AP-3.10Q (Attachment 1, Item 6), and as directed by AP-3.10Q, based on the "Screening Criteria For Grading of Data" (AP-3.15Q, Attachment 1), this FEP-screening analysis is of Level 3 importance. The "Screening Criteria For Grading of Data" indicates, under the heading of "Potentially Disruptive Processes and Events," that this "does not include data used to screen features, events, and processes from further consideration in postclosure performance assessments." Consequently, Level 3 is assigned because the FEPs analyses do not provide estimates of any of the factors listed in the "Screening Criteria for Grading of Data."

Table 1. List of Primary FEPs Addressed in this AMR.

FEP NAME	YMP FEP DATABASE NUMBER
Error in waste or backfill emplacement	1.1.03.01.00
Fault movement shears waste container	1.2.02.03.00
Seismic vibration causes container failure	1.2.03.02.00
Magma interacts with waste	1.2.04.04.00
Corrosion of waste containers	2.1.03.01.00
Stress corrosion cracking of waste containers and drip shields	2.1.03.02.00
Pitting of waste containers and drip shields	2.1.03.03.00
Hydride cracking of waste containers and drip shields	2.1.03.04.00
Microbially-mediated corrosion of waste container and drip shield	2.1.03.05.00
Internal corrosion of waste container	2.1.03.06.00
Mechanical impact of waste container and drip shield	2.1.03.07.00
Juvenile and early failure of waste containers and drip shields	2.1.03.08.00
Copper corrosion	2.1.03.09.00
Container healing	2.1.03.10.00
Container form	2.1.03.11.00
Container failure (long term)	2.1.03.12.00
Effects and degradation of drip shield	2.1.06.06.00
Effects of material interfaces	2.1.06.07.00
Rockfall (Large Block) WFClad-Rockfall	2.1.07.01.00
Creeping of metallic materials in the EBS	2.1.07.05.00
Volume increase of corrosion products	2.1.09.03.00
Electrochemical effects in waste and EBS	2.1.09.09.00
Biological activity in waste and EBS	2.1.10.01.00
Differing thermal expansion of repository components	2.1.11.05.00
Thermal sensitization of waste containers and drip shields increases their fragility	2.1.11.06.00
Gas generation (H_2) from metal corrosion	2.1.12.03.00
Radiolysis	2.1.13.01.00
Radiation damage in waste and EBS	2.1.13.02.00

6.1 APPROACH

The approach used for this analysis is a combination of qualitative and quantitative screening of FEPs. The analyses are based on the criteria provided by the NRC in proposed 10 CFR Part 63 (64 FR 8640) and by the EPA in proposed 40 CFR Part 197 (64 FR 46976) to determine whether or not each FEP should be included in the TSPA.

For FEPs that are excluded from the TSPA based on NRC or EPA criteria, the screening argument includes a summary of the basis and results that indicate either low probability or low consequence. As appropriate, screening arguments cite work done outside this activity, such as in other AMRs. If needed, a more detailed discussion is provided in the Analysis/Discussion section.

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

In addition to documenting the disposition and the justification for the disposition of the primary FEPs that could affect waste package and drip shield degradation, this report serves an additional purpose. In order to fulfill its oversight role for the YMP, the staff of the NRC has developed a process for early resolution of technical issues. The NRC staff issued the Issue Resolution Status Report for Container Life and Source Term Key Technical Issue (CLST KTI) (NRC 1999, Section 4), which is considered by the NRC staff to be one of the technical issues important to post-closure performance of the proposed geologic repository. This AMR shows the correspondence between FEPs that could affect waste package and drip shield degradation processes and technical issues relevant to the CLST KTI. The technical issues that are relevant to the waste package and drip shield degradation are:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

Subissue 2: The Effects of Phase Instability and Initial Defects on the Mechanical Failure and Lifetime of the Containers

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem

In many instances, secondary FEPs are redundant to primary FEPs (or each other) and the discussion provided for the primary FEPs also addresses the secondary FEPs. Further discussion of exclusion arguments for secondary FEPs are presented when necessary. Table 2 lists all of the secondary FEPs pertaining to waste package and drip shield degradation below the associated primary FEP.

Table 2. List of Primary and Secondary FEPs for this AMR.

YMP FEP Database Number	FEP NAME	FEP Class
1.1.03.01.00	**Error in waste or backfill emplacement**	**Primary entry**
1.1.03.01.01	Inadequate backfill or compaction, voidage	Secondary entry
1.1.03.01.02	Containers are improperly placed - on drift floor	Secondary entry
1.1.03.01.03	Containers are placed too close together	Secondary entry
1.1.03.01.04	Emplacement error - containers placed in wet zone	Secondary entry
1.2.02.03.00	**Fault movement shears waste container**	**Primary entry**
1.2.03.02.00	**Seismic vibration causes container failure**	**Primary entry**
1.2.03.02.01	Container failure induced by microseisms associated with dike emplacement	Secondary entry
1.2.04.04.00	**Magma interacts with waste**	**Primary entry**
1.2.04.04.01	Magmatic volatiles attack waste	Secondary entry
1.2.04.04.02	Dissolution of spent fuel in magma	Secondary entry
1.2.04.04.03	Dissolution of other waste in magma	Secondary entry
1.2.04.04.04	Heating of waste container by magma (without contact)	Secondary entry
1.2.04.04.05	Failure of waste container by direct contact w/magma	Secondary entry
1.2.04.04.06	Fragmentation	Secondary entry
2.1.03.01.00	**Corrosion of waste containers**	**Primary entry**
2.1.03.01.01	Metallic corrosion	Secondary entry
2.1.03.01.02	Corrosion on wetting (of waste container)	Secondary entry
2.1.03.01.03	Oxic corrosion (of waste container)	Secondary entry
2.1.03.01.04	Anoxic corrosion (of waste container)	Secondary entry
2.1.03.01.05	Total corrosion rate (of waste container)	Secondary entry

YMP FEP Database Number	FEP NAME	FEP Class
2.1.03.01.06	Corrosion of copper canister	Secondary entry
2.1.03.01.07	Corrosion of steel vessel	Secondary entry
2.1.03.01.08	Container metal corrosion	Secondary entry
2.1.03.01.09	Corrosion (of waste container)	Secondary entry
2.1.03.01.10	Uniform corrosion (of waste container)	Secondary entry
2.1.03.01.11	Corrosive agents, Sulfides, oxygen, etc.	Secondary entry
2.1.03.01.12	Water turnover, copper canister	Secondary entry
2.1.03.02.00	**Stress corrosion cracking of waste containers and drip shields**	**Primary entry**
2.1.03.02.01	Stress corrosion cracking (of waste container)	Secondary entry
2.1.03.02.02	Stress corrosion cracking - dry waste container	Secondary entry
2.1.03.02.03	Stress corrosion cracking induced by secondary stress (container failure)	Secondary entry
2.1.03.02.04	Stress corrosion cracking (in waste and EBS)	Secondary entry
2.1.03.03.00	**Pitting of waste containers and drip shields**	**Primary entry**
2.1.03.03.01	Localized corrosion (of waste container)	Secondary entry
2.1.03.03.02	Pitting (of waste container)	Secondary entry
2.1.03.03.03	Pitting corrosion develops on containers	Secondary entry
2.1.03.04.00	**Hydride cracking of waste containers and drip shields**	**Primary entry**
2.1.03.04.01	Embrittlement and cracking	Secondary entry
2.1.03.05.00	**Microbially-mediated corrosion of waste container and drip shield**	**Primary entry**
2.1.03.06.00	**Internal corrosion of waste container**	**Primary entry**
2.1.03.06.01	DOE SNF waste package internal corrosion	Secondary entry
2.1.03.07.00	**Mechanical impact on waste container and drip shield**	**Primary entry**
2.1.03.07.01	Other canister degradation processes	Secondary entry
2.1.03.07.02	Failure of copper canister	Secondary entry
2.1.03.07.03	Failure of steel canister	Secondary entry
2.1.03.07.04	Reduced mechanical strength	Secondary entry
2.1.03.07.05	Container failure (mechanical)	Secondary entry
2.1.03.07.06	Falling rock hits container, increased seepage occurs, speeds corrosion of container	Secondary entry
2.1.03.08.00	**Juvenile and early failure of waste containers and drip shields**	**Primary entry**
2.1.03.08.01	Canister failure (alternative modes)	Secondary entry
2.1.03.08.02	Mis-sealed canister	Secondary entry
2.1.03.08.03	Container failure (early)	Secondary entry
2.1.03.08.04	Cracking along welds (of waste container)	Secondary entry
2.1.03.08.05	Random canister defects - quality control	Secondary entry
2.1.03.08.06	Common cause canister defects - quality control	Secondary entry
2.1.03.09.00	**Copper corrosion**	**Primary entry**
2.1.03.09.01	Role of chlorides in copper corrosion	Secondary entry
2.1.03.10.00	**Container healing**	**Primary entry**
2.1.03.10.01	Corrosion products (physical effects)	Secondary entry
2.1.03.11.00	**Container form**	**Primary entry**
2.1.03.11.01	Stainless steel fabrication flask	Secondary entry
2.1.03.11.02	Cast steel canister	Secondary entry
2.1.03.11.03	Canister thickness	Secondary entry
2.1.03.11.04	Container integrity	Secondary entry
2.1.03.11.05	DOE SNF waste package design	Secondary entry
2.1.03.11.06	DOE SNF canister design	Secondary entry
2.1.03.11.07	DOE SNF waste package design	Secondary entry
2.1.03.12.00	**Container failure (long-term)**	**Primary entry**
2.1.03.12.01	Canister failure (reference)	Secondary entry

YMP FEP Database Number	FEP NAME	FEP Class
2.1.03.12.02	Long-term physical stability (in waste and EBS)	Secondary entry
2.1.06.06.00	**Effects and degradation of drip shield**	**Primary entry**
2.1.06.06.01	Oxygen embrittlement of Ti drip shield	Secondary entry
2.1.06.07.00	**Effects at material interfaces**	**Primary entry**
2.1.07.01.00	**Rockfall (Large Block)** **WFClad—Rockfall**	**Primary entry**
2.1.07.01.01	Rockbursts in container holes	Secondary entry
2.1.07.01.02	Cave ins	Secondary entry
2.1.07.01.03	Cave in (in waste and EBS)	Secondary entry
2.1.07.01.04	Roof falls	Secondary entry
2.1.07.05.00	**Creeping of metallic materials in the EBS**	**Primary entry**
2.1.07.05.01	Creeping of copper	Secondary entry
2.1.07.05.02	External stress (in waste and EBS)	Secondary entry
2.1.07.05.03	Voids in the lead filling	Secondary entry
2.1.07.05.04	Loss of ductility (of waste container)	Secondary entry
2.1.07.05.05	Incomplete filling of containers	Secondary entry
2.1.09.03.00	**Volume increase of corrosion products**	**Primary entry**
2.1.09.03.01	Swelling of corrosion products (in waste and EBS)	Secondary entry
2.1.09.09.00	**Electrochemical effects (electrophoresis, galvanic coupling) in waste and EBS** **WP—Electrochemical Effects in Waste and EBS**	**Primary entry**
2.1.09.09.01	Repository induced Pb/Cu electrochemical reactions	Secondary entry
2.1.09.09.02	Natural telluric electrochemical reactions (in waste and EBS)	Secondary entry
2.1.09.09.03	Electro-chemical cracking (in waste and EBS)	Secondary entry
2.1.09.09.04	Electrochemical effects/gradients (in waste and EBS)	Secondary entry
2.1.09.09.05	Electrochemical effects of metal corrosion	Secondary entry
2.1.09.09.06	Electrochemical effects (in waste and EBS)	Secondary entry
2.1.09.09.07	Galvanic coupling (in waste and EBS)	Secondary entry
2.1.09.09.08	Electrophoresis (in waste and EBS)	Secondary entry
2.1.09.09.09	Electrochemical gradients (in waste and EBS)	Secondary entry
2.1.09.09.10	Galvanic coupling (in waste and EBS)	Secondary entry
2.1.09.09.11	Galvanic coupling (in waste and EBS)	Secondary entry
2.1.10.01.00	**Biological activity in waste and EBS**	**Primary entry**
2.1.10.01.01	Microbial activity accelerates corrosion of containers	Secondary entry
2.1.10.01.02	Microbial activity accelerates corrosion of cladding	Secondary entry
2.1.10.01.03	Microbial activity accelerates corrosion of contaminants	Secondary entry
2.1.10.01.04	Microbes (in waste and EBS)	Secondary entry
2.1.10.01.05	Microorganisms (in waste and EBS)	Secondary entry
2.1.10.01.06	Microbiological effects (in waste and EBS)	Secondary entry
2.1.10.01.07	Microbial activity (in waste and EBS)	Secondary entry
2.1.10.01.08	Microbial activity (in waste and EBS)	Secondary entry
2.1.10.01.09	Microbial activity (in waste and EBS)	Secondary entry
2.1.10.01.10	Microbial interactions	Secondary entry
2.1.10.01.11	Biofilms	Secondary entry
2.1.11.05.00	**Differing thermal expansion of repository components**	**Primary entry**
2.1.11.05.01	Differential thermal expansion of near-field barriers	Secondary entry
2.1.11.05.02	Shearing of waste containers by secondary stresses from thermal expansion of the rock	Secondary entry
2.1.11.05.03	Differential elastic response (in waste and EBS)	Secondary entry
2.1.11.05.04	Non-elastic response (in waste and EBS)	Secondary entry
2.1.11.06.00	**Thermal sensitization of waste containers and drip shields increases their fragility**	**Primary entry**

YMP FEP Database Number	FEP NAME	FEP Class
2.1.12.03.00	**Gas generation (H2) from metal corrosion**	**Primary entry**
2.1.12.03.01	Chemical effects of corrosion	Secondary entry
2.1.12.03.02	Effect of hydrogen on corrosion	Secondary entry
2.1.12.03.03	Hydrogen production (in waste and EBS)	Secondary entry
2.1.12.03.04	Hydrogen production by metal corrosion	Secondary entry
2.1.12.03.05	Container material inventory	Secondary entry
2.1.13.01.00	**Radiolysis**	**Primary entry**
2.1.13.01.01	Radiolysis (in waste and EBS)	Secondary entry
2.1.13.01.02	Radiolysis	Secondary entry
2.1.13.01.03	Radiolysis (in waste and EBS)	Secondary entry
2.1.13.01.04	Radiolysis (in waste and EBS)	Secondary entry
2.1.13.01.05	Radiolysis prior to wetting (in waste and EBS)	Secondary entry
2.1.13.01.06	Radiolysis of brine	Secondary entry
2.1.13.01.07	Radiolysis of cellulose (in waste and EBS)	Secondary entry
2.1.13.01.08	Radiolysis	Secondary entry
2.1.13.01.09	Radiolysis	Secondary entry
2.1.13.02.00	**Radiation damage in waste and EBS**	**Primary entry**
2.1.13.02.01	Radiation effects (in waste and EBS)	Secondary entry
2.1.13.02.02	Radiation effects on bentonite	Secondary entry
2.1.13.02.03	Material property changes (due to radiation in waste and EBS)	Secondary entry
2.1.13.02.04	Radiation damage (in waste and EBS)	Secondary entry
2.1.13.02.05	Radiation shielding (in waste and EBS)	Secondary entry
2.1.13.02.06	Radiation effects on buffer/backfill	Secondary entry
2.1.13.02.07	Radiation effects on canister	Secondary entry
2.1.13.02.08	Radiological effects on waste	Secondary entry
2.1.13.02.09	Radiological effects on containers	Secondary entry
2.1.13.02.10	Radiological effects on seals	Secondary entry
2.1.13.02.11	Radiation effects on canister	Secondary entry

6.2 FEPS ANALYSES

This AMR addresses the 28 primary FEPs and the associated secondary FEPs that pertain to waste package and drip shield degradation. These FEPs are best dealt with by subject-matter experts in the relevant disciplines. The FEPs discussed in this report are relevant to the waste package and drip shield degradation PMR, however, there may be instances of overlap with other PMRs.

6.2.1 Primary FEP 1.1.03.01.00, Error in Waste or Backfill Emplacement

6.2.1.1 FEP Description:

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

6.2.1.2 Related Primary FEPs:

FEP 2.1.01.02.00, Co-disposal/Co-location of Waste

FEP 2.1.03.07.00, Mechanical Impact of Waste Container and Drip Shield

FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall

FEP 2.1.11.06.00, Thermal Sensitization of Waste Containers and Drip Shields Increases Fragility

6.2.1.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem

6.2.1.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence (all components of FEP not explicitly excluded based on low probability)

Excluded - Low Probability (not credible) (Inadequate Backfill or Compaction- FEP 2.1.03.01.01)

6.2.1.5 Screening Argument:

Deviations from the design and/or errors in waste and backfill emplacement and how they are dealt with are addressed in *Waste Emplacement/Retrieval System Description Document,* (CRWMS M&O 2000ad, Section 2.5). Table 13 of the referenced document specifies the design criterion compliance procedures and references the emplacement/retrieval component design calculations. This set of criteria serves as the quality control measures, which ensures that design deviations are addressed. In the current repository design, no backfill will be used. Thus errors in backfill emplacement are excluded on the basis of low probability (not credible).

In the event that an error does occur with the waste package emplacement system and a waste package is dropped or collides with another component within the drift, no damage of significance is expected to occur. Slap-down analysis of a 21-PWR waste package was performed where the waste packages were dropped on their side from a vertical position. The resulting stresses on the waste package material were less than 90% of the ultimate tensile strength of those materials (CRWMS M&O 2000aj, Section 6.2). Since the impact energy (the "fall-down" height) associated with an emplacement error (CRWMS M&O 2000ad, Section 1.2) is significantly less than that seen by a vertical tip over, an emplacement error is also not expected to result in any damage. Thus, this FEP can be excluded based on negligible consequence to the expected annual dose.

This FEP is also discussed in the EBS FEPs AMR (CRWMS M&O 2000c) and also excluded.

6.2.1.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.1.7 Supplemental Discussion:

Item intentionally left blank.

6.2.1.8 Relevant References:

CRWMS M&O 2000c. *Engineered Barrier System Features, Events, and Processes, and Degradation Modes Analysis.* ANL-EBS-MD-000035

6.2.1.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 1.1.03.01.00, Error in Waste or Backfill Emplacement.

Secondary FEP Number and Name: 1.1.03.01.01, Inadequate Backfill or Compaction, Voidage.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address errors in waste or backfill emplacement.

Screening and Disposition: Voids in the emplaced backfill could result in damage to the waste package and drip shields due to rockfall. The current repository design (CRWMS M&O 2000ab) does not include the emplacement of backfill in the EBS, thus this secondary FEP is not applicable to the Yucca Mountain repository. In addition, as discussed in primary FEPs 2.1.03.07.00, Mechanical Impact of Waste Container and Drip Shield and 2.1.07.01.00, Rockfall (Large Block), waste package integrity is not compromised by rockfall. Since backfill is not included in the current repository design, this secondary FEP is excluded on the basis of low probability (not credible).

Secondary FEP Number and Name: 1.1.03.01.02, Containers are Improperly Placed - on Drift Floor.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address errors in waste emplacement.

Screening and Disposition: This secondary FEP specifically addresses the improper placement of waste canisters onto the drift floor. This improper placement could result in poorer heat removal resulting in higher waste package temperatures. The *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* AMR indicates that the corrosion rate is not adversely effected by higher temperatures (CRWMS M&O 2000b, Sections 6.5.2 and 7). This secondary FEP is therefore excluded due to low consequence to the expected annual dose.

Secondary FEP Number and Name: 1.1.03.01.03, Containers are Placed Too Close Together.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address errors in waste emplacement.

Screening and Disposition: This secondary FEP specifically addresses the improper placement of waste canisters in the drift. Waste packages placed too close together will experience higher temperatures resulting in increased corrosion of the waste form cladding. The corrosion of the waste form cladding is not addressed in this AMR. Secondary FEPs pertaining to waste form/cladding degradation are addressed in the AMR (CRWMS M&O 2000ao). The effects of elevated waste package temperatures are discussed in secondary FEP 1.1.03.01.02 above and primary FEP 2.1.11.06.00, Thermal Sensitization of Waste Containers and Drip Shields Increases Fragility.

Secondary FEP Number and Name: 1.1.03.01.04, Emplacement Error - Containers Placed in Wet Zone.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address errors in waste emplacement.

Screening and Disposition: This secondary FEP specifically addresses the improper placement of waste canisters in wet zones within the drift. The improper placement of waste containers in the drift could result in higher waste package corrosion rates. Furthermore, the *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* AMR (CRWMS M&O 2000b, Sections 6.5.2 and 7) indicates that the general corrosion rate is not a function of dripping water. This secondary FEP is excluded due to low consequence to the expected annual dose.

6.2.2 Primary FEP 1.2.02.03.00, Fault Movement Shears Waste Container

6.2.2.1 FEP Description:

Fault slip could partially or completely offset one or more tunnels in the repository thereby shearing any waste containers that lie across the fault plane.

6.2.2.2 Related Primary FEPs:

1.2.02.02.00, Faulting

2.1.03.07.00, Mechanical Impact of Waste Container and Drip Shield

6.2.2.3 IRSR Issues:

Item intentionally left blank.

6.2.2.4 Screening Decision and Regulatory Basis:

Excluded – Low Probability

6.2.2.5 Screening Argument:

This FEP is outside the scope of the Waste Package AMR and is addressed in the Disruptive Events PMR (CRWMS M&O 2000ap) and Disruptive Events FEPS AMR (CRWMS M&O 2000f).

6.2.2.6 TSPA Disposition:

Excluded from the TSPA for the waste package as described under the Screening Argument.

6.2.2.7 Supplemental Discussion:

Item intentionally left blank.

6.2.2.8 Relevant References:

CRWMS M&O 2000e. *Effects of Fault Displacement on Emplacement Drifts*. ANL-EBS-GE-000004

CRWMS M&O 2000f. *Disruptive Events FEPS*. ANL-WIS-MD-000005

CRWMS M&O 2000ap. *Disruptive Events Process Model Report*. TDR-NBS-MD-000002

6.2.2.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 1.2.02.03.00, Fault Movement Shears Waste Container.

No secondary FEPs have been associated with this primary FEP.

6.2.3 Primary FEP 1.2.03.02.00, Seismic Vibration Causes Container Failure

6.2.3.1 FEP Description:

Seismic activity causes repeated vibration of the waste container and drip shield and/or waste container and drip shield-rock wall contact, damaging the drip shield and waste container and its contents.

6.2.3.2 Related Primary FEPs:

1.2.03.01.00, Seismic Activity

2.1.03.07.00, Mechanical Impact of Waste

6.2.3.3 IRSR Issues:

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.3.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.3.5 Screening Argument:

This FEP was originally directed at vertical emplacement of containers in boreholes. The current design is to place large containers horizontally in the drifts under titanium drip shields (CRWMS M&O 2000ab, Design Constraint 5.2.11). Seismic activity will not induce stress corrosion cracking (SCC) of the waste packages or drip shields, regardless of magnitude, since a sustained tensile stress is required for SCC and an earthquake is only temporary in nature (CRWMS M&O 2000q, Section 5, Assumption 1). In addition, the Emplacement Drift System design criteria require that the drip shield be designed to withstand a Category 2 design basis earthquake without rupturing or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.16 and 1.2.1.17). Damage to the waste package resulting from dislodgment from the emplacement pallet has been excluded. Slap-down analysis has shown that the resulting stress of a waste package falling on its side from a vertical position results in stresses that are less than 90% of the ultimate tensile strength. This stress level is insufficient to cause a waste package breach (CRWMS M&O 2000aj, Table 18). Since the horizontal fall of the waste package from the emplacement pallet is at a lower energy level (the fall distance is shorter) the resulting stress level will also not result in a breach.

Based on the above rationale, this FEP is excluded for both waste package and drip shield due to its negligible consequence.

This AMR does not address damage of the contents of the waste package. Damage to the fuel rod-cladding is included in the TSPA analysis (CRWMS M&O 2000ae).

This FEP is also addressed in the Disruptive Events PMR (CRWMS M&O 2000ap) and Disruptive Events FEPs AMR (CRWMS M&O 2000f).

6.2.3.6 TSPA Disposition:

Excluded from the TSPA for the waste package as described under the Screening Argument.

6.2.3.7 Supplemental Discussion:

Item intentionally left blank.

6.2.3.8 Relevant References:

CRWMS M&O 2000aa. *Emplacement Drift System Description Document.* SDD-EDS-SE-000001

CRWMS M&O 2000aj. *Design Analysis for UCF Waste Packages.* ANL-UDC-MD-000001

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material.* ANL-EBS-MD-000005

CRWMS M&O 2000ap. *Disruptive Events Process Model Report.* TDR-NBS-MD-000002

6.2.3.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 1.2.03.02.00, Seismic Vibration Causes Container Failure.

Secondary FEP Number and Name: 1.2.03.02.01, Container Failure Induced by Microseisms Associated with Dike Emplacement.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address container failure associated with seismic activity.

Screening and Disposition: Similar to the primary FEP, this secondary FEP specifically addresses container-rock wall contact during seismic disruptions. This secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument for the primary FEP 1.2.03.02.00, Seismic Vibration Causes Container Failure.

6.2.4 Primary FEP 1.2.04.04.00, Magma Interacts with Waste

6.2.4.1 FEP Description:

An igneous intrusion in the form of a dikeoccurs through the repository, intersecting waste. This leads to accelerated waste-container failure (e.g., attack by magmatic volatiles (FEP 1.2.04.04.01), damage by fragmented magma (FEP 1.2.04.04.06), thermal effects (FEP 1.2.04.04.04), and dissolution of waste (FEP 1.2.04.04.02, 1.2.04.04.03)).

6.2.4.2 Related Primary FEPs:

Item intentionally left blank.

6.2.4.3 IRSR Issues:

Item intentionally left blank.

6.2.4.4 Screening Decision and Regulatory Basis:

Included

6.2.4.5 Screening Argument:

Included in TSPA as described under TSPA Disposition.

6.2.4.6 TSPA Disposition:

Magma interactions with the waste are included in the TSPA as part of disruptive events analyses. For the no-backfill design, all drip shields and waste form cladding in drifts that are intersected by magma are completely damaged (CRWMS M&O 2000aq, Section 6.2). All waste packages in drifts that are intersected by magma are damaged to some degree by the igneous intrusion event. The seven waste packages nearest the point of magmatic intrusion are assumed to be completely damaged by the igneous event and provide no protection to the waste form (CRWMS M&O 2000aq, Section 6.2). All remaining waste packages in drifts intersected by magma are assumed to be breached with an opening of uncertain cross-sectional area as discussed in the AMR entitled *Igneous Consequence Modeling for the TSPA-SR* (CRWMS M&O 2000aq, Section 6.2).

6.2.4.7 Supplemental Discussion:

Item intentionally left blank.

6.2.4.8 Relevant References:

CRWMS M&O 2000f. *Disruptive Events FEPS.* ANL-WIS-MD-000005

CRWMS M&O 2000v. *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (T0015).* ANL-MGR-GS-000001

CRWMS M&O 2000aq. *Igneous Consequence Modeling for the TSPA-SR.* ANL-WIS-MD-000017

6.2.4.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 1.2.04.04.00, Magma Interacts with Waste.

Secondary FEP Number and Name: 1.2.04.04.01, Magmatic Volatiles Attack Waste.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address disruptive events and the impact on the ability of the waste packages to retain radionuclides. The second part of this secondary FEP addresses the effects of magmatic volatiles on radionuclide solubility.

Screening and Disposition: This secondary FEP specifically addresses the effects of corrosive gases associated with the magma released during a disruptive event. As stated in the screening argument for the primary FEP 1.2.04.04.00, Magma Interacts with Waste, the effects of disruptive events are included in the TSPA analysis. Specifically all waste packages that are affected by intrusion are assumed damaged sufficiently that they provide no further protection for the waste and radionuclides are immediately available for release (CRWMS M&O 2000ap, Section 3.1). As stated in the primary FEP, 1.2.04.04.00, Magma Interacts with Waste, the first part of this secondary FEP is included in the TSPA analysis. This FEP is also addressed in the *Disruptive Events FEPS* screening document (CRWMS M&O 2000f). This WP FEPs AMR does not address the second part of this secondary FEP, the effects of volatiles on the solubility of the radionuclides.

Secondary FEP Number and Name: 1.2.04.04.02, Dissolution of Spent Fuel in Magma.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address disruptive events and the impact on radionuclide release.

Screening and Disposition: This secondary FEP does not pertain to waste package degradation and hence is not discussed herein. See the *Disruptive Events FEPS* AMR (CRWMS M&O 2000f) and the *Miscellaneous Waste-Form FEPs* AMR (CRWMS M&O 2000an) for the screening discussion of this secondary FEP.

Secondary FEP Number and Name: 1.2.04.04.03, Dissolution of Other Waste in Magma.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address disruptive events and the impact on radionuclide release.

Screening and Disposition: This secondary FEP does not pertain to waste package degradation and hence is not discussed herein. See the *Disruptive Events FEPS* AMR (CRWMS M&O 2000f) and the *Miscellaneous Waste-Form FEPs* AMR (CRWMS M&O 2000an) for the screening discussion of this secondary FEP. The TSPA analysis treats all fuel types equally in the disruptive event scenario.

Secondary FEP Number and Name: 1.2.04.04.04, Heating of Waste Container by Magma (without Contact).

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address waste package failure due to igneous events.

Screening and Disposition: Redundant. This secondary FEP is included in the primary FEP 1.2.04.04.00, Magma Interacts with Waste as stated in the TSPA Disposition.

Secondary FEP Number and Name: 1.2.04.04.05, Failure of Waste Container by Direct Contact w/Magma.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address waste package failure due to igneous events.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP 1.2.04.04.00, Magma Interacts with Waste and as stated in the TSPA Disposition is included in the TSPA analysis.

Secondary FEP Number and Name: 1.2.04.04.06, Fragmentation

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address waste package failure due to igneous events.

Screening and Disposition: This secondary FEP does not pertain to waste package degradation as implemented in the WAPDEG software and hence is not discussed herein. See the *Disruptive Events FEPS* AMR (CRWMS M&O 2000f) for a discussion on this secondary FEP.

6.2.5 Primary FEP 2.1.03.01.00, Corrosion of Waste Containers

6.2.5.1 FEP Description:

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.

6.2.5.2 Related Primary FEPs:

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

FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields

FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields

FEP 2.1.03.05.00, Microbially Mediated Corrosion of Waste Container and Drip Shield

FEP 2.1.03.06.00, Internal Corrosion of Waste Container

FEP 2.1.03.09.00, Copper Corrosion

FEP 2.1.03.12.00, Container Failure (Long-Term)

FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion

FEP 2.1.13.01.00, Radiolysis.

6.2.5.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.5.4 Screening Decision and Regulatory Basis:

Included (all components of FEP not explicitly excluded)

Excluded - Low Probability (not credible) (Corrosion of Copper Canister- FEP 2.1.03.01.06)

6.2.5.5 Screening Argument:

Included in TSPA as described under TSPA Disposition. However, copper corrosion is excluded based on low probability (not credible) as described in Section 6.2.5.9 (FEP 2.1.03.01.06).

6.2.5.6 TSPA Disposition:

Corrosion is the most likely process leading to degradation and failure of waste containers and drip shields in the repository. All significant corrosion modes are included in waste container/drip shield corrosion modeling. These include dry-air oxidation, humid-air corrosion, and aqueous corrosion processes such as general corrosion, localized (pitting and crevice) corrosion, SCC, hydrogen induced cracking, and microbial influenced corrosion (CRWMS M&O 2000b, CRWMS M&O 2000h and CRWMS M&O 2000p).

Corrosion is included in TSPA as part of waste package degradation analyses. Waste container/drip shield corrosion is modeled with WAPDEG (CRWMS M&O 2000p). WAPDEG produces waste package/drip shield degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per failed waste package/drip shield) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model.

6.2.5.7 Supplemental Discussion:

Item intentionally left blank.

6.2.5.8 Relevant References:

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier.* ANL-EBS-MD-000003

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004

CRWMS M&O 2000i. *Calculation of General Corrosion Rate of Drip Shield and Waste Package Outer Barrier to Support WAPDEG Analysis.* CAL-EBS-PA-000002

CRWMS M&O 2000l. *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier*. ANL-EBS-MD-000001

CRWMS M&O 2000m. *Aging and Phase Stability of Waste Package Outer Barrier*. ANL-EBS-MD-000002

CRWMS M&O 2000n. *Abstraction of Models for Pitting and Crevice Corrosion of Drip Shield and Waste Package Outer Barrier*. ANL-EBS-PA-000003

CRWMS M&O 2000o. *Abstraction of Models of Stress Corrosion Cracking of Drip Shield and Waste Package Outer Barrier and Hydrogen Induced Corrosion of Drip Shield*. ANL-EBS-PA-000004

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation*. ANL-EBS-PA-000001

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material*. ANL-EBS-MD-000005

CRWMS M&O 2000r. *Hydrogen Induced Cracking of Drip Shield*. ANL-EBS-MD-000006

CRWMS M&O 2000s. *Degradation of Stainless Steel Structural Material*. ANL-EBS-MD-000007

CRWMS M&O 2000ai. *Abstraction of Models for Stainless Steel Structural Material Degradation*. ANL-EBS-PA-000005

6.2.5.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.01.00, Corrosion of Waste Containers.

Secondary FEP Number and Name: 2.1.03.01.01, Metallic Corrosion.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: Redundant. This secondary FEP is identical to one of the scenarios discussed in the primary FEP 2.1.03.01.00, Corrosion of Waste Containers and as stated in the TSPA Disposition (Section 6.2.5.6 in this WP FEP AMR) is included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.01.02, Corrosion on Wetting (of Waste Container)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion in an aqueous environment.

Screening and Disposition: Redundant. This secondary FEP is identical to one of the scenarios discussed in the primary FEP 2.1.03.01.00, Corrosion of Waste Containers and as stated in the TSPA Disposition (Section 6.2.5.6 in this WP FEP AMR) is included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.01.03, Oxic Corrosion (of Waste Container).

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: In the waste package degradation analysis numerous corrosion scenarios have been proposed. As stated in the primary FEP 2.1.03.01.00, Corrosion of Waste Containers, all significant corrosion modes are included in waste container/drip shield corrosion modeling. For a discussion on the corrosion models addressed, see the documents listed in the section Relevant References (Section 6.2.5.8 in this WP FEP AMR).

Secondary FEP Number and Name: 2.1.03.01.04, Anoxic Corrosion (of Waste Container).

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: In the waste package degradation analysis numerous corrosion scenarios have been proposed. As stated in the primary FEP 2.1.03.01.00, Corrosion of Waste Containers, all significant corrosion modes are included in waste container/drip shield corrosion modeling. For a discussion on the corrosion models addressed, see the documents listed in the section Relevant References (Section 6.2.5.8 of this WP FEP AMR).

Secondary FEP Number and Name: 2.1.03.01.05, Total Corrosion Rate (of Waste Container)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: In the waste package degradation analysis numerous corrosion scenarios have been proposed. As stated in the primary FEP 2.1.03.01.00, Corrosion of Waste Containers, all significant corrosion modes are included in waste container/drip shield corrosion modeling. For a discussion on the corrosion models addressed, see the documents listed in the section Relevant References (Section 6.2.5.8 of this WP FEP AMR).

Secondary FEP Number and Name: 2.1.03.01.06, Corrosion of Copper Canister.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: This secondary FEP is excluded from the TSPA analysis as it is not pertinent to the proposed repository at Yucca Mountain. This FEP has low probability (not credible). The discussion provided for by the primary FEP 2.1.03.09.00, Copper Corrosion addresses this secondary FEP. Namely, copper is not considered for use as an engineered barrier at Yucca Mountain, and all copper materials at the site surface will be removed prior to repository closure (CRWMS M&O 1994, Section 1.2). Corrosion of the waste package is included in the TSPA analysis as stated in the TSPA Disposition for the primary FEP 2.1.03.01.00, Corrosion of Waste Containers (Section 6.2.5.6 of this WP FEPs AMR).

Secondary FEP Number and Name: 2.1.03.01.07, Corrosion of Steel Vessel.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: This secondary FEP is excluded from the TSPA analysis. The 316NG stainless steel inner barrier of the waste containers yields no performance credit in the WAPDEG analysis (CRWMS M&O 2000p Section 5.1). Thus, by not accounting for the inner barrier in the degradation analysis, the stainless steel provides a beneficial effect with respect to waste package corrosion. This secondary FEP is excluded based on low consequence to the expected annual dose (beneficial).

Secondary FEP Number and Name: 2.1.03.01.08, Container Metal Corrosion

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP 2.1.03.01.00, Corrosion of Waste Containers and as stated in the TSPA Disposition (Section 6.2.5.6 of this WP FEP AMR) is included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.01.09, Corrosion (of Waste Container)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP 2.1.03.01.00, Corrosion of Waste Containers and as stated in the TSPA Disposition (Section 6.2.5.6 of this WP FEP AMR) is included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.01.10, Uniform Corrosion (of Waste Container)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: In the waste package degradation analysis numerous corrosion scenarios have been proposed. As stated in the primary FEP 2.1.03.01.00, Corrosion of Waste Containers, all significant corrosion modes are included in waste container/drip shield corrosion modeling. For a discussion on the corrosion models addressed, see the documents listed in the section Relevant References (Section 6.2.5.8 of this WP FEP AMR).

Secondary FEP Number and Name: 2.1.03.01.11, Corrosive Agents, Sulfides, Oxygen, Etc.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: Taken specifically, this secondary FEP is excluded from the waste package degradation analysis because the current repository design does not consider copper material for an engineered barrier (see primary FEP 2.1.03.09.00, Copper Corrosion). In the current TSPA waste package degradation analysis, numerous corrosion scenarios have been proposed. The effects of the chemical environment are considered in waste package and drip shield corrosion as discussed in the AMR *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (CRWMS M&O 2000p). For a discussion on the corrosion models addressed, see the documents listed in the section Relevant References (Section 6.2.5.8 of this WP FEP AMR).

Secondary FEP Number and Name: 2.1.03.01.12, Water Turnover, Copper Canister.

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the degradation of the waste packages by corrosion.

Screening and Disposition: Taken specifically, this secondary FEP is excluded from the waste package degradation analysis because the current repository design does not consider copper material for an engineered barrier (see primary FEP FEP 2.1.03.09.00, Copper Corrosion). In the current TSPA waste package degradation analysis, numerous corrosion scenarios have been proposed, including aqueous corrosion of the Alloy 22 outer barrier. As stated in the AMR WAPDEG Analysis of Waste Package and Drip Shield Degradation (CRWMS M&O 2000p Section 5.1), no performance credit is taken for the 316NG stainless steel inner barrier, under aqueous or non-aqueous conditions. For a discussion on the corrosion models addressed, see the documents listed in the section Relevant References (Section 8 of this WP FEP AMR).

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

6.2.6.1 FEP Description:

Waste packages and drip shields become wet at specific locations that are stressed. Stress-corrosion cracking ensues. The possibility of SCC under dry conditions or due to thermal stresses are also addressed as part of this FEP.

6.2.6.2 Related Primary FEPs:

FEP 2.1.03.01.00, Corrosion of Waste Container

6.2.6.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

6.2.6.4 Screening Decision and Regulatory Basis:

Included (waste container)

Excluded – Low Consequence (for drip shield)

6.2.6.5 Screening Argument:

Included in TSPA for the waste container, as described under TSPA Disposition (Section 6.2.6.6 of this WP FEP AMR). All fabrication welds of the drip shield will be fully annealed before being placed in the emplacement drift (CRWMS M&O 2000k, Section 8.3) and thus are not subject to SCC.

The only other possible source of stress corrosion cracks on the drip shields is due to cold work stress and cracks caused by rockfall. However, these cracks tend to be tight (i.e., small crack opening displacement) and fill with corrosion products and precipitates such as carbonate minerals (CRWMS M&O 2000q, Section 6.5.5). These corrosion products will limit water transport through the DS, and thus not contribute significantly to the overall radionuclide release rate from the underlying failed waste packages.

Based on the above rationale, this FEP is included for the waste container (see Section 6.2.6.6 TSPA Dispostion of this WP FEPs AMR) and excluded for the drip shield due to low consequence to the expected annual dose.

6.2.6.6 TSPA Disposition:

SCC is one of a number of corrosion mechanisms that could potentially lead to eventual compromise of waste containers and/or drip shields. SCC is included in TSPA as part of waste package degradation analysis but is excluded in the analysis of drip shield degradation.

Waste container SCC is modeled with the WAPDEG computer code (CRWMS M&O 2000ah) as discussed in the WAPDEG analysis AMR (CRWMS M&O 2000p Section 6.3). WAPDEG produces waste package/drip shield degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per failed waste package/drip shield) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00, Corrosion of Waste Containers).

Because, among other exposure condition parameters, tensile stress is required to initiate SCC, and the waste container closure welds are the only places with such tensile stresses, only the waste container closure welds are considered for SCC (CRWMS M&O 2000q, Section 5 Assumption 1). The other fabrication welds of the waste container will be fully annealed before waste is loaded into the waste containers (CRWMS M&O 2000k, Section 8.1.7) and thus are not subject to SCC.

Presence of stable "liquid" water is required to initiate corrosion processes (including SCC) that are supported by electrochemical corrosion reactions. A threshold relative humidity is used in the waste package degradation analysis to simulate such a corrosion initiation condition. The threshold relative humidity is based on the deliquescence point of $NaNO_3$ salt (CRWMS M&O 2000l, Section 6). Therefore, under conditions with the relative humidity below the threshold value (i.e., dry conditions as described in secondary FEP 2.1.03.02.02,), SCC will not occur.

6.2.6.7 Supplemental Discussion:

Item intentionally left blank.

6.2.6.8 Relevant References:

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material.* ANL-EBS-MD-000005

CRWMS M&O 2000l. *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier.* ANL-EBS-MD-000001

6.2.6.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Secondary FEP Number and Name: 2.1.03.02.01, Stress Corrosion Cracking (of Waste Container)

Relationship to Primary FEP: Redundant. This secondary FEP is identical to the associated primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.6.5 of this WP FEP AMR) and TSPA Disposition (Section 6.2.6.6 of this WP FEP AMR) for primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Secondary FEP Number and Name: 2.1.03.02.02, Stress Corrosion Cracking - Dry Waste Container

Relationship to Primary FEP: Redundant. This secondary FEP is identical to the associated primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.6.5 of this WP FEP AMR) and TSPA Disposition (Section 6.2.6.6 of this WP FEP AMR) for primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Secondary FEP Number and Name: 2.1.03.02.03, Stress Corrosion Cracking Induced by Secondary Stress (Container Failure)

Relationship to Primary FEP: Redundant. This secondary FEP is identical to the associated primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.6.5 of this WP FEP AMR) and TSPA Disposition (Section 6.2.6.6 of this WP FEP AMR) for primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Secondary FEP Number and Name: 2.1.03.02.04, Stress Corrosion Cracking (in Waste and EBS)

Relationship to Primary FEP: Redundant. As it pertains to the waste package, this secondary FEP is identical to the associated primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields.

Screening and Disposition: Taken specifically, this secondary FEP is excluded from the waste package degradation analysis because the current repository design does not consider copper material for an engineered barrier (see primary FEP 2.1.03.09.00, Copper Corrosion). However, when considering the proposed EBS design, this secondary FEP is redundant. See the Screening Argument (Section 6.2.6.5 of this WP FEP AMR) and TSPA Disposition (Section 6.2.6.6 of this WP FEP AMR) for primary FEP 2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields. Stress Corrosion Cracking in the waste form and other areas of the EBS are not considered in this AMR. For further discussion on SCC impacts in these areas, see the *Miscellaneous Waste-Form FEPs* AMR (CRWMS M&O 2000an) and the *Engineered Barrier System Features, Events, and Processes* AMR (CRWMS M&O 2000c).

6.2.7 Primary FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields

6.2.7.1 FEP Description:

Localized corrosion in pits leads to failure of the waste package and drip shield.

6.2.7.2 Related Primary FEPs:

FEP 2.1.03.01.00, Corrosion of Waste Containers

6.2.7.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

6.2.7.4 Screening Decision and Regulatory Basis:

Included

6.2.7.5 Screening Argument:

Included in TSPA as described under TSPA Disposition.

6.2.7.6 TSPA Disposition:

Localized (pitting and crevice) corrosion is one of a number of corrosion mechanisms that potentially lead to eventual compromise of waste containers and/or drip shields in the repository.

As discussed in detail in the pitting abstraction AMR (CRWMS M&O 2000n), localized corrosion of the waste container outer barrier (Alloy 22) and drip shield is not likely to occur under repository-relevant exposure conditions (CRWMS M&O 2000n, Section 7). Localized corrosion initiation and propagation models are included in TSPA as part of waste package degradation analysis. Waste container localized corrosion is modeled with the WAPDEG computer code (CRWMS M&O 2000ah). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages failed versus time and the average (per waste package) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00 Corrosion of Waste Containers).

6.2.7.7 Supplemental Discussion:

Item intentionally left blank.

6.2.7.8 Relevant References:

CRWMS M&O 2000n. *Abstraction of Models for Pitting And Crevice Corrosion of Drip Shield and Waste Package Outer Barrier.* ANL-EBS-PA-000003

6.2.7.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields.

Secondary FEP Number and Name: 2.1.03.03.01, Localized corrosion (of Waste Container).

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address localized (pitting and crevice) corrosion on a waste package container.

Screening and Disposition: Redundant. See the Screening Argument and TSPA Disposition for primary FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields (Sections 6.2.7.5 and 6.2.7.6 of this WP FEPs AMR). This secondary FEP is included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.03.02, Pitting (of Waste Container).

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address localized (pitting and crevice) corrosion on a waste package container.

Screening and Disposition: Redundant. See the Screening Argument and TSPA Disposition for primary FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields (Sections 6.2.7.5 and 6.2.7.6 of this WP FEPs AMR). This secondary FEP is included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.03.03, Pitting corrosion develops on containers

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address localized (pitting and crevice) corrosion on a waste package container.

Screening and Disposition: Redundant. See the Screening Argument and TSPA Disposition for primary FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields (Sections 6.2.7.5 and 6.2.7.6 of this WP FEPs AMR). This secondary FEP is included in the TSPA analysis.

6.2.8 Primary FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields

6.2.8.1 FEP Description:

A potential failure mechanism for containers (and drip shields) involves the uptake of hydrogen and the formation of metal hydrides, which may mechanically weaken the container and promote corrosion.

6.2.8.2 Related Primary FEPs:

FEP 2.1.03.01.00, Corrosion of Waste Container

6.2.8.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

6.2.8.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence (drip shield, waste package outer barrier)

6.2.8.5 Screening Argument:

Hydrogen generated at a cathodic site of corroding metal can migrate into the metal and form hydride phases within the metal components. This could make the metal more brittle and degrade its mechanical properties. The hydride phases cause the metal to be more susceptible to cracking. The extent of the hydride phases is determined by the amount of hydrogen uptake by the metal.

Hydrogen induced cracking (HIC) in the presence of sustained stress or mechanical impact could cause the formation of cracks in the drip shield if the hydrogen uptake in the titanium drip shield is greater than the critical hydrogen concentration (CRWMS M&O 2000r, Section 6.1.3). In the current design (CRWMS M&O 2000ab), crevice corrosion, passive general corrosion and galvanic coupling of the drip shield are three feasible processes in the repository that could lead to HIC failure of the drip shield. Hydrogen is produced as a result of the corrosion processes, and the titanium metal can absorb some of this hydrogen. The absorbed hydrogen then diffuses into the metal forming the hydrides in the metal. Because the drip shield will not be subject to crevice corrosion under the exposure conditions anticipated in the repository (CRWMS M&O 2000n, Section 7), galvanic coupling and general corrosion are the only mechanisms that could cause HIC in the drip shield.

Galvanic coupling with various metal components within the drift may lead to hydrogen uptake and consequently, HIC of the drip shield. Hydrogen embrittlement of α alloys such as the Titanium Grade-7 drip shield occur when three general conditions are simultaneously met (CRWMS M&O 2000r, Section 6.3):

- A mechanism for generating hydrogen on a titanium surface.
- Metal temperature above approximately 80°C (175°F).
- Solution pH less than 3 or greater than 12, or impressed potentials more negative than -0.7 V (SCE).

In the current repository design without backfill, a mechanism for generating hydrogen can occur through the galvanic coupling between the titanium drip shield surface and the steel structural components that may fall onto the drip shield. In addition, conditions two and three are met at certain repository locations where temperatures are high (≥ 80°C) and concentrated groundwater is present. When all three conditions are present simultaneously, local hydrided "hot spots" can be anticipated.

Despite the presence of "hot spots" where hydrogen absorption into the bulk structure may occur, noticeable hydrogen embrittlement of Titanium Grade 7 is not expected. This is mainly due to the drip shield's large tolerance for hydrogen, where substantial concentrations must be achieved before any degradation in fracture toughness is observed (CRWMS M&O 2000r, Section 6.3). This critical concentration level that was suggested in an earlier analysis (CRWMS M&O 2000r, Section 6.2.2) was at least 400 $\mu g.g^{-1}$. Recent analyses of published data for titanium alloys whose performance is similar to the candidate material suggest that the critical concentration may be well in excess of 1000 $\mu g.g^{-1}$ (CRWMS M&O 2000r, Section 6.3). The hydrogen concentration in the drip shield from passive corrosion 10,000 years after emplacement is 257 $\mu g.g^{-1}$ resulting from a conservative estimate and 58 μg/g from a best estimate (CRWMS M&O 2000r, Section 7). This is well below the threshold concentration, and would not result in any noticeable hydrogen embrittlement or any degradation of fracture toughness.

Cracks in passive alloys, such as Titanium Grade 7, tend to be tight (i.e., small crack opening displacement) (CRWMS M&O 2000q, Section 6.5.5). The opposing sides of through-wall cracks will continue to corrode at very low passive corrosion rates until the gap region of the tight crack opening is "plugged" by corrosion products and precipitates such as carbonate minerals. Any water transport through this oxide/salt filled crack area will mainly be by diffusion-type transport processes (CRWMS M&O 2000q, Section 6.5.5). Thus, the effective water flow rate through cracks in the drip shield will be extremely low, and will not contribute significantly to the overall radionuclide release rate from the repository. Therefore, since the primary role of the drip shield is to keep water from contacting the waste package, HIC of the drip shield would not compromise its intended design purpose and is thus of low consequence to the expected annual dose rate.

HIC of the waste container outer barrier (Alloy 22) is not considered to be a possible degradation mechanism under repository-relevant exposure conditions. Handbook data (ASM International 1987, pp. 650-651) indicate that fully annealed nickel-base alloys such as Alloy 22 may be immune to hydrogen-induced embrittlement (hydride cracking). The susceptibility to hydride cracking may be enhanced only when the strength level of this alloy is increased either by cold working or by aging at a temperature of 540°C, at which point ordering and/or grain-boundary segregation can occur. The susceptibility to cracking will be reduced with decreasing strength level and correspondingly with increasing aging temperature. However, since the waste package temperature never exceeds 186°C (CRWMS M&O 2000z, Section 6.3.1) significant ordering and grain-boundary segregation does not occur and the degree of hydrogen embrittlement is negligible. Therefore, this FEP and its associated secondary FEP (2.1.03.04.01, Embrittlement and Cracking) are excluded for the waste package outer barrier on the basis of low consequence to the expected annual dose rate.

6.2.8.6 TSPA Disposition:

Excluded from TSPA as described under the Screening Argument.

6.2.8.7 Supplemental Discussion:

Item intentionally left blank.

6.2.8.8 Relevant References:

CRWMS M&O 2000r. *Hydrogen Induced Cracking of Drip Shield.* ANL-EBS-MD-000006

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material.* ANL-EBS-MD-000005

CRWMS M&O 2000z. *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux.* ANL-EBS-HS-000003

6.2.8.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.04.00, Hydride cracking of waste containers and drip shields.

Secondary FEP Number and Name: 2.1.03.04.01, Embrittlement and Cracking

Relationship to Primary FEP: This secondary and the associated primary FEP both address hydride cracking of waste containers and drip shields.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP 2.1.03.04.00- Hydride Cracking of Waste Containers and Drip Shields, and is excluded based on low consequence to the expected annual dose as described in the screening argument above (Section 6.2.8.5 of this WP FEPS AMR).

6.2.9 Primary FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield

6.2.9.1 FEP Description:

Microbial activity may catalyze corrosion by otherwise kinetically hindered oxidizing agents. The most likely process is microbial reduction of groundwater sulfates to sulfides and reaction of iron with dissolved sulfides.

6.2.9.2 Related Primary FEPs:

FEP 2.1.10.01.00, Biological Activity in Waste and EBS

6.2.9.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

6.2.9.4 Screening Decision and Regulatory Basis:

Included (waste container)

Excluded- Low consequence (drip shield)

6.2.9.5 Screening Argument:

Quantitative data on microbially influenced corrosion (MIC) of drip shield materials such as Titanium (Ti) Grades 7 and 16 are not available from the literature. However, even if the drip shield were susceptible to MIC, it would not have any effect on dose release as indicated in the supplemental discussion below. Therefore, this FEP is excluded for the drip shield based on low consequence to the expected annual dose.

6.2.9.6 TSPA Disposition:

Microbially influenced corrosion (MIC) is included in TSPA as part of the waste package degradation analysis (CRWMS M&O 2000p Section 6.3.14). Waste container microbiologically influenced corrosion is modeled with the WAPDEG computer code (CRWMS M&O 2000ah). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages failed versus time and the average (per waste package) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00, Corrosion of Waste Containers).

The potential effect of MIC on waste container corrosion is analyzed with an enhancement factor approach, assuming MIC increases the corrosion penetration rate. In this approach, the abiotic corrosion rate is multiplied by the enhancement factor when the exposure conditions in the emplacement drift warrant significant microbial activity (CRWMS M&O 2000b).

6.2.9.7 Supplemental Discussion:

Figure 5.3.3 from the TSPA-SR technical document (CRWMS M&O 2000ae, Section 5.3) shows that the mean dose rate for the SR design with a drip shield corroding at the base case rate, an accelerated rate (degraded drip shield), and a decelerated rate (enhanced drip shield).

Since MIC has the effect of accelerating the general corrosion rate, the degraded drip shield curve represents what may occur should MIC take place. The graph indicates that the degraded curve will not have any significant impact on dose rate, and therefore neither would MIC. Thus, MIC on the titanium drip shield has little consequence to the expected annual dose.

6.2.9.8 Relevant References:

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003

CRWMS M&O 2000j. *In Drift Microbial Communities*. ANL-EBS-MD-000038

CRWMS M&O 2000ae. *Total System Performance Assessment - Site Recommendation.* TDR-WIS-PA-000001

6.2.9.9 Treatment of Secondary FEPs:

Secondary FEPs addressed by Primary FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield.

No secondary FEPs have been associated with this primary FEP.

6.2.10 Primary FEP 2.1.03.06.00, Internal Corrosion of Waste Container

6.2.10.1 FEP Description:

Aggressive chemical conditions within the waste package could contribute to corrosion from the inside out. Effects of different waste forms, including CSNF and DSNF, are considered in this FEP.

6.2.10.2 Related Primary FEPs:

Item intentionally left blank.

6.2.10.3 IRSR Issues:

Item intentionally left blank.

6.2.10.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.10.5 Screening Argument:

After being loaded with waste, the waste containers are filled with an inert gas (helium) prior to closure, displacing water and oxygen (necessary components for corrosion) from inside the container (CRWMS M&O 2000ag, p. II-30). The inert gas environment within the container will result in a negligible amount of corrosion degradation prior to the breach of the waste containers.

Analyses performed by Kohli and Pasupathi (1986) suggest that the most likely cause of internal corrosion is the residual moisture remaining in the waste package at the time of emplacement. The source of this residual moisture is primarily from waterlogged failed fuel rods. Analyses presented in the above reference indicate that the amount of moisture available to cause internal corrosion is very limited and even with very conservative assumptions, the potential for degradation of the container materials is very remote.

DSNF canisters containing N-reactor spent fuel may have significant quantities of residual free and chemically bound water at the time of sealing prior to interim storage. However, the N-reactor spent fuel cladding is significantly damaged, thus exposing chemically reactive uranium metal surfaces, which would scavenge this residual water producing uranium oxide and uranium hydride. Other forms of DSNF are less damaged, and will contain much lower quantities of residual water due to drying prior to sealing for interim storage. Damaged DSNF will be placed in high integrity canisters (CRWMS M&O 2000am) that will contain any residual water until breached.

The CSNF assemblies will be dried prior to their insertion into the waste packages (CRWMS M&O 2000ag, p. II-10).

Since all of these waste package types have sufficient internal surfaces of carbon steel, the insignificant amount of remaining residual water will be scavenged by carbon steel. Thus, the potential for corrosion damage to the container internal surfaces is very low.

In view of the above discussion, it can be concluded that insignificant corrosion damage of DSNF canisters, DHLW glass canisters, and CSNF canisters will occur due to any residual water present in the waste form. Thus this FEP is excluded based on low consequence to the expected annual dose.

6.2.10.6 TSPA Disposition:

Excluded from TSPA as described under the Screening Argument.

6.2.10.7 Supplemental Discussion:

Item intentionally left blank.

6.2.10.8 Relevant References:

Item intentionally left blank.

6.2.10.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.06.00, Internal Corrosion of Waste Container

Secondary FEP Number and Name: 2.1.03.06.01, DOE SNF Waste Package Internal Corrosion

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address internal corrosion of a waste package container. This secondary FEP specifically addresses DOE spent nuclear fuel (SNF).

Screening and Disposition: Redundant. See the Screening Argument and TSPA Disposition for primary FEP 2.1.03.06.00, Internal Corrosion of Waste Container (Section 6.2.10.5 and 6.2.10.6 of this WP FEPS AMR). This secondary FEP is excluded in the TSPA analysis based on low consequence to the expected annual dose. The differences in DOE SNF are addressed in the discussion of the primary FEP 2.1.03.06.00, Internal Corrosion of Waste Container.

6.2.11 Primary FEP 2.1.03.07.00, Mechanical Impact on Waste Container and Drip Shield

6.2.11.1 FEP Description

Mechanical impact on the waste container is caused by internal and external forces such as internal gas pressure, forces caused by swelling corrosion products, rock fall, ground motion during seismic events, and possible waste package movement.

6.2.11.2 Related Primary FEPs:

FEP 1.2.03.02.00, Seismic Vibration Causes Waste Container and Drip Shield Failure

FEP 2.1.07.01.00, Rockfall (Large Block)

FEP 2.1.07.04.00, Hydrostatic pressure on container

FEP 2.1.07.05.00, Creeping of metallic materials in the EBS

6.2.11.3 IRSR Issues:

Subissue 2: The Effects of Phase Instability and Initial Defects on the Mechanical Failure and Lifetime of the Containers.

6.2.11.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence (all components of FEP not explicitly excluded based on low probability)

Excluded – low probability (not credible) (Failure of Copper Canister – FEP 2.1.03.01.07)

6.2.11.5 Screening Argument:

Mechanical damage of the waste container and drip shield by rockfall is discussed in greater detail under FEP 2.1.07.01.00, Rockfall (Large Block). This FEP discussion also provides relevant references discussing the issue in greater detail. In addition, the Emplacement Drift System design criteria requires that the drip shield be designed to withstand a 13 metric ton rock fall, without rupturing the drip shield or causing individual drip shield units to separate and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.14 and 1.2.1.15). In view of the above rationale, this FEP is excluded based on low consequence to the expected annual dose rate.

Mechanical damage of the waste container and drip shield by ground motion during seismic events is discussed in greater detail under FEP 1.2.03.02.00, Seismic Vibration Causes Waste Container and Drip Shield Failure. In addition, the Emplacement Drift System design criteria require that the drip shield be designed to withstand a Category 2 design basis earthquake without rupturing or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.16 and 1.2.1.17). In view of the above rationale, this FEP is excluded as low consequence to the expected annual dose rate.

A calculation of the maximum stresses developed in the waste package due to internal pressurization as a result of fuel rod rupture at 400°C is less than the ASME code requirements for the allowable tensile strength (CRWMS M&O 2000aj, Section 6.2.2.8). Therefore, with the current robust waste container design, the pressurization of the internal gas under the expected repository condition would not cause mechanical damage to the waste container.

In general, corrosion products have greater volume than the bare metal. When the corrosion products form in a tightly confined space, the volume increase by the corrosion products generates swelling pressures that could lead to mechanical damage of the surrounding material. Since the current design precludes the use of shrink fitting the outer and inner barrier components, mechanical damage to the Alloy 22 container due to the pressure exerted by the corrosion product (Cr_2O_3) of the inner shell (Type 316NG stainless steel) will not occur. Analyses cited in *Degradation of Stainless Steel Structural Material* (CRWMS M&O 2000s, Section 6.1), indicates that even under very conservative assumptions, the growth of this corrosion product will not exceed 93 μm after 10,000 years. This oxide layer is not thick enough to produce enough pressure to cause mechanical damage to the Alloy 22 container. In the current design of waste package and engineered barrier system in the emplacement drift (CRWMS M&O 2000ab), there is no possibility of forming such a tightly confined space such that the swelling corrosion products could cause mechanical damage to the Alloy 22 outer barrier. Therefore, mechanical damages by internal gas pressure and swelling corrosion products are excluded based on low consequence to the expected annual dose.

Since copper canisters will not be used in the current repository design, mechanical damage of copper canisters has been excluded on the basis of low probability (not credible).

6.2.11.6 TSPA Disposition:

Excluded from TSPA as described under the Screening Argument.

6.2.11.7 Supplemental Discussion:

Item intentionally left blank.

6.2.11.8 Relevant References:

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001

6.2.11.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.07.00, Mechanical Impact on Waste Container and Drip Shield

Secondary FEP Number and Name: 2.1.03.07.01, Other Canister Degradation Processes

Relationship to Primary FEP: The discussion provided for the primary FEP also addresses this secondary FEP. Other canister degradation processes are considered subcategories of mechanical impact on waste container and drip shield. In the case of the primary, other canister degradation processes are discussed in terms of mechanical damage of the waste container and drip shield by rock fall, mechanical damage of the waste container and drip shield by ground motion during seismic events, mechanical damage of the waste container by internal gas pressure, and mechanical damage of the waste container and engineered barrier system by swelling corrosion products. In addition, other canister degradation processes, i.e., corrosion, rock fall, and seismic vibration, etc. can be found in other related FEPS. Retained in FEP list for completeness.

Screening and Disposition: Same as the Primary FEP.

Secondary FEP Number and Name: 2.1.03.07.02, Failure of Copper Canister

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address mechanical impact on waste container and drip shield.

Screening and Disposition: Discussion provided for by the primary FEP 2.1.03.09.00, Copper Corrosion, addresses this secondary FEP. Copper is not considered for use as an engineered barrier at Yucca Mountain, and all copper materials at the site surface will be removed prior to repository closure (CRWMS M&O 1994, Section 1.2). This FEP is thus excluded based on low probability (credibility).

Secondary FEP Number and Name: 2.1.03.07.03, Failure of Steel Canister

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address mechanical impact on waste container and drip shield.

Screening and Disposition: In the waste package degradation analysis, no performance credit is taken for the inner shell (Type 316NG stainless steel) waste package barrier (CRWMS M&O 2000p (Section 5.1). Once the Alloy 22 barrier is breached it is assumed that radionuclides are available for transport. This secondary FEP is therefore excluded based on low consequence (beneficial FEP) to the expected annual dose.

Secondary FEP Number and Name: 2.1.03.07.04, Reduced Mechanical Strength

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address mechanical impact on waste container and drip shield.

Screening and Disposition: Mechanical damage of the drip shield by rockfall is discussed in greater detail under FEP 2.1.07.01.00, Rockfall (Large Block), where it is shown that significant rockfall damage will not occur. This FEP discussion also provides relevant references that discusses the issue in detail. Exclusion screening arguments are also dealt with in the proper related primary FEPs (see *Related Primary FEP* Section 6.2.17.2 of this WP FEPs AMR). WAPDEG analysis of waste package and drip shield degradation shows that drip shields do not start to fail in the repository until about 20,000 years after emplacement. Thus, it is therefore reasonable to expect the drip shield to provide adequate protection to the waste package from rock fall during the first 10,000 years and this secondary FEP maybe excluded based on low consequence to the annual dose.

Secondary FEP Number and Name: 2.1.03.07.05, Container Failure (Mechanical)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address mechanical impact on waste container and drip shield.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.11.5 of this WP FEPs AMR) of the associated primary FEP 2.1.03.07.00, Mechanical Impact on Waste Container and Drip Shield. This secondary FEP is excluded in the TSPA analysis based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.03.07.06, Falling Rock Hits Container, Increased Seepage Occurs, Speeds Corrosion of Container

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address mechanical impact on waste container and drip shield.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.11.5 of this WP FEPs AMR) of the associated primary FEP 2.1.03.07.00, Mechanical Impact on Waste Container and Drip Shield. This secondary FEP is excluded in the TSPA analysis based on low consequence to the expected annual dose.

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

6.2.12.1 FEP Description

Waste packages and drip shields may fail prematurely because of manufacturing defects, improper sealing, or other factors related to quality control during manufacture and emplacement of the waste packages and drip shields.

6.2.12.2 Related Primary FEPs:

FEP 1.1.03.01.00, Error in Waste or Backfill Emplacement

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

6.2.12.3 IRSR Issues:

Subissue 2: The Effects of Phase Instability and Initial Defects on the Mechanical Failure and Lifetime of the Containers.

6.2.12.4 Screening Decision and Regulatory Basis:

Included (manufacturing and welding defects in waste container degradation analysis)

Excluded – Low Consequence (manufacturing defects in drip shield degradation analysis; early failure of waste container and drip shield from improper quality control during the emplacement).

6.2.12.5 Screening Argument:

The major effect of pre-existing manufacturing defects is to provide sites for crack growth by SCC, potentially leading to an early failure. Among other exposure condition parameters, tensile stress is required to initiate SCC (CRWMS M&O 2000q, Section 6.1). Because all the fabrication welds in drip shields will be fully annealed before placement in the emplacement drift, drip shields are not subject to SCC (CRWMS M&O 2000q, Section 5, Assumption 1). Also, other sources of stresses in the drip shield induced by backfill (should backfill be used in the design) and earthquakes are insignificant to SCC (CRWMS M&O 2000q, Section 5, Assumption 1). Thus manufacturing defects in the drip shield are excluded from TSPA analysis based on low consequence to the expected annual dose rate.

An emplacement error may cause the waste package to be dropped or collide with another component within the drift. However, as described in FEP 1.1.03.01.00, *Error in Waste or Backfill Emplacement*, early failure of the waste container or drip shield from improper quality control is of negligible consequence. Slap-down analysis of a 21-PWR waste package was performed where the waste packages were dropped on their side from a vertical position. The resulting stresses on the waste package material were less than 90% of the ultimate tensile strength of those materials (CRWMS M&O 2000aj, Section 6.2). Since the impact energy (the "fall-down" height) associated with an emplacement error (CRWMS M&O 2000ad, Section 1.2) is significantly less than that seen by a vertical tip over, it is also not expected to result in any damage. Thus, manufacturing defects in the drip shield and early failure of the waste container and drip shield from improper quality control during the emplacement can be excluded based on negligible consequence to the expected annual dose rate.

6.2.12.6 TSPA Disposition:

The effect of manufacturing and welding defects on waste container failure is addressed by including the defect flaws in the SCC analysis (CRWMS M&O 2000q). As discussed in Section 6.2.6 (FEP2.1.03.02.00, Stress Corrosion Cracking of Waste Containers and Drip Shields), only the closure welds are considered for SCC. Accordingly, the defects in the closure welds will be considered in TSPA analysis through the SCC analysis.

6.2.12.7 Supplemental Discussion:

Item intentionally left blank.

6.2.12.8 Relevant References:

CRWMS M&O 2000o. *Abstraction of Models of Stress Corrosion Cracking of Drip Shield and Waste Package Outer Barrier and Hydrogen Induced Corrosion of Drip Shield.* ANL-EBS-PA-000004

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001.

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material.* ANL-EBS-MD-000005

CRWMS M&O 2000x. *Analysis of Mechanisms for Early Waste Package Failure*. ANL-EBS-MD-000023

6.2.12.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.08.00, Juvenile and Early Failure of Waste Containers and Drip Shields

Secondary FEP Number and Name: 2.1.03.08.01, Canister Failure (Alternative Modes)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the premature failure of the waste containers.

Screening and Disposition: Redundant. Alternative canister failure modes are addressed in the Screening Arguments and TSPA Dispositions of the primary FEPs contained within this WP FEPs AMR.

Secondary FEP Number and Name: 2.1.03.08.02, Mis-Sealed Canister

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the premature failure of the waste containers.

Screening and Disposition: Redundant. The discussion within the Screening Argument (Section 6.2.12.5 of this WP FEPs AMR) for the primary FEP 2.1.03.08.00, Juvenile and Early Failure of Waste Containers and Drip Shields also addresses this secondary FEP. This secondary FEP is excluded from the TSPA analysis based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.03.08.03, Container Failure (Early)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the premature failure of the waste containers.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP. The discussion within the Screening Argument (Section 6.2.12.5 of this WP FEPs AMR) for the primary FEP 2.1.03.08.00, Juvenile and Early Failure of Waste Containers and Drip Shields also addresses this secondary FEP.

Secondary FEP Number and Name: 2.1.03.08.04, Cracking Along Welds (of Waste Container)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the premature failure of the waste containers.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP. The discussion within the Screening Argument (Section 6.2.12.5 of this WP FEPs AMR) for the primary FEP 2.1.03.08.00, Juvenile and Early Failure of Waste Containers and Drip Shields also addresses this secondary FEP.

Secondary FEP Number and Name: 2.1.03.08.05, Random Canister Defects - Quality Control

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the premature failure of the waste containers.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP. The discussion within the Screening Argument (Section 6.2.12.5 of this WP FEPs AMR) for the primary FEP 2.1.03.08.00, Juvenile and Early Failure of Waste Containers and Drip Shields also addresses this secondary FEP. In addition, as described in FEP 1.1.03.01.00, Error in Waste or Backfill Emplacement, early failure of the waste container or drip shield from improper quality control is of negligible consequence.

Secondary FEP Number and Name: 2.1.03.08.06, Common Cause Canister Defects - Quality Control

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the premature failure of the waste containers.

Screening and Disposition: Redundant. This secondary FEP is identical to the primary FEP. The discussion within the Screening Argument (Section 6.2.12.5 of this WP FEPs AMR) for the primary FEP 2.1.03.08.00, Juvenile and Early Failure of Waste Containers and Drip Shields also addresses this secondary FEP. In addition, as described in FEP 1.1.03.01.00, Error in Waste or Backfill Emplacement, early failure of the waste container or drip shield from improper quality control is of negligible consequence.

6.2.13 Primary FEP 2.1.03.09.00, Copper Corrosion

6.2.13.1 FEP Description

Chemical reactions involving copper corrosion have been identified as being of potential interest for repository programs considering the use of copper containers.

6.2.13.2 Related Primary FEPs:

FEP 2.1.03.01.00, Corrosion of Waste Containers

6.2.13.3 IRSR Issues:

Item intentionally left blank.

6.2.13.4 Screening Decision and Regulatory Basis:

Excluded – Low Probability (not credible) (copper canisters)

Excluded – Low Consequence (gantry rail system)

6.2.13.5 Screening Argument:

Copper is not considered for use as an engineered barrier at Yucca Mountain, and all copper materials at the site surface will be removed prior to repository closure (CRWMS M&O 1994, Section 1.2). This FEP is thus excluded based on low probability (credibility).

A small percentage of copper may be used as part of the gantry rail system. This will not adversely affect corrosion of the Alloy 22 canisters or the Titanium drip shields since copper is a more active metal than the engineered barrier materials and will thus act as a sacrificial anode. Thus, corrosion due to copper in the gantry rail system may be excluded based on low consequence.

6.2.13.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.13.7 Supplemental Discussion:

Item intentionally left blank.

6.2.13.8 Relevant References:

Item intentionally left blank.

6.2.13.9 Treatment of Secondary FEPs:

Secondary FEPs addressed by Primary FEP 2.1.03.09.00, Copper Corrosion

Secondary FEP Number and Name: 2.1.03.09.01, Role of Chlorides in Copper Corrosion

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address copper corrosion in the waste package.

Screening and Disposition: Taken specifically, this secondary FEP is excluded based on low probability (credibility). The current repository design does not consider copper in the engineered barriers (see the Screening Argument (Section 6.2.13.5 of this WP FEPs AMR) for the primary FEP 2.1.03.09.00, Copper Corrosion). However, the effects of the chemical environment on waste package corrosion rates are considered in the TSPA analysis. These effects are discussed in the AMR WAPDEG Analysis for Waste Package and Drip Shield Degradation (CRWMS M&O 2000p) as well as in the primary FEP 2.1.03.01.00, Corrosion of Waste Containers.

6.2.14 Primary FEP 2.1.03.10.00, Container Healing

6.2.14.1 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 container. Passivation by corrosion products is a potential mechanism for container healing.

6.2.14.2 Related Primary FEPs:

FEP 2.1.03.01.00, Corrosion of Waste Containers

FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields

FEP 2.1.09.03.00, Volume Increase of Corrosion Products

6.2.14.3 IRSR Issues:

Item intentionally left blank.

6.2.14.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.14.5 Screening Argument:

Plugging (or healing) of corrosion holes or pits in waste container by corrosion products and mineral precipitates is a possible process in the repository. However, there are large uncertainties associated with the quantification of the effect of the process on water flow and radionuclide transport through the openings. Because of this, potential performance credit from the plugging (or healing) of the corrosion penetration openings are not taken into account in TSPA analysis. Therefore, this FEP is excluded based on low consequence to the expected annual dose rate.

6.2.14.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.14.7 Supplemental Discussion:

Item intentionally left blank.

6.2.14.8 Relevant References:

CRWMS M&O 1999e. *In Drift Corrosion Products.* ANL-EBS-MD-000041

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001

6.2.14.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.10.00, Container Healing.

Secondary FEP Number and Name: 2.1.03.10.01, Corrosion Products (Physical Effects)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of corrosion product build-up on slowing the waste package corrosion rate.

Screening and Disposition: No performance credit is taken for the 316NG stainless steel inner barrier despite its potential to hinder the radionuclide release rate. Furthermore, no performance credit is taken for the build-up of corrosion products which may hinder further corrosion on the waste package by limiting the waste package surface exposure to the environment. In addition, no credit is taken for this build-up which may hinder the release of radionuclides through the corroded parts of the container surface. This beneficial effect is excluded from the TSPA analysis as discussed in the primary FEP 2.1.03.10.00, Container Healing Screening Argument (Section 6.2.14.5 of this WP FEPs AMR).

6.2.15 Primary FEP 2.1.03.11.00, Container Form

6.2.15.1 FEP Description:

The specific forms of the various waste packages and internal waste containers that are proposed for the Yucca Mountain repository can affect long-term performance. Waste package form may affect container strength through the shape and dimensions of the container and affect heat dissipation through container volume and surface area. Waste package materials may affect physical and chemical behavior of the disposal area environment. Waste package integrity will affect the releases of radionuclides from the disposal system. Waste packages may have both local effects and repository scale effects. All types of waste packages and containers, including CSNF, DSNF, and DHLW, should be considered.

6.2.15.2 Related Primary FEPs:

FEP 1.1.07.00.00, Repository Design

6.2.15.3 IRSR Issues:

Item intentionally left blank.

6.2.15.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.15.5 Screening Argument:

The waste package/drip shield/repository design has been standardized for the Yucca Mountain Project (CRWMS M&O 2000ab). While there is more than one waste package design expected to be used in the proposed repository, they are all similar in their design, their fabrication methodology used, and their dimensions (CRWMS M&O 2000k, Section 1). Therefore, there will be little variation in strength, dimensions, and shape of the waste packages used in the proposed repository. Effects of different waste forms (CSNF, DSNF, and DHLW) on heat dissipation and physical and chemical conditions in the vicinity of the waste packages are indirectly included in the TSPA analysis through different thermal-hydrologic-geochemical responses and their impacts on corrosion processes. Waste package and drip shield degradation modes are modeled with WAPDEG (CRWMS M&O 2000ah). The WAPDEG code makes use of several different thermal-hydrologic-geochemical "time histories" during a given simulation which encompass the variability in exposure conditions due to "container form."

Based on the above discussion, this FEP is excluded based on low consequence to the annual expected dose.

6.2.15.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.15.7 Supplemental Discussion:

Item intentionally left blank.

6.2.15.8 Relevant References:

CRWMS M&O 2000k. *Waste Package Operations Fabrication Process Report.* TDR-EBS-ND-000003

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001

CRWMS M&O 2000ab. *Monitored Geologic Repository Project Description Document.* TDR-MGR-SE-000004

6.2.15.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.11.00, Container Form.

Secondary FEP Number and Name: 2.1.03.11.01, Stainless Steel Fabrication Flask

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the configuration of the different waste packages and the impact on container performance.

Screening and Disposition: This secondary FEP addresses the structural support provided by the stainless steel form surrounding the vitrified HLW glass waste form. According to WAPDEG analysis (CRWMS M&O 2000p) the structural integrity of the waste package is provided by both the Alloy 22 outer barrier and 316NG inner barrier. These two barriers are common to each waste package types regardless of the waste form used to contain the radionuclides. This secondary FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.03.11.02, Cast Steel Canister

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the capability of the repository design, specifically the design of the waste packages, to meet the performance criteria.

Screening and Disposition: Taken specifically, this secondary FEP is not applicable to TSPA analysis because the current design does not include/take credit for steel canisters. However, when considering the design of the proposed waste packages, the purpose of the TSPA analysis is to investigate whether or not the proposed design meets the performance requirements. Hence, this secondary FEP can be considered included in the TSPA analysis as the basis for the TSPA analysis. The waste package/drip shield/repository design has been standardized for the Yucca Mountain Project (CRWMS M&O 2000ab). The TSPA analysis for waste package degradation has been configured to match the proposed design.

Secondary FEP Number and Name: 2.1.03.11.03, Canister Thickness

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the configuration of the different waste packages and the impact on container performance.

Screening and Disposition: The waste package/drip shield/repository design has been standardized for the Yucca Mountain Project (CRWMS M&O 2000ab). The TSPA analysis for waste package degradation has been configured to match the proposed design. The secondary FEP can be excluded on the basis that it applies to accepted design criteria.

Secondary FEP Number and Name: 2.1.03.11.04, Container Integrity

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the structural integrity of the waste package based on the proposed waste package design.

Screening and Disposition: Investigating the integrity of the container is one of the objectives of the TSPA analysis. The WAPDEG analysis (CRWMS M&O 2000p) investigates the ability of the proposed waste package design to meet performance requirements. This analysis considers numerous waste package failure mechanisms which could effect the structural integrity of the waste package. The waste package/drip shield/repository design has been standardized for the Yucca Mountain Project (CRWMS M&O 2000ab). The TSPA analysis for waste package degradation has been configured to match the proposed design. Considerations of this secondary FEP are included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.11.05, DOE SNF Waste Package Design

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the configuration of the different waste packages and the impact on container performance.

Screening and Disposition: Similar to secondary FEP 2.1.03.11.01, Stainless Steel Fabrication Flask, this secondary FEP addresses the differences in the waste form contained within the waste package inner and outer barriers. The waste package/drip shield/repository design has been standardized for the Yucca Mountain Project (CRWMS M&O 2000ab). While there is more than one waste package design expected to be used in the proposed repository, they are all similar in their design, their fabrication methodology used, and their dimensions (CRWMS M&O 2000k, Section 1). Therefore, there will be little variation in strength, dimensions, and shape of the waste packages used in the proposed repository. This FEP is excluded due to low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.03.11.06, DOE SNF Canister Design

Relationship to Primary FEP: Redundant. See the discussion for secondary FEP 2.1.03.11.05, DOE SNF Waste Package Design.

Screening and Disposition: Redundant. See the discussion for secondary FEP 2.1.03.11.05, DOE SNF Waste Package Design.

Secondary FEP Number and Name: 2.1.03.11.07, DOE SNF waste package design

Relationship to Primary FEP: Redundant. See the discussion for secondary FEP 2.1.03.11.05, DOE SNF Waste Package Design.

Screening and Disposition: Redundant. See the discussion for secondary FEP 2.1.03.11.05, DOE SNF Waste Package Design.

6.2.16 Primary FEP 2.1.03.12.00, Container Failure (Long-Term)

6.2.16.1 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, SCC, pit corrosion, hydride cracking, microbially-mediated corrosion, internal corrosion, and mechanical impacts.

6.2.16.2 Related Primary FEPs:

FEP 2.1.03.01.00, Corrosion of Waste Containers

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

FEP 2.1.03.03.00, Pitting of Waste Containers and Drip Shields

FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields

FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield

FEP 2.1.03.06.00, Internal Corrosion of Waste Container

FEP 2.1.13.01.00, Radiolysis

6.2.16.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.16.4 Screening Decision and Regulatory Basis:

Included

6.2.16.5 Screening Argument:

Included in the TSPA as described under TSPA Disposition. Exclusion screening arguments are dealt with in the proper related primary FEPs (see *Related Primary FEP*, Section 6.2.16.2 of this WP FEPs AMR).

6.2.16.6 TSPA Disposition:

As discussed in Section 6.2.5 of this WP FEPs AMR, long-term corrosion degradation and failure of waste containers and drip shields in the repository are included in TSPA as part of waste package degradation analyses. Aspects of this FEP are also addressed in the *Related*

Primary FEPs, Section 6.2.16.2 of this WP FEPs AMR. The TSPA analyses accounts for the major degradation mechanisms and processes that are likely in the repository. The waste container and drip shield corrosion are modeled with WAPDEG (CRWMS M&O 2000ah). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per failed waste package/drip shield) number of penetration openings versus time (CRWMS M&O 2000p, Section 6). The degradation profiles are used as input into the TSPA model.

6.2.16.7 Supplemental Discussion:

Item intentionally left blank.

6.2.16.8 Relevant References:

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001

6.2.16.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.03.12.00, Container Failure (Long-Term).

Secondary FEP Number and Name: 2.1.03.12.01, Canister Failure (Reference)

Relationship to Primary FEP: This secondary FEP is identical to the primary FEP 2.1.03.12.00, Container Failure (Long Term).

Screening and Disposition: Redundant. See the discussion for the primary FEP 2.1.03.12.00, Container Failure (Long Term). This secondary FEP is included in the TSPA analysis.

Secondary FEP Number and Name: 2.1.03.12.02, Long-Term Physical Stability (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the long term stability of the waste containers. Furthermore, this secondary FEP also addresses the long-term stability of the waste forms and other areas of the EBS.

Screening and Disposition: The primary FEP 2.1.03.12.00, Container Failure (Long Term), addresses the first part of this secondary FEP. This secondary FEP is included in the TSPA analysis. The second part of this secondary FEP is not addressed by this AMR. This discussion is included in the EBS FEPs document (CRWMS M&O 2000c).

6.2.17 Primary FEP 2.1.06.06.00, Effects and Degradation of Drip Shield

6.2.17.1 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.

6.2.17.2 Related Primary FEPs:

FEP 1.2.03.02.00, Seismic Vibration Causes Container Failure

FEP 2.1.03.01.00, Corrosion of Waste Containers

FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields

FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield

FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall

6.2.17.3 IRSR Issues:

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.17.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence (damage to drip shield by rock fall, damage to drip shield by ground motion during seismic events, oxygen embrittlement)

Included (physical and chemical degradation processes, effect on thermal hydrology and geochemistry)

6.2.17.5 Screening Argument:

Mechanical damage of the drip shield by rockfall is discussed in greater detail under FEP 2.1.07.01.00, Rockfall (Large Block), where it is shown that significant rockfall damage will not occur. This FEP discussion also provides relevant references that discusses the issue in detail. Exclusion screening arguments are also dealt with in the proper related primary FEPs (see *Related Primary FEP* Section 6.2.17.2 of this WP FEPs AMR).

Mechanical damage of the drip shield by ground motion during seismic events is discussed under FEP 1.2.03.02.00, Seismic Vibration Causes Waste Container and Drip Shield Failure. Mechanical damage due to seismic events are most likely to occur in the form of crack development and propagation (SCC). However, seismic activity will not induce SCC of the waste packages or drip shields, regardless of magnitude, since a sustained tensile stress is required for SCC and an earthquake is only temporary in nature (CRWMS M&O 2000q, Section 5, Assumption 1).

In view of the above rationale, the FEP relating to rockfall and seismic ground motion is excluded due to low consequence to the expected annual dose

Effects of the drip shield on heat dissipation and physical and chemical conditions in the vicinity the waste packages are indirectly included in the TSPA analysis through different thermal-hydrologic-geochemical responses and their impacts on corrosion processes. Waste package and drip shield degradation modes are modeled with WAPDEG (CRWMS M&O 2000ah). The WAPDEG code makes use of several different thermal-hydrologic-geochemical "time histories" during a given simulation which include the effect of the presence of the drip shield.

Thus, the effects of the drip shield on the disposal region environment are included in the TSPA analyses.

Oxygen embrittlement of titanium results from diffusion of interstitial oxygen into the metal at higher temperatures (> 340°C) (ASM International 1987, p. 681). The time to failure depends on the alloy composition, material thickness, and stress state. For the thermal hydrologic time history files used in the TSPA analyses, the waste package surface temperatures never exceed 186°C, which is less than the threshold temperature of 340°C (CRWMS M&O 2000z, Section 6.3.1). Therefore, oxygen embrittlement of the titanium drip shields is excluded on the basis of low consequence to the expected annual dose.

6.2.17.6 TSPA Disposition:

Physical and chemical degradation processes for the drip shield are included in TSPA as part of waste package and drip shield degradation analyses. The analyses account for the major degradation mechanisms and processes that are likely in the repository (CRWMS M&O 2000p). This includes corrosion-induced and other degradation and failure processes.

The waste container and drip shield degradation are modeled with WAPDEG (CRWMS M&O 2000ah). WAPDEG produces waste package and drip shield degradation profiles consisting of the fraction of waste packages/drip shields failed versus time and the average (per failed waste package/drip shield) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model. In addition, the model is designed to account for the effect on the drip shield of non-corrosion degradation processes such as rockfall or seismic motion. These effects are considered for both the intact and degraded states of the drip shield.

6.2.17.7 Supplemental Discussion:

See Related Primary FEPs (Section 6.2.17.2 of this WP FEPs AMR) for additional discussions of other aspects relevant to this FEP.

6.2.17.8 Relevant References:

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001

CRWMS M&O 2000z. *Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux.* ANL-EBS-HS-000003

6.2.17.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.06.06.00, Effects and degradation of drip shield

Secondary FEP Number and Name: 2.1.06.06.01, Oxygen Embrittlement of Ti Drip Shield

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address oxygen embrittlement of the titanium drip shield. This secondary FEP also addresses hydrogen embrittlement of the drip shield.

Screening and Disposition: The first part of this secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the Screening Arguments (Section 6.2.17.5) of the primary FEP 2.1.06.06.00, Effects and Degradation of Drip Shield. The second part of this secondary FEP, hydrogen embrittlement, is discussed in detail in the primary FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields. As stated in the TSPA Screening Argument (Section 6.2.8.5 of this WP FEPs AMR), this secondary FEP is excluded due to low consequence to the total dose.

6.2.18 Primary FEP 2.1.06.07.00, Effects at Material Interfaces

6.2.18.1 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.

6.2.18.2 Related Primary FEPs:

FEP 1.1.03.01.00, Error in Waste or Backfill Emplacement

FEP 2.1.03.01.00, Corrosion of Waste Containers

FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields

FEP 2.1.06.06.00, Effects and Degradation of Drip Shield

FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall

6.2.18.3 IRSR Issues:

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.18.4 Screening Decision and Regulatory Basis:

Included (chemical effects)

Excluded Low Consequence (hydride cracking; physical effects)

6.2.18.5 Screening Argument:

Included in the TSPA as described under TSPA Disposition.

Hydride cracking is excluded due to low consequence to the expected annual dose as discussed in the Screening Argument (Section 6.2.8.5) for the primary FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields. In that discussion, it is stated that structural components such as rock bolts, wire mesh, etc. may contact the drip shield surface leading to the possibility of hydrogen induced cracking (hydride cracking). It is concluded that hydrogen induced cracking due to this mechanism is of low consequence to the expected annual dose, due to the negligible effect of drip shield cracks on dose rate.

In the discussion of FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall (Section 6.2.19 of this WP FEPs AMR), it is stated that the deflection of the drip shield due to rock fall is not enough to cause contact with the waste package. Therefore, it is concluded that rockfalls do not cause a material interface between the waste package and drip shield.

Thus, hydride cracking and physical effects on the material interfaces are excluded based on low consequence to the annual expected dose.

6.2.18.6 TSPA Disposition:

Waste container and drip shield corrosion degradation analysis includes the effects of material interfaces in the repository. The thermal-hydrologic-geochemical condition analyses in the repository include effects of materials present in the emplacement drift, including waste package, drip shield and backfill (if used) (CRWMS M&O 2000p, Section 6.3.16).

The waste container and drip shield degradation are modeled with WAPDEG (CRWMS M&O 2000ah). In the WAPDEG model (CRWMS M&O 2000p Section 5.1), no performance credit is taken for the waste package inner barrier, thus the material interface between the waste package outer barrier (Alloy 22) and the waste package inner barrier (316NG stainless steel) is not explicitly modeled. However, upon first penetration of the waste package outer barrier, inside-out corrosion of the waste package outer barrier is modeled using exposure conditions which are based on in-package chemistry (CRWMS M&O 2000p Section 6.3.16). The waste package in-package chemistry is affected by the degradation of the waste package inner barrier and the waste package internals including the waste form itself (CRWMS M&O 2000ar). Therefore, the waste container degradation analysis includes the effects of the waste package outer barrier/inner barrier interface indirectly.

6.2.18.7 Supplemental Discussion:

Item intentionally left blank.

6.2.18.8 Relevant References:

CRWMS M&O 2000l. *Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier.* ANL-EBS-MD-000001

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001

CRWMS M&O 2000u. *EBS Radionuclide Transport Abstraction.* ANL-WIS-PA-000001

CRWMS M&O 2000y. *Physical and Chemical Environment Abstraction Model.* ANL-EBS-MD-000046

6.2.18.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.06.07.00, Effects at Material Interfaces

No secondary FEPs have been associated with this primary FEP.

6.2.19 Primary FEP 2.1.07.01.00, Rockfall (Large Block)

6.2.19.1 FEP Description:

Rockfalls occur large enough to mechanically tear or rupture waste packages and drip shields.

6.2.19.2 Related Primary FEPs:

Item intentionally left blank.

6.2.19.3 IRSR Issues:

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.19.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence (drip shield)

Excluded – Low Probability (waste package)

6.2.19.5 Screening Argument:

This FEP is also addressed in the Disruptive Events PMR (CRWMS M&O 2000ap, Section 3.2) and *Disruptive Events FEPS* AMR (CRWMS M&O 2000f) and excluded based on low consequence.

According to the *Rock Fall on Drip Shield* calculation (CRWMS M&O 2000ac, Section 6), the effective rock mass over a 3-m partial length of drip shield cannot exceed 10 metric tons (MT) (As mentioned in Section 6.2.11 of this document, the design basis rock size is 13 MT. Even so, the effective rock size due to the stress distribution cannot exceed 10 MT). Thus, even if a 52 MT rock (which is the estimated maximum rock size) were to fall on the drip shield, the drip shield would experience the same load as a 10 MT rock. This is due to the rock geometry and its loading distribution on the drip shield (CRWMS M&O 2000ac, Section 5.2).

LS-DYNA finite element analysis was performed to evaluate the effects of rock fall on the drip shield (CRWMS M&O 2000ac). Using the maximum effective rock mass of 10 MT, results indicate that the greatest damage caused to the drip shield will be in the form of cracks 13 cm in length, rather than a large cavity type of failure. These cracks are extremely tight and with time, become plugged with corrosion products and other mineral precipitates (CRWMS M&O 2000q, Section 6.5.5). This plugging process limits water transport through the drip shield to negligible amounts, and maintains the functionality of the drip shield. Therefore, rockfall on drip shield is of negligible consequence to the annual expected dose.

In addition, LS-DYNA analysis shows that the deflection of the drip shield due to rock fall is not enough to cause contact with the waste package. Thus, the drip shield provides adequate protection to the waste package from rock fall.

The WAPDEG analysis of waste package and drip shield degradation (CRWMS M&O 2000p, Section 6.4) shows that drip shields do not start to fail in the repository until about 20,000 years after emplacement. It is therefore reasonable to expect that the drip shield provides adequate protection to the waste package from rock fall during the first 10,000 years of emplacement. On this basis, rockfall on the waste package is excluded from consideration based on low probability, i.e., the probability of rockfall impacting the waste package is less than 1 in 10,000 during the first 10,000 years of emplacement.

6.2.19.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.19.7 Supplemental Discussion:

Item intentionally left blank.

6.2.19.8 Relevant References:

CRWMS M&O 2000c. *Engineered Barrier System Features, Events, and Processes*. ANL-WIS-PA-000002.

CRWMS M&O 2000d. *Drift Degradation Analysis*. ANL-EBS-MD-000027

CRWMS M&O 2000f. *Disruptive Events FEPS*. ANL-WIS-MD-000005

CRWMS M&O 2000q. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier and the Stainless Steel Structural Material*. ANL-EBS-MD-000005

CRWMS M&O 2000ap. *Disruptive Events Process Model Report*. TDR-NBS-MD-000002

6.2.19.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall.

Secondary FEP Number and Name: 2.1.07.01.01, Rockbursts in Container Holes

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address waste container damage which may result from a rock fall event.

Screening and Disposition: This secondary FEP is excluded based on low consequence to the expected annual dose. As discussed in the Screening Argument (Section 6.2.19.5 of this WP FEPs AMR) for the primary FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall, the drip shield will provide adequate waste package protection from rock fall for 10,000 years.

Secondary FEP Number and Name: 2.1.07.01.02, Cave Ins

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address waste container damage which may result from a rock fall event.

Screening and Disposition: This secondary FEP addresses the indirect effects of a rock fall event in that it considers the changing water flow characteristics which may arise from a rock fall event. It is feasible that stress fractures in the host rocks and rock fall events may increase the flow of water into the repository. Given that the drip shield is capable of withstanding a rock fall event, as discussed in the screening argument for primary FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall, it is reasonable to predict that the drip shield continues to divert water from falling on the waste package until the drip shield fails after 10,000 years. Furthermore, the waste package Alloy 22 corrosion rate is independent of the amount of water contacting the waste package (CRWMS M&O 2000p, Section 6.3.6). Thus this secondary FEP is excluded from the TSPA analysis based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.07.01.03, Cave In (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address waste container damage which may result from a rock fall event.

Screening and Disposition: Redundant. The screening arguments for both the primary FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall and the secondary FEP 2.1.07.01.02, Cave Ins support the exclusion of this FEP based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.07.01.04, Roof Falls

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address waste container damage which may result from a rock fall event.

Screening and Disposition: Redundant. The screening arguments for both the primary FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall and the secondary FEP 2.1.07.01.02, Cave Ins support the exclusion of this FEP based on low consequence to the expected annual dose.

6.2.20 Primary FEP 2.1.07.05.00, Creeping of Metallic Materials in the EBS

6.2.20.1 FEP Description:

Metals used in the waste package or drip shield may deform by creep processes in response to deviatoric stress.

6.2.20.2 Related Primary FEPs:

FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall

FEP 1.2.03.02.00, Seismic Vibration Causes Waste Container and Drip Shield Failure

6.2.20.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem

6.2.20.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence (all components of FEP not explicitly excluded based on low probability)

Excluded - Low Probability (not credible) (Creeping of Copper – FEP 2.1.07.05.01)

6.2.20.5 Screening Argument:

Based on the current analyses, the maximum surface temperatures at the drip shield and the waste package will be 157°C and 186°C, respectively (CRWMS M&O 2000z, Section 6.3.1, 6.3.5). Literature (ASM International 1990, p. 626) indicates that between 200 and 315°C (400 and 600°F), the deformation of many titanium alloys loaded to yield point does not increase with time. Thus, creep strength is seldom a factor for these alloys in this temperature range. No data exist for Ni-base alloys such as Alloy 22 in this temperature regime. However, the melting temperature of Ni/Cr based alloys is approximately 1370°C (Haynes International, 1988). Since the maximum surface temperature is only 17.4% of the melting temperature, strength loss due to high temperature creep is of negligible consequence. With respect to austenitic stainless steels such as Type 304, literature (ASM International 1990, p. 622) indicates that creep will not be observed in this alloy at temperatures below 370°C.

In view of the above rationale, this FEP is excluded based on low consequence to the expected annual dose. However, creep of copper, which is discussed in Section 6.2.20.9, is excluded based on low probability (not credible).

6.2.20.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.20.7 Supplemental Discussion:

Item intentionally left blank.

6.2.20.8 Relevant References:

Item intentionally left blank.

6.2.20.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.07.05.00, Creeping of Metallic Materials in the EBS.

Secondary FEP Number and Name: 2.1.07.05.01, Creeping of Copper

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the structural integrity of the waste package by considering creep in metallic materials.

Screening and Disposition: The primary FEP addresses the impact of creep in the Ti alloy, Ni/Cr alloy and stainless steel alloy proposed in the current waste package/drip shield design (CRWMS M&O 2000ab). This secondary FEP addresses creep in a specific metallic material, copper. To address this secondary FEP specifically, the primary FEP 2.1.03.09.00, Copper Corrosion, is referenced. As stated in Screening Argument (Section 6.2.13.5 in this WP FEPs AMR) primary FEP 2.1.03.09.00, Copper Corrosion, copper is not considered for use as an engineered barrier at Yucca Mountain, and all copper materials at the site surface will be removed prior to repository closure (CRWMS M&O 1994, Section 1.2). This secondary FEP is thus excluded based on low probability (not credible), as it is not applicable to the current repository design.

Secondary FEP Number and Name: 2.1.07.05.02, External Stress (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the structural integrity of the waste package by considering creep in the structural components of the waste package and EBS induced by external stresses.

Screening and Disposition: The basis for this secondary FEP is that external stress, by rock displacements for example, may lead to plastic deformations and creep in the canister and subsequent leakage of radionuclides. Mechanical damage of the waste container and drip shield by rockfall is discussed in greater detail under FEP 2.1.07.01.00, Rockfall (Large Block) WFClad-Rockfall (Section 6.2.19 of this WP FEPs AMR). This FEP discussion also provides relevant references discussing the issue in greater detail. In addition, the Emplacement Drift System design criteria requires that the drip shield be designed to withstand a 13 metric ton rock fall, without rupturing the drip shield or causing individual drip shield units to separate and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.14 and 1.2.1.15). In view of the above rationale, this FEP is excluded based on low consequence to the expected annual dose rate.

Mechanical damage of the waste container and drip shield by ground motion during seismic events is discussed in greater detail under FEP 1.2.03.02.00, Seismic Vibration Causes Waste Container and Drip Shield Failure. In addition, the Emplacement Drift System design criteria require that the drip shield be designed to withstand a Category 2 design basis earthquake without rupturing or parting between individual drip shield units and without contacting waste packages (CRWMS M&O 2000aa, System Design Criteria 1.2.1.16 and 1.2.1.17). In view of the above rationale, this FEP is excluded as low consequence to the expected annual dose rate.

Secondary FEP Number and Name: 2.1.07.05.03, Voids in the Lead Filling

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the structural integrity of the waste package by considering creep in the structural components of the waste package induced by voids in the waste package filling material.

Screening and Disposition: This secondary FEP is not specifically applicable because waste package in-fill is not proposed in the current waste package design (CRWMS M&O 2000ab). Furthermore, as discussed in the associated primary FEP, the structural integrity of the waste package is not expected to be compromised by creep in the waste package alloys. This secondary FEP is excluded as discussed in the associated primary FEP.

Secondary FEP Number and Name: 2.1.07.05.04, Loss of Ductility (of Waste Container)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the structural integrity of the waste package by considering creep in the structural components of the waste package induced by loss of ductility of copper materials from plastic and/or creeping deformations. Loss of ductility may take place due to impurities in the copper material, or bad manufacturing methods.

Screening and Disposition: As addressed in Primary FEP 2.1.03.09.00, Copper Corrosion, copper is not considered for use as an engineered barrier at Yucca Mountain, and all copper materials at the site surface will be removed prior to repository closure (CRWMS M&O 1994, Section 1.2). Furthermore, as discussed in the associated primary FEP, the structural integrity of the waste package is not expected to be compromised by creep in the waste package alloys. This secondary FEP is excluded as discussed in the associated primary FEP.

Secondary FEP Number and Name: 2.1.07.05.05, Incomplete Filling of Containers

Relationship to Primary FEP: Redundant. See discussion for secondary FEP 2.1.07.05.03, Voids in the Lead Filling.

Screening and Disposition: Redundant. See discussion for secondary FEP 2.1.07.05.03, Voids in the Lead Filling.

6.2.21 Primary FEP 2.1.09.03.00, Volume Increase of Corrosion Products

6.2.21.1 FEP Description:

Corrosion products have a higher molar volume than the uncorroded material. Increases in volume during corrosion will change the stress state in the material being corroded.

6.2.21.2 Related Primary FEPs:

FEP 2.1.03.07.00, Mechanical Impact of Waste Container and Drip Shield

6.2.21.3 IRSR Issues:

Item intentionally left blank.

6.2.21.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.21.5 Screening Argument:

FEP 2.1.03.07.00, Mechanical Impact on the Waste Container and Drip Shield, (Section 6.2.11 of this WP FEPs AMR) also deals with corrosion products, namely, the internal and external forces caused by swelling corrosion products. The discussion provided in Section 6.2.11 of this WP FEPs AMR provides sufficient rationale for exclusion of this FEP based on low consequence to the expected annual dose.

6.2.21.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.21.7 Supplemental Discussion:

Item intentionally left blank.

6.2.21.8 Relevant References:

Item intentionally left blank.

6.2.21.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEP addressed by Primary FEP 2.1.09.03.00, Volume Increase of Corrosion Products.

Secondary FEP Number and Name: 2.1.09.03.01, Swelling of Corrosion Products (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the swelling of corrosion products and the impacts on the waste package. This secondary FEP also addresses the swelling of corrosion products and the impacts on the waste form and other components of the EBS.

Screening and Disposition: Swelling of corrosion products in the waste package is addressed by the primary FEP 2.1.03.07.00, Mechanical Impact on the Waste Container and Drip Shield, (Section 6.2.11 of this WP FEPs AMR). The first part of this secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument for the primary FEP 2.1.09.03. 07.00, Mechanical Impact on the Waste Container and Drip Shield. The second part of this secondary FEP is not addressed as this AMR only pertains to waste package degradation. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form/Miscellaneous FEPs document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

6.2.22 Primary FEP 2.1.09.09.00 Electrochemical Effects in Waste and EBS

6.2.22.1 FEP Description:

Electrochemical effects may establish an electric potential within the drift or between materials in the drift and more distant metallic materials. Migration of ions within such an electric field could affect corrosion of metals in the EBS and waste, and could also have a direct effect on the transport of radionuclides as charged ions.

6.2.22.2 Related Primary FEPs:

Item intentionally left blank.

6.2.22.3 IRSR Issues:

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.22.4 Screening Decision and Regulatory Basis:

Excluded – Low consequence

6.2.22.5 Screening Argument:

Due to the large distances involved, it is reasonable to consider electrochemical effects between materials in the drift and more distant metallic materials to be less important to waste package materials degradation than electrochemical effects within the drift. Such long-range interactions are more appropriate for consideration in modeling processes such as radionuclide transport away from the potential repository rather than in consideration of relatively local phenomena such as waste package or drip shield degradation.

The current waste package design (CRWMS M&O 2000ab) includes an outer barrier of Alloy 22 over a 316NG stainless steel inner barrier. In addition, a titanium drip shield is added to this design to provide defense in depth. No performance credit is taken for the 316NG stainless steel inner barrier. Results of electrochemical polarization studies performed at the Lawrence Livermore National Laboratories indicate that the threshold potential and corrosion potential for Alloy 22 in simulated acidified water (SAW) at 90°C (this aggressive water chemistry and temperature reasonably bounds the potential repository exposure environment) will be 595 mV and –171mV (CRWMS M&O 2000b, Table 4), respectively. For 316NG in SAW at 90°C, the threshold and corrosion potentials will be 304 mV and -361 mV (CRWMS M&O 2000s, Table 5), respectively. Clearly any electrochemical coupling of the Alloy 22 waste package outer barrier with the 316NG waste package inner barrier will result in increased corrosion degradation of the 316NG waste package inner barrier and enhanced performance of the Alloy 22 waste package outer barrier. The coupled 316NG waste package inner barrier would serve as a sacrificial anode to the Alloy 22 waste package outer barrier.

The waste container and drip shield degradation are modeled with WAPDEG (CRWMS M&O 2000ah). In the WAPDEG model (CRWMS M&O 2000p, Section 5.1), no performance credit is taken for the 316NG waste package inner barrier. This conservatism is incorporated into the WAPDEG simulations used to evaluate waste container and drip shield degradation.

For Titanium Grade 7 (the drip shield material) in simulated acidified water (SAW) at 90°C, the threshold and corrosion potentials will be 1340 mV and -181 mV (CRWMS M&O 2000h, Table 4), respectively. While it is not expected that the waste package and drip shield will ever be in electrical contact, the similarity of the corrosion potentials of the materials (Alloy 22 and

Titanium Grade 7) used indicates that even if electrical contact were established, it would be of little consequence to the degradation characteristics of the waste package or the drip shield. Therefore, electrochemical coupling of the Alloy 22 waste package outer barrier and the Titanium Grade 7 drip shield is of low consequence to the expected annual dose.

6.2.22.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.22.7 Supplemental Discussion:

Item intentionally left blank.

6.2.22.8 Relevant References:

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield*. ANL-EBS-MD-000004

CRWMS M&O 2000s. *Degradation of Stainless Steel Structural Material*. ANL-EBS-MD-000007

6.2.22.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS.

Secondary FEP Number and Name: 2.1.09.09.01, Repository Induced Pb/Cu Electrochemical Reactions

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address electrochemical reactions and the impacts on corrosion rates in the waste package.

Screening and Disposition: Taken specifically, this secondary FEP is not pertinent to the Yucca Mountain repository because this secondary FEP was developed for a different waste package design which included in-filling a copper canister waste package with lead. However, the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS, addresses electrochemical corrosion of the current waste package design. This secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument (Section 6.2.22.5 in this WP FEPs AMR) for the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS.

Secondary FEP Number and Name: 2.1.09.09.02, Natural Telluric Electrochemical Reactions (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address electrochemical reactions and the impacts on corrosion rates in the waste package. This secondary FEP also addresses electrochemical effects in the waste form and other components of the EBS. Furthermore this secondary FEP also addresses the possibility of the transport of elements through the bentonite buffer by electro-osmosis or electrophoresis (the former for dissolved species, the latter for particulates).

Screening and Disposition: Electrochemical corrosion of the waste package is addressed by the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. The first part of this secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument (Section 6.2.22.5 in this WP FEPs AMR) for the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. The second part of this secondary FEP is not addressed by this AMR as this AMR only pertains to waste package degradation. The final part of this secondary FEP addresses the mobilization of radionuclides by an induced electrochemical gradient. The transport of radionuclides is not addressed in this AMR. For a discussion on this topic as it pertains to the Waste Form and EBS, see the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.09.09.03, Electro-Chemical Cracking (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address electrochemical reactions and the impacts on corrosion rates in the waste package. This secondary FEP also addresses electrochemical effects in the waste form and other components of the EBS.

Screening and Disposition: The first part of this secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument (Section 6.2.22.5 in this WP FEPs AMR) for the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. The second part of this secondary FEP is not addressed by this AMR as this AMR only pertains to waste package degradation. For a discussion on this topic as it pertains to the Waste Form and EBS, see the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.09.09.04, Electrochemical Effects/Gradients (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address electrochemical reactions and the impacts on corrosion rates in the waste package. This secondary FEP also addresses electrochemical effects in the waste form and other components of the EBS.

Screening and Disposition: The first part of this secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument (Section 6.2.22.5 of this WP FEPs AMR) for the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. The second part of this secondary FEP is not addressed by this AMR as this AMR only pertains to waste package degradation. For a discussion on this topic as it pertains to the Waste Form and EBS, see the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.09.09.05, Electrochemical Effects of Metal Corrosion

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address electrochemical reactions and the impacts on corrosion rates in the waste package. This secondary FEP also addresses the possibility of the radionuclide transport induced by low voltage electrical currents in the near field.

Screening and Disposition: Electrochemical corrosion of the waste package is addressed by the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. The first part of this secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument (Section 6.2.22.5 in this WP FEPs AMR) for the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. The second part of this secondary FEP addresses the mobilization of radionuclides by an induced electrochemical gradient. The transport of radionuclides is not addressed in this AMR. For a discussion on this topic as it pertains to the Waste Form and EBS, see the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.09.09.06, Electrochemical Effects (In Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for secondary FEP 2.1.09.09.04, Electrochemical Effects/Gradients (In Waste and EBS).

Screening and Disposition: Redundant. See the discussion for secondary FEP 2.1.09.09.04, Electrochemical Effects/Gradients (In Waste and EBS).

Secondary FEP Number and Name: 2.1.09.09.07, Galvanic Coupling (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the electrochemical effects on waste package and drip shield corrosion due to galvanic coupling. This secondary FEP also addresses galvanic coupling effects in the waste form and other components of the EBS.

Screening and Disposition: The effects of electrochemical effects on waste package and drip shield corrosion due to galvanic coupling is discussed in the screening argument (Section 6.2.22.5 of this WP FEPs AMR) for primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. Since no performance credit is taken for the internal stainless steel structure, galvanic coupling enhances the integrity of the waste package. Hence, the first part of this secondary FEP is excluded due to low consequence to the expected annual dose. The second part of this secondary FEP is not addressed by this AMR as this AMR only pertains to waste package and drip shield degradation. For a discussion on this topic as it pertains to the Waste Form and EBS, see the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.09.09.08, Electrophoresis (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address electrochemical reactions and the impacts on corrosion rates in the waste package. This secondary FEP also addresses the possibility of the radionuclide transport induced by electrochemical gradients.

Screening and Disposition: The primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS, addresses electrochemical corrosion of the waste package. The first part of this secondary FEP is excluded due to low consequence to the expected annual dose as discussed in the screening argument (Section 6.2.22.5 of this WP FEPs AMR) for the primary FEP 2.1.09.09.00, Electrochemical Effects in Waste and EBS. The second part of this secondary FEP addresses the mobilization of radionuclides by an induced electrochemical gradient. The transport of radionuclides is not addressed in this AMR. For a discussion on this topic as it pertains to the Waste Form and EBS, see the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.09.09.09, Electrochemical Gradients (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for secondary FEP 2.1.09.09.08, Electrophoresis (in Waste and EBS).

Screening and Disposition: Redundant. See the discussion for secondary FEP 2.1.09.09.08, Electrophoresis (in Waste and EBS).

Secondary FEP Number and Name: 2.1.09.09.10, Galvanic Coupling (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for secondary FEP 2.1.09.09.07, Galvanic Coupling (in Waste and EBS).

Screening and Disposition: Redundant. See the discussion for secondary FEP 2.1.09.09.07, Galvanic Coupling (in Waste and EBS).

Secondary FEP Number and Name: 2.1.09.09.11, Galvanic Coupling (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for secondary FEP 2.1.09.09.07, Galvanic Coupling (in Waste and EBS).

Screening and Disposition: Redundant. See the discussion for secondary FEP 2.1.09.09.07, Galvanic Coupling (in Waste and EBS).

6.2.23 Primary FEP 2.1.10.01.00, Biological Activity in Waste and EBS

6.2.23.1 FEP Description:

Biological activity in the waste and engineered barrier system (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.

6.2.23.2 Related Primary FEPs:

FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield

6.2.23.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers.

6.2.23.4 Screening Decision and Regulatory Basis:

Included (waste container)

Excluded - Low Consequence (drip shield)

6.2.23.5 Screening Argument:

This FEP, when considered from the waste package/drip shield degradation standpoint, is identical to FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container (Section 6.2.9). See the discussion outlined in that FEP.

6.2.23.6 TSPA Disposition:

See the discussion outlined in FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield (Section 6.2.9, of this WP FEPs AMR).

6.2.23.7 Supplemental Discussion:

See the discussion outlined in FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield (Section 6.2.9, of this WP FEPs AMR).

6.2.23.8 Relevant References:

See the discussion outlined in FEP 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield (Section 6.2.9, of this WP FEPs AMR).

6.2.23.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.10.01.00, Biological Activity in Waste and EBS

Secondary FEP Number and Name: 2.1.10.01.01, Microbial Activity Accelerates Corrosion of Containers

<u>Relationship to Primary FEP</u>: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Secondary FEP Number and Name: 2.1.10.01.02, Microbial Activity Accelerates Corrosion of Cladding

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of microbial activity on corrosion rates. The primary FEP addresses the effects of microbial activity on the corrosion rate of the waste package and this secondary FEP addresses the effects of microbial activity on the corrosion rate of the cladding.

Screening and Disposition: See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS for more details on the effects of biological activity on the corrosion rate of the waste package. The effect of microbial activity on cladding corrosion is not addressed by this AMR; hence, this secondary FEP is excluded because it is not applicable to waste package degradation. For a discussion on this topic as it pertains to the Waste Form, see the Waste Form Colloids document (CRWMS M&O 2000at).

Secondary FEP Number and Name: 2.1.10.01.03, Microbial Activity Accelerates Corrosion of Contaminants

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of microbial activity on corrosion rates. The primary FEP addresses the effects of microbial activity on the corrosion rate of the waste package and this secondary FEP addresses the effects of microbial activity on the corrosion rate of the cladding. The title of this secondary FEP is misleading. The FEP database (CRWMS M&O 2000al) indicates that this FEP addresses microbial activity in the waste containers as it accelerates corrosion of the waste form and mobilization of contaminants.

Screening and Disposition: See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS for more details on the effects of biological activity on the corrosion rate of the waste package. The effects of microbial activity on waste form corrosion and mobilization of contaminants is not addressed by this AMR; hence, this secondary FEP is excluded because it is not applicable to waste package degradation. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form Colloids document (CRWMS M&O 2000at) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.10.01.04, Microbes (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form Colloids document (CRWMS M&O 2000at) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.10.01.05, Microorganisms (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form Colloids document (CRWMS M&O 2000at) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.10.01.06, Microbiological Effects (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form Colloids document (CRWMS M&O 2000at) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.10.01.07, Microbial Activity (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form Colloids document (CRWMS M&O 2000at) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.10.01.08, Microbial Activity (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form Colloids document (CRWMS M&O 2000at) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.10.01.09, Microbial Activity (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS. For a discussion on this topic as it pertains to the Waste Form and EBS, see the Waste Form Colloids document (CRWMS M&O 2000at) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.10.01.10, Microbial Interactions

Relationship to Primary FEP: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Screening and Disposition: Redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS.

Secondary FEP Number and Name: 2.1.10.01.11, Biofilms

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address microbial activity and the impact of biofilms on waste package degradation. This secondary FEP also addresses the impact of biofilms on radionuclide transport.

Screening and Disposition: The first part of this secondary FEP is redundant. See the discussion for the two primary FEPs 2.1.03.05.00, Microbially-Mediated Corrosion of Waste Container and Drip Shield and 2.1.10.01.00, Biological Activity in Waste and EBS. The second part of this secondary FEP is excluded as not applicable to the waste package because this AMR does not address radionuclide transport.

6.2.24 Primary FEP 2.1.11.05.00, Differing Thermal Expansion of Repository Components

6.2.24.1 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.

6.2.24.2 Related Primary FEPs:

Item intentionally left blank.

6.2.24.3 IRSR Issues:

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem.

6.2.24.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.24.5 Screening Argument:

The coefficient of thermal expansion for Type 316L stainless steel (an analogue for the 316NG stainless steel used for the waste package inner barrier) is 18.2×10^{-6} m/m·K over the temperature range of 293 to 773 K (MO0003RIB00076.000). The coefficient of thermal expansion for Alloy 22 is 13.9×10^{-6} m/m·K over the temperature range of 297 to 811 K (a comparable temperature range) (MO0003RIB00071.000). Thus, the coefficient of thermal expansion for Type 316L stainless steel will be higher than that of Alloy 22 over a comparable temperature range. Currently, many scenarios with respect to WP skirt-to-skirt spacing and ventilation time are being considered to determine the peak surface temperature as function of backfill versus no backfill. For example, calculations cited in "Drift Scale Thermal Analysis," (CRWMS M&O 2000af, Table 6-19) indicate that for skirt-to-skirt spacing and ventilation time values of 0.5 meters and 50 years, the peak surface temperature will be 278 and 176°C (551 and 449 K) for backfill and no backfill cases, respectively. The calculation entitled Thermal History of Cladding in a 21-PWR WP Loaded with Average Fuel (CRWMS M&O 2000g, Section 6 Table 6-2) indicates that the difference in temperature between the inside of the waste package inner barrier (316NG) and the outside of the waste package outer barrier (Alloy 22) never exceeds 2°C. As an illustrative example, using the coefficients of thermal expansion for the two materials discussed above and a bounding 5°C (or 5 K) temperature difference between them, the calculated strain is $2.15 \cdot 10^{-5}$ m/m. This strain is so small that thermal expansion of waste package barriers will result in a negligible effect on expected mean dose rate.

A ~1 mm gap will prevent the resultant stress due to the differing thermal expansion coefficients of the waste package materials from reaching a critical level that could lead to stresses in the waste package barriers. The Waste Package Operation Fabrication Process Report (CRWMS M&O 2000k, Section 8.1.8) requires a loose fit between the outer barrier (Alloy 22) and the inner shell (316NG stainless steel) to accommodate the differing thermal expansion coefficients, and so this FEP can be excluded for the waste packages based on low consequence to the expected annual dose.

The drip shield design is presented in Attachment II (p. II-1 and II-2) of the Design Analysis for the Ex-Container Components (CRWMS M&O 2000w). As shown in Figure 2 in Section 6.1.1 of the Design Analysis for the Ex-Container Components, the drip shield connectors are designed in such a way that allows for thermal expansion with no effect on drip shield performance. The drip shield segments are interlocked with a significant amount of freedom to expand and still maintain their intended purpose. Therefore, this FEP can be excluded for the drip shields based on low consequence to the expected annual dose.

6.2.24.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.24.7 Supplemental Discussion:

Item intentionally left blank.

6.2.24.8 Relevant References:

CRWMS M&O 2000c. *Engineered Barrier System Features, Events, and Processes.* ANL-WIS-PA-000002

CRWMS M&O 2000d. *Drift Degradation Analysis.* ANL-EBS-MD-000027

6.2.24.9 Treatment of Secondary FEPs:

The following is a discussion of the secondary FEPs addressed by Primary FEP 2.1.11.05.00, Differing Thermal Expansion of Repository Components

Secondary FEP Number and Name: 2.1.11.05.01, Differential Thermal Expansion of Near-field Barriers

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address thermal expansion of repository components in the EBS

Screening and Disposition: Redundant, see primary FEP discussion. Thermal expansion in the near field environment is outside the scope of the waste package FEP AMR. For additional discussion, see EBS FEPs (CRWMS M&O 2000c). Excluded, not pertinent to this AMR.

Secondary FEP Number and Name: 2.1.11.05.02, Shearing of Waste Containers by Secondary Stresses from Thermal Expansion of The Rock

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address thermal expansion of repository components in the EBS.

Screening and Disposition: The current design is to place large containers horizontally in the drifts under titanium drip shields (CRWMS M&O 2000ab, Design Constraint 5.2.11). Under this design, it is not possible for thermal expansion of the rock to result in rock-package contact (CRWMS M&O 2000aa, Section 2.3).

Secondary FEP Number and Name: 2.1.11.05.03, Differential Elastic Response (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address thermal expansion of repository components in the EBS.

Screening and Disposition: Redundant, see primary FEP discussion. Differential elastic response in the waste and EBS are outside the scope of the waste package FEP AMR. For additional discussion, see EBS FEPs (CRWMS M&O 2000c) and *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2000an). Excluded, not pertinent to this AMR.

Secondary FEP Number and Name: 2.1.11.05.04, Non-elastic Response (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address thermal expansion of repository components in the EBS.

Screening and Disposition: Redundant, see primary FEP discussion. Differential elastic response in the waste and EBS are outside the scope of the waste package FEP AMR. For additional discussion, see EBS FEPs (CRWMS M&O 2000c) and *Miscellaneous Waste-Form FEPs* (CRWMS M&O 2000an). Excluded, not pertinent to this AMR.

6.2.25 Primary FEP 2.1.11.06.00, Thermal Sensitization of Waste Containers and Drip Shields Increases Fragility

6.2.25.1 FEP Description:

Phase changes in waste package materials can result from long-term storage at moderately hot temperatures in the repository. Stress-corrosion cracking, intergranular corrosion, or mechanical degradation may ensue.

6.2.25.2 Related Primary FEPs:

FEP 2.1.03.07.00, Mechanical Impact on Waste Container and Drip Shield

FEP 2.1.03.01.00, Corrosion of Waste Containers

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

6.2.25.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

6.2.25.4 Screening Decision and Regulatory Basis:

Included

6.2.25.5 Screening Argument:

Included in the TSPA as described under TSPA Disposition.

6.2.25.6 TSPA Disposition:

Alloy 22 is known to be subject to "aging" and phase instability when exposed to elevated temperatures. The processes involve precipitation of different secondary phases and restructuring of the microstructure. The affected material exhibits increased brittleness and decreased resistance to corrosion, especially to localized corrosion and SCC (CRWMS M&O 2000m, Section 6.3). Preliminary testing results have shown that the waste container outer barrier (Alloy

22) could be subject to aging and phase instability under repository thermal conditions (CRWMS M&O 2000m, Section 6.3). Analyses and models of these effects are currently underway.

Effects of potential thermal sensitization of the waste package outer barrier (such as thermally induced stress-corrosion cracking, intergranular corrosion, or mechanical degradation) are included in TSPA as part of waste package degradation analysis. The effects are accounted for with a corrosion enhancement factor that is applied to the corrosion rate for the non-affected condition (CRWMS M&O 2000b). The waste container thermally induced corrosion mechanisms are modeled with WAPDEG (CRWMS M&O 2000ah). WAPDEG produces waste package degradation profiles consisting of the fraction of waste packages failed versus time and the average (per waste package) number of penetration openings versus time. The degradation profiles are used as input into the TSPA model (see FEP 2.1.03.01.00, Corrosion of Waste Containers).

6.2.25.7 Supplemental Discussion:

Item intentionally left blank.

6.2.25.8 Relevant References:

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003

CRWMS M&O 2000m. *Aging and Phase Stability of Waste Package Outer Barrier*. ANL-EBS-MD-000002

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation*. ANL-EBS-PA-000001

6.2.25.9 Treatment of Secondary FEPs:

Secondary FEPs addressed by Primary FEP 2.1.11.06.00, Thermal sensitization of waste containers and drip shields increases their fragility.

No secondary FEPs have been associated with this primary FEP.

6.2.26 Primary FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion

6.2.26.1 FEP Description:

Gas generation can affect the mechanical behavior of the host rock and engineered barriers, chemical conditions, and fluid flow, and, as a result, the transport of radionuclides. Gas generation due to oxic corrosion of waste containers, 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 due to the thermal heating in the repository will produce steam around the canister which will excluded oxygen from the iron, thus inhibiting further corrosion for a limited amount of time in the early period of the repository.

6.2.26.2 Related Primary FEPs:

FEP 2.1.03.01.00, Corrosion of Waste Containers

FEP 2.1.02.13.00, General Corrosion of Cladding

6.2.26.3 IRSR Issues:

Item intentionally left blank.

6.2.26.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.26.5 Screening Argument:

A repository in the unsaturated zone of the Yucca Mountain repository is expected to be connected to the atmosphere and to be operating under oxidizing conditions. Therefore, any gases generated by metal corrosion would escape from the drifts. However, hydrogen may be evolved when passive alloys such as titanium are galvanically coupled to more active metals such as carbon steel. The possible consequence of this hydrogen evolution would be to cause hydrogen induced-cracking (HIC). Since the titanium drip shield will not be in contact with any other active metals in the current design, the susceptibility of titanium alloys to HIC is minimal (see also FEP 2.1.03.04.00, Hydride Cracking of Waste Containers and Drip Shields (Section 6.2.8 in this WP FEPs AMR)).

The literature (ASM International 1987, pp. 650-651) indicates that fully annealed nickel-base alloys such as Alloy 22 may be immune to hydrogen-induced embrittlement (hydride cracking). The susceptibility to hydride cracking may be enhanced only when the strength level of this alloy is increased either by cold working or by aging at a temperature of 540°C at which ordering and/or grain-boundary segregation can occur. The susceptibility to cracking may be reduced with decreasing strength level and correspondingly with increasing aging temperature. However, since the WP temperature will be sufficiently less than 540°C, the degree of hydrogen adsorption is negligible and HIC of Alloy 22 will be of low consequence (see also FEP # 2.1.03.04.00).

Based on the above rationale, this FEP is excluded based on low consequence to the expected annual dose.

This FEP is also addressed in the Engineered Barrier System (EBS) PMR and EBS FEPs AMR (CRWMS M&O 2000c) and excluded based on low consequence.

6.2.26.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.26.7 Supplemental Discussion:

Item intentionally left blank.

6.2.26.8 Relevant References:

CRWMS M&O 2000r. *Hydrogen Induced Cracking of Drip Shield.* ANL-EBS-MD-000006

CRWMS M&O 2000t. *In-Drift Gas Flux & Composition.* ANL-EBS-MD-000040

CRWMS M&O 2000y. *Physical and Chemical Environmental Abstraction Model.* ANL-EBS-MD-000046

6.2.26.9 Treatment of Secondary FEPs:

Secondary FEPs addressed by Primary FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion

Secondary FEP Number and Name: 2.1.12.03.01, Chemical Effects of Corrosion

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address gas generation (H_2) from metal corrosion.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.26 of this WP FEPs AMR) for the primary FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion. This FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.12.03.02, Effect of Hydrogen on Corrosion

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of evolved gases on corrosion.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.26 of this WP FEPs AMR) for the primary FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion. This FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.12.03.03, Hydrogen Production (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of evolved gases on corrosion.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.26 of this WP FEPs AMR) for the primary FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion. This FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.12.03.04, Hydrogen Production by Metal Corrosion

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of evolved gases on corrosion.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.26 of this WP FEPs AMR) for the primary FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion. This FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.12.03.05, Container Material Inventory

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of evolved gases on corrosion.

Screening and Disposition: Redundant. See the Screening Argument (Section 6.2.26 of this WP FEPs AMR) for the primary FEP 2.1.12.03.00, Gas Generation (H_2) from Metal Corrosion. This FEP is excluded based on low consequence to the expected annual dose.

6.2.27 Primary FEP 2.1.13.01.00, Radiolysis

6.2.27.1 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, and concentration of reactive radicals).

6.2.27.2 Related Primary FEPs:

FEP 2.1.12.01.00, Gas Generation

FEP 2.1.09.06.00, Reduction-oxidation Potential in Waste and EBS

6.2.27.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the containers.

6.2.27.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence (all components of FEP not explicitly excluded based on low probability)

Excluded – Low Probability (not credible) (Radiolysis of Cellulose – FEP 2.1.13.01.07)

6.2.27.5 Screening Argument:

The dominant contributor to dose rate at the waste package surface is from gamma radiation (CRWMS M&O 2000a, Section 6). Anodic shifts in the open circuit potential of stainless steel in gamma irradiated aqueous environments have been experimentally observed. The shift in corrosion potential was shown and subsequently confirmed to be due to the formation of hydrogen peroxide (CRWMS M&O 2000b, Section 6.4.4).

As the waste package is made of Alloy 22 and not stainless steel, additional studies of the corrosion threshold potentials due to gamma radiation have been performed. To determine the maximum impact of gamma radiolysis, hydrogen peroxide was added to repository-relevant solutions used for Alloy 22 corrosion testing (CRWMS M&O 2000b, Section 6.4.4). As the concentration of hydrogen peroxide in simulated acidic concentrated water (SAW) at 25°C approaches 72 parts per million (ppm), a value that could result only from extremely high gamma radiation levels (CRWMS M&O 2000b, Section 6.4.4), the corrosion potential asymptotically approaches 150 mV versus the silver/silver chloride (Ag/AgCl) reference electrode. This is a shift in corrosion potential of about 230 mV relative to a hydrogen peroxide-free SAW solution, however, this potential is still well below any threshold where localized attack would be expected in SAW. Similarly, as the concentration of hydrogen peroxide in simulated concentrated water (SCW) approaches 72 ppm, the corrosion potential asymptotically approaches –25mV versus the silver/silver chloride (Ag/AgCl) reference electrode. This is a shift in corrosion potential of about 200 mV relative to a hydrogen peroxide-free SCW solution (CRWMS M&O 2000b, Section 6.4.4), however, this potential is well below any threshold where localized attack would be expected in SCW, and well below any level where a change in oxidation state would be expected (CRWMS M&O 2000b, Section 6.4.4).

Since extremely high radiation levels would be required to achieve such shifts in corrosion potential (i.e., 72 ppm hydrogen peroxide) and the maximum shift in potential is less than that required for breakdown of the passive film, gamma radiolysis will not result in localized corrosion of Alloy 22. Although the shift in corrosion potential for the Titanium Grade 7 drip shield material would likely differ from that of Alloy 22, the magnitude of the shift in potential due to gamma radiolysis would not be greater than that required to cause breakdown of the passive film and initiation of localized corrosion (CRWMS M&O 2000h, Section 6.8). Gamma radiolysis will have no significant effect on general corrosion rates (CRWMS M&O 2000h, Section 6.4.4). This FEP is excluded due to low consequence because gamma radiolysis does not initiate localized corrosion or have any significant effect on the rate of general corrosion and therefore, no significant effect on dose rate. However, secondary FEP 2.1.13.01.07 (Section 6.2.27.9) is excluded on the basis of low probability (not credible).

6.2.27.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.27.7 Supplemental Discussion:

Item intentionally left blank.

6.2.27.8 Relevant References:

CRWMS M&O 2000a. *Dose Rate Calculation for the 21-PWR UCF Waste Package.* CAL-UDC-NU-000002

CRWMS M&O 2000b. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier.* ANL-EBS-MD-000003

CRWMS M&O 2000h. *General Corrosion and Localized Corrosion of the Drip Shield.* ANL-EBS-MD-000004

CRWMS M&O 2000p. *WAPDEG Analysis of Waste Package and Drip Shield Degradation.* ANL-EBS-PA-000001

6.2.27.9 Treatment of Secondary FEPs:

The following section discusses the secondary FEPs addressed by Primary FEP 2.1.13.01.00, Radiolysis.

Secondary FEP Number and Name: 2.1.13.01.01, Radiolysis (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion. The second part of this FEP addresses radiolysis effects on the waste form and the other parts of the EBS.

Screening and Disposition: Redundant. See the screening argument for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose. The second part of this secondary FEP is not addressed by this AMR. For a discussion on these topics see the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.01.02, Radiolysis

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.13.01.03, Radiolysis (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion. The second part of this FEP addresses radiolysis effects on the waste form and the other parts of the EBS.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose. The second part of this secondary FEP is not addressed by this AMR. For a discussion on these topics see the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.01.04, Radiolysis (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion. The second part of this FEP addresses radiolysis effects on the waste form and the other parts of the EBS.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose. The second part of this secondary FEP is not addressed by this AMR. For a discussion on these topics see the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.01.05, Radiolysis Prior to Wetting (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion. The second part of this FEP addresses radiolysis effects on the waste form and the other parts of the EBS.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose. The second part of this secondary FEP is not addressed by this AMR. For a discussion on these topics see the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.01.06, Radiolysis of Brine

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion. The second part of this FEP addresses radiolysis effects on the waste form and the other parts of the EBS.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.13.01.07, Radiolysis of cellulose (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion. The second part of this FEP addresses radiolysis effects on the waste form and the other parts of the EBS.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low probability (not credible) since there is no cellulose present in the waste. The second part of this secondary FEP is not addressed by this AMR. For a discussion on these topics see the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.01.08, Radiolysis

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.13.01.09, Radiolysis

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address the effects of radiolysis on waste package corrosion.

Screening and Disposition: Redundant. See the screening argument (Section 6.2.27 of this WP FEPs AMR) for the primary FEP 2.1.13.01.00, Radiolysis. This secondary FEP is excluded based on low consequence to the expected annual dose.

6.2.28 Primary FEP 2.1.13.02.00, Radiation Damage in Waste and EBS

6.2.28.1 FEP Description:

Strong radiation fields could lead to radiation damage to the waste forms and containers (CSNF, DSNF, DHLW), backfill, drip shield, seals and surrounding rock.

6.2.28.2 Related Primary FEPs:

FEP 2.1.02.01.00, DSNF Degradation, Alteration, and Dissolution

FEP 2.1.02.02.00, CSNF Alteration, Dissolution, and Radionuclide Release

FEP 2.1.02.03.00, Glass Degradation, Alteration, and Dissolution

6.2.28.3 IRSR Issues:

Subissue 1: The Effects of Corrosion Processes on the Lifetime of the Containers

Subissue 2: The Effects of Phase Instability and Initial Defects on the Mechanical Failure and Lifetime of the Containers

Subissue 6: The Effects of Alternate Engineered Barrier Subsystem Design Features on Container Lifetime and Radionuclide Release from the Engineered Barrier Subsystem

6.2.28.4 Screening Decision and Regulatory Basis:

Excluded – Low Consequence

6.2.28.5 Screening Argument:

The dose rate of gamma radiation (the predominant form of radiation fluence) at the surface of the WP and DS will be determined by the concentration of the various radioactive isotopes within the package (as functions of age, type, and length of time the fuel was in the reactor, etc.) and the attenuation provided by the container. Maximum dose rates at the surface of the container are not expected to exceed 1040 rem/hr (CRWMS M&O 2000a, Section 6), which for gamma radiation is equivalent to 1040 rads/hr. The general conclusion reached by most investigators is dose rates below 10^5 rads/hr of the type of radiation emitted from decay wastes are not adequate to degrade the metallurgical and mechanical properties of the WP and DS materials, and their protective/passive layers (ASM International 1987, p. 973). The only significant effect of radiation will be the change in external environment due to groundwater radiolysis (ASM International 1987, pp. 971-974) (see primary FEP 2.1.13.01.00).

Based on the above rationale, this FEP is excluded based on low consequence to the annual expected dose.

6.2.28.6 TSPA Disposition:

Excluded from the TSPA as described under the Screening Argument.

6.2.28.7 Supplemental Discussion:

Item intentionally left blank.

6.2.28.8 Relevant References:

Item intentionally left blank.

6.2.28.9 Treatment of Secondary FEPs:

The following is a discussion on the secondary FEPs addressed by Primary FEP 2.1.13.02.00, Radiation Damage in Waste and EBS.

Secondary FEP Number and Name: 2.1.13.02.01, Radiation Effects (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address EBS damage by radiation emitted from the waste.

Screening and Disposition: As it pertains to the waste package, this secondary FEP is identical to the primary FEP 2.1.13.02.00, Radiation Damage in Waste and EBS. This secondary FEP is excluded, as discussed in the screening argument (Section 6.2.28 of this WP FEPs AMR) for the primary FEP, based on low consequence to the expected annual dose. The second part of this secondary FEP, the damaging effects of radiation on the waste form and other areas of the EBS, is not addressed by this AMR. See the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.02.02, Radiation Effects on Bentonite

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address EBS damage by radiation emitted from the waste.

Screening and Disposition: This secondary FEP addresses the effects of radiation on the EBS environment and does not address waste package degradation. Hence, it is not applicable to this document. For a detailed discussion of this FEP see the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.02.03, Material property changes (due to radiation in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address EBS damage by radiation emitted from the waste.

Screening and Disposition: As it pertains to the waste package, this secondary FEP is identical to the primary FEP 2.1.13.02.00, Radiation Damage in Waste and EBS. This secondary FEP is excluded, as discussed in the screening argument for the primary FEP, based on low consequence to the expected annual dose. The second part of this secondary FEP, the damaging effects of radiation on the waste form and other areas of the EBS, is not addressed by this AMR. See the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.02.04, Radiation damage (in Waste and EBS)

Relationship to Primary FEP: Redundant. See the discussion for the secondary FEP 2.1.13.02.01, Radiation Effects (in Waste and EBS).

Screening and Disposition: Redundant. See the discussion for the secondary FEP 2.1.13.02.01, Radiation Effects (in Waste and EBS).

Secondary FEP Number and Name: 2.1.13.02.05, Radiation Shielding (in Waste and EBS)

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address EBS damage by radiation emitted from the waste.

Screening and Disposition: The secondary FEP addresses the benefits of the container to reduce the amount of radiation emitted to the drift environment. This secondary FEP does not address waste package degradation. Hence, it is not applicable to this document.

Secondary FEP Number and Name: 2.1.13.02.06, Radiation Effects on Buffer/Backfill

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address EBS damage by radiation emitted from the waste.

Screening and Disposition: The first part of this secondary FEP, the effects of radiation on the buffer is redundant. See the discussion for the secondary FEP 2.1.13.02.02, Radiation Effects on Bentonite. The second part of this of this FEP is not applicable because the current repository design (CRWMS M&O 2000ab) does not consider the emplacement of backfill. This secondary FEP is excluded based on low probability (not credible).

Secondary FEP Number and Name: 2.1.13.02.07, Radiation Effects on Canister

Relationship to Primary FEP: This secondary FEP and the associated primary FEP are identical.

Screening and Disposition: Redundant. See the discussion for the primary FEP 2.1.13.02.00, Radiation damage in Waste and EBS. This secondary FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.13.02.08, Radiological Effects on Waste

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address EBS damage by radiation emitted from the waste.

Screening and Disposition: As it pertains to the waste package, this secondary FEP is identical to the primary FEP 2.1.13.02.00, Radiation damage in Waste and EBS. This secondary FEP is excluded, as discussed in the screening argument for the primary FEP, based on low consequence to the expected annual dose. The second part of this secondary FEP, the damaging effects of radiation on the waste form and other areas of the EBS, is not addressed by this AMR. See the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.02.09, Radiological Effects on Containers

Relationship to Primary FEP: This secondary FEP and the associated primary FEP are identical.

Screening and Disposition: Redundant. See the discussion for the primary FEP 2.1.13.02.00, Radiation damage in Waste and EBS. This secondary FEP is excluded based on low consequence to the expected annual dose.

Secondary FEP Number and Name: 2.1.13.02.10, Radiological Effects on Seals

Relationship to Primary FEP: This secondary FEP and the associated primary FEP both address EBS damage by radiation emitted from the waste.

Screening and Disposition: As it pertains to the waste package, this secondary FEP is identical to the primary FEP 2.1.13.02.00, Radiation damage in Waste and EBS. This secondary FEP is excluded, as discussed in the screening argument for the primary FEP, based on low consequence to the expected annual dose. The second part of this secondary FEP, the damaging effects of radiation on the waste form and other areas of the EBS, is not addressed by this AMR. See the *Miscellaneous Waste-Form FEP* document (CRWMS M&O 2000an) and the EBS FEPs document (CRWMS M&O 2000c).

Secondary FEP Number and Name: 2.1.13.02.11, Radiation Effects on Canister

Relationship to Primary FEP: This secondary FEP and the associated primary FEP are identical.

Screening and Disposition: Redundant. See the discussion for the primary FEP 2.1.13.02.00, Radiation damage in Waste and EBS. This secondary FEP is excluded based on low consequence to the expected annual dose.

7. CONCLUSIONS

The analyses documented in this AMR are for the current SR design (CRWMS M&O 2000ab). In this design, a drip shield is placed over the waste package (see Design Constraint 5.2.11 of CRWMS M&O 2000ab). Repository designs that are lower in temperature than the current SR design will not affect the screening decision of any of the waste package FEPs. Most of the waste package degradation mechanisms have no temperature dependence and those that do, have a positive correlation with rising temperatures and increased degradation rates (see screening arguments and TSPA Disposition discussions listed in this document). This is true for designs that only affect the repository temperature and not any other aspects of the design, such as waste package spacing in the repository, drift orientation, etc. Twenty-eight (28) primary FEPs relevant to waste package and drip shield degradation processes have been screened and are summarized in Table 3. This table shows the FEP number, FEP name, screening decision (included/excluded) and basis for the screening decision (i.e. low consequence or low probability).

Table 3. Summary of Waste Package FEPs.

FEP Number	FEP Name	Screening Decision	Screening Basis
1.1.03.01.00	Error in waste or backfill emplacement	Excluded	Low consequence
1.2.02.03.00	Fault movement shears waste container	Excluded	Low probability
1.2.03.02.00	Seismic vibration causes container failure	Excluded	Low consequence
1.2.04.04.00	Magma interacts with waste	Included	
2.1.03.01.00	Corrosion of waste containers	Included	
2.1.03.02.00	Stress corrosion cracking of waste containers and drip shields	Included WP/Excluded DS	Low consequence
2.1.03.03.00	Pitting of waste containers and drip shields	Included	
2.1.03.04.00	Hydride cracking of waste containers and drip shields	Excluded DS/Excluded WP	Low consequence DS/Low probability WP
2.1.03.05.00	Microbially-mediated corrosion of waste container and drip shield	Included WP/ Excluded DS	Low consequence
2.1.03.06.00	Internal corrosion of waste container	Excluded	Low consequence
2.1.03.07.00	Mechanical impact of waste container and drip shield	Excluded	Low consequence
2.1.03.08.00	Juvenile and early failure of waste containers and drip shields	Included WP (manfucaturing and weld defects)/ Excluded DS/Excluded WP (improper quality control during emplacement)	Low consequence
2.1.03.09.00	Copper corrosion	Excluded (copper canisters)/ Excluded (gantry rail system)	Low probability/Low consequence

FEP Number	FEP Name	Screening Decision	Screening Basis
2.1.03.10.00	Container healing	Excluded	Low consequence
2.1.03.11.00	Container form	Excluded	Low consequence
2.1.03.12.00	Container failure (long term)	Included	
2.1.06.06.00	Effects and degradation of drip shield	Excluded (rockfall)/Excluded (seismic and oxygen embrittlement)/ Included(chemical)	Low consequence/Low consequence
2.1.06.07.00	Effects at material interfaces	Included (chemical effects)/ Excluded (hydride cracking)	Low consequence
2.1.07.01.00	Rockfall (Large Block)	Excluded	Low consequence (DS) / Low probability (WP)
2.1.07.05.00	Creeping of metallic materials in the EBS	Excluded	Low consequence
2.1.09.03.00	Volume increase of corrosion products	Excluded	Low consequence
2.1.09.09.00	Electrochemical effects in waste and EBS	Excluded	Low consequence
2.1.10.01.00	Biological activity in waste and EBS	Included WP/ Excluded DS	Low consequence
2.1.11.05.00	Differing thermal expansion of repository components	Excluded	Low consequence
2.1.11.06.00	Thermal sensitization of waste containers and drip shields increases their fragility	Included	
2.1.12.03.00	Gas generation (H_2) from metal corrosion	Excluded	Low consequence
2.1.13.01.00	Radiolysis	Excluded	Low consequence
2.1.13.02.00	Radiation damage in waste and EBS	Excluded	Low consequence

In addition to FEPs screening, this analysis addresses the NRC Issue Resolution Status Report (IRSR) for Container Life and Source Term Key Technical Issue (CLST KTI) for container life and source term (NRC 1999).

8. INPUTS AND REFERENCES

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