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October 2004

Screening Analysis of Criticality Features, Events, and Processes for License Application

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Office of Repository Development
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QA: QA

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11. Remarks

This report was written by D. A. Brownson (lead), J. K. Knudsen (Appendices C & D and SAPHIRE FEPs analysis development), J. A. McClure (Sections 4.0, 5.0 and 8.0), C. T. Hsu (Sections 4.0, 5.0, 8.0, and DIRS), D. Newell (Section 8.0 and DIRS).

This report was checked by A. A. Alsaed (lead), H. Radulescu (DIRS), J. Huffer (DIRS), J. Ryman (DIRS), B. Bullard (MATHCAD files), and W. J. Galyean (SAPHIRE analysis).

Appendix G is a CD-ROM containing EXCEL, MATHCAD, and SAPHIRE files used in this report.

Change History

12. Revision No.	13. Description of Change
00	Initial Issue
01	Update to expand analysis to address REV 00 limitations and incorporate additional LA-specific information. The entire report has been revised and changes are too extensive to use change bars. ~~check copy~~ JAM 10/20/04

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EXECUTIVE SUMMARY

This report documents the screening analysis of postclosure criticality features, events, and processes. It addresses the probability of criticality events resulting from degradation processes as well as disruptive events (i.e., seismic, rock fall, and igneous). Probability evaluations are performed utilizing the configuration generator described in *Configuration Generator Model*[1], a component of the methodology from *Disposal Criticality Analysis Methodology Topical Report*[2].

The total probability per package of criticality is compared against the regulatory probability criterion for inclusion of events established in 10 CFR 63.114(d)[3] (consider only events that have at least one chance in 10,000 of occurring over 10,000 years). The total probability of criticality accounts for the evaluation of identified potential critical configurations of all baselined commercial and U.S. Department of Energy spent nuclear fuel waste form and waste package combinations, both internal and external to the waste packages.

This criticality screening analysis utilizes available information for the 21–Pressurized Water Reactor Absorber Plate, 12–Pressurized Water Reactor Absorber Plate, 44–Boiling Water Reactor Absorber Plate, 24–Boiling Water Reactor Absorber Plate, and the 5-Defense High-Level Radioactive Waste/U.S. Department of Energy Short waste package types. Where defensible, assumptions have been made for the evaluation of the following waste package types in order to perform a complete criticality screening analysis: 21–Pressurized Water Reactor Control Rod, 5–Defense High-Level Radioactive Waste/U.S. Department of Energy Long, and 2–Multi-Canister Overpack/2–Defense High-Level Radioactive Waste package types.

The inputs used to establish probabilities for this analysis report are based on information and data generated for the Total System Performance Assessment for the License Application, where available.

This analysis report determines whether criticality is to be included or excluded from the Total System Performance Assessment for the License Application. The updated criticality features, events, and processes screening analysis contained herein are prepared in accordance with the guidance specified in *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes*[4].

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[1] BSC (Bechtel SAIC Company) 2004 [DIRS 168552]. *Configuration Generator Model.* CAL-DS0-NU-000002 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: TBD.

[2] YMP (Yucca Mountain Site Characterization Project) 2003 [DIRS 165505]. *Disposal Criticality Analysis Methodology Topical Report.* YMP/TR-004Q, Rev. 02. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: DOC.20031110.0005.

[3] 10 CFR 63 [DIRS 156605]. Energy: *Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada*. Readily available.

[4] BSC (Bechtel SAIC Company) 2004 [DIRS 168706]. The Development of the Total System Performance Assessment-License Application Features, Events, and Processes. TDR-WIS-MD-000003 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: TBD.

The total probability per package of criticality resulting from the criticality features, events, and processes analyses documented in this report has a calculated value below the regulatory probability criterion. Therefore, it is recommended that criticality be excluded from the Total System Performance Assessment for the License Application evaluation.

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FIGURES

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ACRONYMS

BWR	boiling water reactor
DHLW	defense high-level (radioactive) waste
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FEPs	features, events, and processes
HLW	high-level (radioactive) waste
LA	License Application
MCNP	Monte Carlo N-Particle Transport Code System
MCO	multi-canister overpack
MGR	monitored geologic repository
MTHM	metric tons of heavy metal
NRC	U.S. Nuclear Regulatory Commission
PGV	peak ground velocity
PWR	pressurized water reactor
RH	relative humidity
SNF	spent nuclear fuel
STN	Software Tracking Number
SZ	saturated zone
TSPA-LA	Total System Performance Assessment for the License Application
TSPA-SR	Total System Performance Assessment for the Site Recommendation
TSbv	Topopah Spring basal vitrophyre
TSw	Topopah Spring welded hydrogeologic unit
UZ	unsaturated zone
WAPDEG	Waste Package Degradation computer code
YMP	Yucca Mountain Project

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1. PURPOSE

The purpose of this analysis report is to evaluate and document the inclusion or exclusion of the criticality features, events, and processes (FEPs) with respect to modeling used to support the Total System Performance Assessment for License Application (TSPA-LA). A screening decision, either *Included* or *Excluded,* is given for each FEP along with the technical basis for screening decisions. This information is required by the Nuclear Regulatory Commission (NRC) in 10 CFR 63.114 (d, e, and f) [DIRS 156605].

The criticality FEPs screening analysis calculates the probability per package (Table 6.7-1) of criticality resulting from degradation processes (in-package and external) as well as disruptive events (i.e., seismic, rock fall, and igneous). Probability evaluations are performed utilizing the configuration generator described in *Configuration Generator Model* (BSC 2004 [DIRS 168552]), a component of the methodology from *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). The calculated probabilities for the individual criticality FEPs analyses are summed to obtain a total probability per package of criticality, which is then compared to the regulatory probability criterion for inclusion of events (10 CFR 63.114(d) [DIRS 156605]) for determination of criticality's inclusion in, or exclusion from, evaluation in the TSPA-LA. This comparison is the basis of the screening recommendation for the criticality FEPs. This revision addresses the LA FEP List (DTN: MO0407SEPFEPLA.000 DIRS [170760]). The analyses in the document do not apply to naval spent nuclear fuel. In Section 2.2.1.4.2 of its classified Technical Support Document for the License Application, the NNPP provides its screening analysis and calculation of the probability per package of criticality for naval spent nuclear fuel in the repository.

1.1 PLANNING AND DOCUMENTATION

Documentation requirements for this analysis report are described in the technical work plan (TWP) entitled *Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002* (BSC 2004 [DIRS 166964]). Any changes in the assigned criticality FEP list for TSPA-LA that resulted from the planned work scope are further described in Section 6.1.

All of the NUREG-1804 acceptance criteria specified in *Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002* (BSC 2004 [DIRS 166964], Table 4) have not been addressed as many of these criteria were determined not to be relevant to this document. The acceptance criteria that have been determined to be relevant are presented in Table 4.2-2. The acceptance criteria deemed to be not relevant to this document (model and design criteria) are listed in Table 1.1-1. Additionally, the results of this analysis are utilized in the resolution of Key Technical Issue (KTI) Agreements CLST (Container Lifetime and Source Term) 5.03, 5.05, 5.06, and 5.07.

Table 1.1-1. Non-Relevant Yucca Mountain Review Plan Acceptance Criteria

YMRP Section	Acceptance Criterion
System Description and Demonstration of Multiple Barriers: Areas of Review (NRC 2003 [DIRS 163274], Section 2.2.1.1.3)	**Acceptance Criterion 3:** Technical Basis for Barrier Capability is Adequately Presented.
Scenario Analysis and Event Probability: Identification of Events with Probability Greater than 10^{-8} per Year (NRC 2003 [DIRS 163274], Section 2.2.1.2.2.3)	**Acceptance Criterion 3:** Probability Model Support is Adequate. **Acceptance Criterion 4:** Probability Model Parameters Have Been Adequately Established.
Model Abstraction Degradation of Engineered Barriers (NRC 2003 [DIRS 163274], Section 2.2.1.3.1.3)	**Acceptance Criterion 1:** System Description and Model Integration Are Adequate.
Model Abstraction Mechanical Disruption of Engineered Barriers (NRC 2003 [DIRS 163274], Section 2.2.1.3.2.3)	**Acceptance Criterion 1:** System Description and Model Integration Are Adequate.
Model Abstraction Mechanical Disruption of Engineered Barriers (NRC 2003 [DIRS 163274], Section 2.2.1.3.3.3)	**Acceptance Criterion 1:** System Description and Model Integration Are Adequate. **Acceptance Criterion 3:** Data Uncertainty is Characterized and Propagated Through the Model Abstraction.
Model Abstraction Radionuclide Release Rates and Solubility Limits (NRC 2003 [DIRS 163274], Section 2.2.1.3.4.3)	**Acceptance Criterion 1:** System Description and Model Integration Are Adequate. **Acceptance Criterion 3:** Data Uncertainty is Characterized and Propagated Through the Model Abstraction.
Model Abstraction Radionuclide Transport in the Unsaturated Zone (NRC 2003 [DIRS 163274], Section 2.2.1.3.7.3)	**Acceptance Criterion 3:** Data Uncertainty is Characterized and Propagated Through the Model Abstraction
Model Abstraction Radionuclide Transport in the Saturated Zone (NRC 2003 [DIRS 163274], Section 2.2.1.3.9.3)	**Acceptance Criterion 3:** Data Uncertainty is Characterized and Propagated Through the Model Abstraction
Acceptance Criteria (NRC 2003 [DIRS 163274], Section 2.5.1.3)	**Acceptance Criterion 3:** The Activities Related to Design Control are Acceptable Provided that: …

1.2 SCOPE

The scope of this report is to describe, evaluate, and document screening decisions and technical bases for the criticality FEPs for TSPA-LA. For FEPs that are included in the TSPA-LA, this analysis provides a TSPA-LA disposition, which is a consolidated summary of how the FEP has been included and addressed in the TSPA-LA model, based on the various supporting technical analysis reports and model reports (collectively, AMRs) that describe the inclusion of the FEP. It also provides a list, or reference roadmap, of the specific supporting technical AMRs that provide more detailed discussions of the FEP. For FEPs that are excluded from the TSPA-LA, this analysis report provides a screening argument, which identifies the basis for the screening decision (i.e., low probability, low consequence, or by regulation) and discusses the technical basis that supports that decision. It also provides appropriate references to project and non-project information that supports the exclusion.

In cases where a FEP covers multiple technical areas and is shared with other FEP analysis reports, this analysis report provides only a partial technical basis for the screening decision as it relates to criticality concerns. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP analysis reports. This information is provided in Section 6.8 and subsequent sections and subsections

An overview of the YMP FEP analysis and scenario development process is available in *The Development of the TSPA-LA Features, Events, and Processes* (BSC 2004, Sections 2.4, 3, and 4 [DIRS 168706]), describing the TSPA-LA FEP identification and screening process that led to the development of the LA FEP List documented in DTN: MO04075SEPFEPLA.000 ([DIRS 170760]). Changes in the FEP list, FEP names, and FEP descriptions can also be traced through that report. The criticality FEPs addressed in this report form a subset of the revised LA FEP List. These FEPs are listed in Table 1.2-1, including the designation of shared FEPs.

Direct inputs supporting the screening decisions are listed in Section 4. Indirect inputs supporting the screening decisions are listed in Section 6.1. The individual FEP discussions providing identification (FEP number, name, and description) and screening (screening decision, screening argument or TSPA disposition) information are in Section 6.8.

Table 1.2-1. Criticality FEPs List to be Utilized in Criticality Screening Analysis

FEP Number	FEP Name	FEP Description
Base Case FEPs		
2.1.14.15.0A	In-package criticality (intact configuration)	The waste package internal structures and the waste form remain intact. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ. In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.1.14.16.0A	In-package criticality (degraded configurations)	The waste package internal structures and the waste form may degrade. If a critical configuration (sufficient fissile material and neutron moderator, lack of neutron absorbers) develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.1.14.17.0A	Near-field criticality	Near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.2.14.09.0A	Far-field criticality	Far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.

Table 1.2-1. Criticality FEPs List to be Utilized in Criticality Screening Analysis (Continued)

FEP Number	FEP Name	FEP Description
Seismic Disruptive Event FEPs		
2.1.14.18.0A	In-package criticality resulting from a seismic event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a seismic disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.
2.1.14.19.0A	In-package criticality resulting from a seismic event (degraded configurations)	Either during, or as a result of, a seismic disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.20.0A	Near-field criticality resulting from a seismic event	Either during, or as a result of, a seismic disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.10.0A	Far-field criticality resulting from a seismic event	Either during, or as a result of, a seismic disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
Rock Fall Disruptive Event FEPs		
2.1.14.21.0A	In-package criticality resulting from rock fall (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a rock fall event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ. 2.1.14.14.0A
2.1.14.22.0A	In-package criticality resulting from rock fall (degraded configurations)	Either during, or as a result of, a rock fall event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.23.0A	Near-field criticality resulting from rock fall	Either during, or as a result of, a rock fall event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.11.0A	Far-field criticality resulting from rock fall	Either during, or as a result of, a rock fall event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Table 1.2-1. Criticality FEPs List to be Utilized in Criticality Screening Analysis (Continued)

FEP Number	FEP Name	FEP Description
Igneous Disruptive Event FEPs		
2.1.14.24.0A	In-package criticality resulting from an igneous event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after an igneous disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.
2.1.14.25.0A	In-package criticality resulting from an igneous event (degraded configurations)	Either during, or as a result of, an igneous disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.26.0A	Near-field criticality resulting from an igneous event	Either during, or as a result of, an igneous disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.12.0A	Far-field criticality resulting from an igneous event	Either during, or as a result of, an igneous disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Source: DTN: MO0407SEPFEPLA.000 ([DIRS 170760])

1.3 SCIENTIFIC ANALYSIS LIMITATIONS AND USE

The intended use of this analysis report is to provide FEP screening information for a project specific FEP database, and to promote traceability and transparency for both included and excluded criticality FEPs. This analysis report is intended for use as the source documentation for inclusion or exclusion of criticality FEPs within or from the TSPA-LA model. The following limitations apply to this analysis report:

- Because this analysis report cites other AMRs and controlled documents as direct input, the limitations of this analysis report inherently include any limitations or constraints described in the cited AMRs or controlled documents.

- For screening purposes, this analysis report generally uses mean values of probabilities, mean amplitude of events, or mean value of consequences (e.g., mean time to waste package degradation) as a basis for reaching an include/exclude decision. Mean values are determined based on the range of possible values.

- The results of the FEP screening presented herein are specific to the repository design and processes for YMP available at the time of the TSPA-LA. Changes in direct inputs listed in Section 4.1, in baseline conditions used for this evaluation, or in other subsurface conditions, will need to be evaluated to determine whether the changes are within the limits stated in the FEP evaluations. Engineering and design changes are subject to evaluation to determine whether there are any adverse impacts to safety, as codified at 10 CFR 63.73 and in Subparts F and G ([DIRS 156605]). (See also the requirements at 10 CFR 63.44 ([DIRS 156605]).

- Only specific information and data for the 21–Pressurized Water Reactor (PWR) Absorber Plate, 12–PWR Absorber Plate, 44–Boiling Water Reactor (BWR) Absorber Plate, 24–BWR Absorber Plate, and 5–Defense High-Level Radioactive Waste (DHLW)/U.S. Department of Energy (DOE) Short waste package types are utilized. Assumptions (which require confirmation) are utilized to extend the probability evaluation to the 21–PWR Control Rod, 5–DHLW/DOE Long and 2–Multi-Canister Overpack (MCO)/2–DHLW waste package types.

- The inputs used to establish probabilities for this analysis are based on information and data for the TSPA-LA, where available. Assumptions requiring confirmation and/or verification are utilized when TSPA-LA specific information is not available.

1.4 IMPLEMENTATION OF DISPOSAL CRITICALITY ANALYSIS METHODOLOGY

The criticality FEPs screening analysis implements the disposal criticality analysis methodology as outlined in *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). An overview of the disposal criticality analysis methodology is presented in Figure 1-1. The criticality FEPs screening analysis uses the configuration generator (BSC 2004 [DIRS 168552]) to provide a systematic process to develop and evaluate the potential criticality scenarios of each waste package/waste form combination. The development of potential criticality scenarios is based on the standard configuration classes of the Master Scenario List (Box 1 of Figure 1-1) (YMP 2003 [DIRS 165505], Section 3.3). These criticality scenarios have been identified as having the most likely potential to increase the reactivity of an in-package or external system.

The configuration generator uses an event tree methodology to develop and define end states that represent the configuration classes derived from criticality scenarios. As is documented in this analysis, the characteristics of the waste form, waste package, drip shield and repository (Boxes 2, 3, and 4), as well as the geochemical performance characteristics (Box 5), are used to develop the configuration generator inputs used in the development and quantification of the configuration classes applicable to each waste package/waste form combination (Boxes 6 and 7). A configuration class is considered to have *potential for criticality* if the probability of configuration class formation is above the probability screening criterion (Box 8). This criterion is used to screen from further consideration configuration classes that contribute insignificantly to the total probability of a criticality occurring in the repository during the period of regulatory concern. For this analysis, a value of 10^{-15} is set as the probability screening criterion as utilized for SAPHIRE sequence evalutions. This value is the lowest limit that can maintain any significant digits with double precision arithmetic on PC hardware. Configuration classes with probabilities below this cutoff threshold have a negligible contribution to the total probability per package of criticality and are discarded. The reactivity of configuration classes with probabilities above the cutoff threshold are assessed (Box 9). If the reactivity of the configuration class satisfies the criticality acceptance criterion, i.e., its k_{eff} range does not exceed the critical limit (Box 10), then this configuration class does not have any criticality potential and is discarded. The *probability of criticality* (Box 11), derived from the probability values of the range of configuration class parameters, is evaluated only for configuration classes that exceed the criticality potential criterion, i.e., have a k_{eff} range exceeding the critical limit for the waste form.

After establishing the inputs for waste package/waste form combinations, the configuration generator has the capability of processing all waste package/waste form combinations individually or as a group (Boxes 7 through 15). The analysis results are not impacted by the processing method. Once all waste package/waste form combinations are evaluated, the probabilities from the individual waste package/waste form configuration classes are summed to obtain the total probability per package of criticality for the regulatory period (Box 16). The total probability of criticality is then compared to the design probability criterion of one chance of occurring during the regulatory period (Box 17). If the total probability of criticality is equal to or exceeds the design probability criterion, then a redesign of the waste package or other components is necessary (Box 23) to reduce the total probability of criticality and meet the design probability criterion.

If the total probability per package of criticality is less than the design probability criterion, the total probability is then compared to the regulatory probability criterion for inclusion of events established in 10 CFR 60.114(d) [DIRS 156605] as one chance in 10,000 of occurring during the 10,000-year regulatory period (Box 18). If the total probability per package is less than the regulatory probability criterion, then the repository design is acceptable (Box 22). The criticality evaluations are then complete and criticality excluded from further evaluation in the TSPA. Otherwise, it is necessary to perform criticality consequence evaluations (Box 19) for the development of additional radionuclide source terms for inclusion in the TSPA (Box 20).

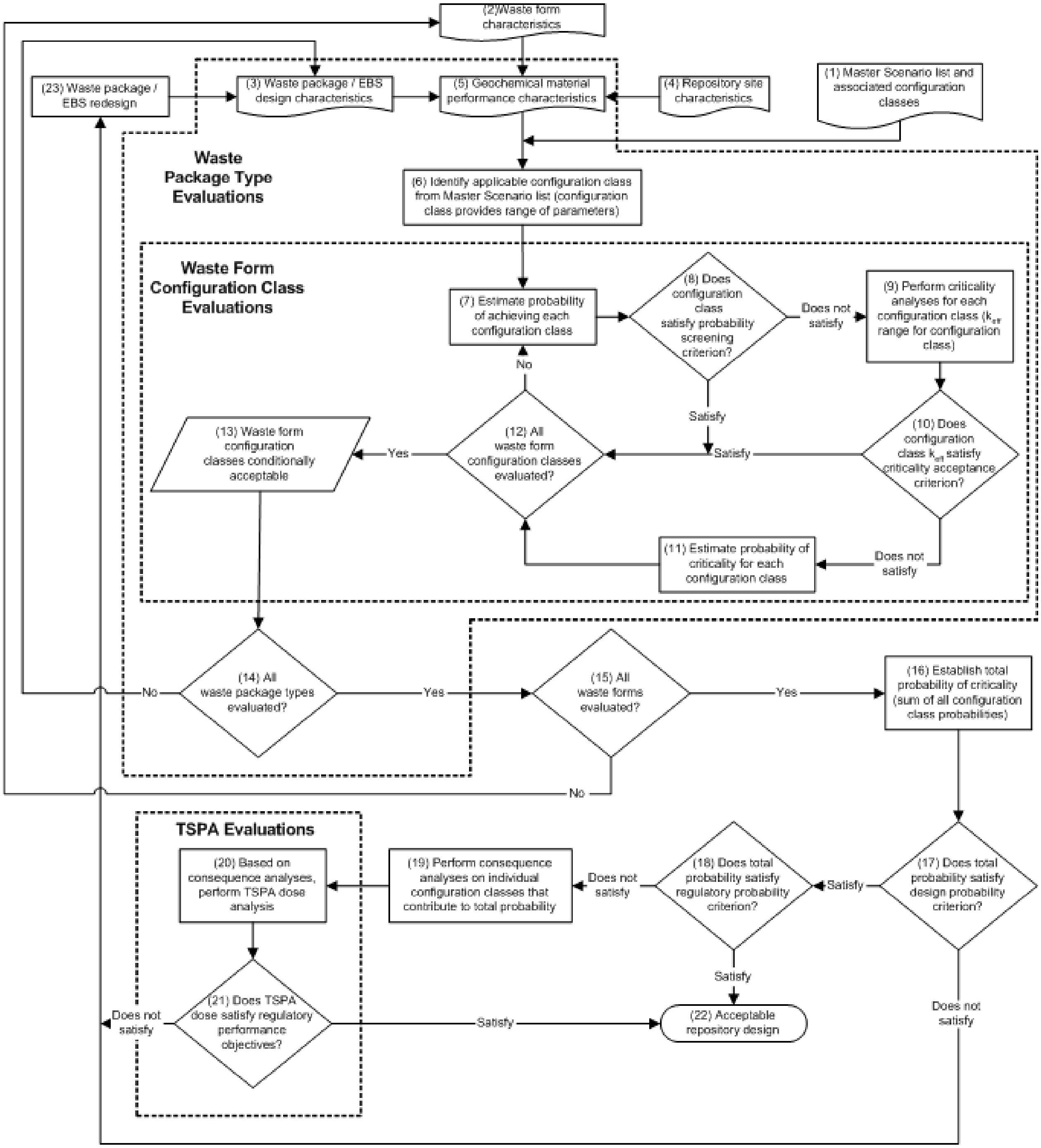

Figure 1-1. Overview of Approach to the Disposal Criticality Analysis Methodology

2. QUALITY ASSURANCE

Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002 (BSC 2004 [DIRS 166964], Section 8) determined that the development of this analysis report and the associated activities are subject to *Quality Assurance Requirements and Description* (DOE 2004 [DIRS 171539]). This report contributes to the analysis and modeling used to support performance assessment. This analysis report investigates the performance of the following natural and engineered barriers that are important to waste isolation:

- Commercial Spent Nuclear Fuel Cladding
- DOE and Commercial Waste Packages
- Emplacement Drift Invert
- Drip Shield
- Saturated Zone (between the repository and the accessible environment)
- Surface Topography, Soils and Bedrock
- Unsaturated Zone above the Repository
- Unsaturated Zone below the Repository
- Waste Form.

Although these barriers are categorized as “Safety Category” in *Q-List* (BSC 2004 [DIRS 171190]), the evaluations and conclusions do not directly impact the features important to safety, defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*. The methods used to control the electronic management of data as required by AP-SV.1Q, *Control of the Electronic Management of Information*, are identified in *Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002* (BSC 2004 [DIRS 166964], Section 8).

Also, in accordance with *Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002* (BSC 2004 [DIRS 166964], Table 1), development of this analysis was controlled by AP-SIII.9Q, *Scientific Analyses*.

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3. USE OF SOFTWARE

3.1 QUALIFIED AND BASELINE SOFTWARE

3.1.1 SAPHIRE

- Title: SAPHIRE
- Version/Revision number: 7.18
- Software Tracking Number (STN): 10325-7.18-00
- Status/Operating System: Microsoft Windows 2000 Professional
- Computer Type: DELL Latitude C640 Laptop PC
  Computer processing unit number: CRWMS M&O Tag number 501215
- Computer Type: DELL OptiPlex GX260 PC
  Computer processing unit number: CRWMS M&O Tag number 152369

The software code SAPHIRE V.7.18 (BSC 2002 [DIRS 160873]) was used to develop and quantify event trees and fault trees in this analysis. SAPHIRE (Systems Analysis Programs for Hands-on Integrated Reliability Evaluations) is a state-of-the-art probabilistic risk analysis software program that utilizes an integrated event tree/fault tree methodology to develop and analyze the logical interactions that may occur between systems and components to determine the probability or frequency of an event's occurrence.

SAPHIRE is qualified software that was obtained from Software Configuration Management. It is appropriate for use in the present analysis, and is used only within its range of validation, in accordance with LP-SI.11Q-BSC, *Software Management*. No limitations have been identified for the output of these analyses resulting from the use of this software.

The event trees, fault trees, and logic rules developed for the SAPHIRE calculations are documented in Appendix B. All of the electronic files necessary for the performance of the SAPHIRE calculation are found in Appendix G (a CD-ROM). The input files in Appendix B allow an independent reproduction of the calculations.

3.2 COMMERCIAL OFF-THE-SHELF SOFTWARE

The following commercial off-the-shelf software programs were utilized in the criticality FEPS screening analysis for the development of the analysis results and conclusions.

3.2.1 EXCEL

- Title: Excel
- Version/Revision number: Microsoft Excel 97 SR-2
- Status/Operating System: Microsoft Windows 2000 Professional
- Computer Type: Latitude C640 Laptop PC
  Computer processing unit number: CRWMS M&O Tag number 501215

Microsoft Excel for Windows, Version 97 SR-2, is used in this analysis to manipulate the inputs using standard mathematical expressions and operations. It is also used to tabulate and chart results. The user-defined formulas, inputs, and results are documented in sufficient detail to allow an independent repetition of computations. Thus, Microsoft Excel is used only as a worksheet and not as a software routine. Microsoft Excel 97 SR-2 is controlled under the Software Configuration Management, but is not required to be qualified as specified in Sections 2.1.1 and 2.1.6 of LP-SI.11Q-BSC, *Software Management*.

Electronic files of the Excel calculations used in this analysis are found in Appendix G (a CD-ROM). The input files in Appendix G allow an independent reproduction of the calculations.

3.2.2 MATHCAD

- Title: Mathcad
- Version/Revision number: Mathsoft Engineering and Education, Inc. Mathcad 2001i Professional
- Status/Operating System: Microsoft Windows 2000 Professional
- Computer Type: DELL OptiPlex GX260 PC
- Computer processing unit number: CRWMS M&O Tag number 152369

Mathcad for Windows 2000, Version “2001i Professional,” is a problem-solving environment used in calculations and analyses. It is also used to tabulate and chart results. The user-defined expressions, inputs, and results are documented in sufficient detail to allow an independent repetition of computations. Thus, Mathcad is used as a worksheet and not as a software routine. Mathcad is controlled under the Software Configuration Management, but is not required to be qualified as specified in Sections 2.1.1 and 2.1.6 of LP-SI.11Q-BSC.

Input and output files for the various Mathcad calculations are documented in Appendices C and D. The electronic files of these calculations are found in Appendix G (a CD-ROM). The input files in Appendix G allow an independent reproduction of the calculations.

4. INPUTS

AP-3.15Q, *Managing Technical Product Inputs*, categorizes technical product input usage as either direct input or indirect input. Direct input is used to develop the results or conclusions in a technical product. Indirect input is used to provide additional information that is not used in the development of results or conclusions. Direct inputs are addressed in this Section. Indirect inputs are addressed in Section 6.1.3.

Section 4.1 identifies all direct inputs used in this report. The direct inputs were obtained from controlled source documents and other appropriate sources in accordance with the controlling procedure AP-3.15Q, *Managing Technical Product Inputs*. Section 4.2 identifies the FEP screening criteria described in 10 CFR Part 63 [DIRS 156605] along with the regulatory derived FEP screening criteria. Section 4.3 identifies codes and standards applicable to the criticality FEPs screening analysis.

4.1 DIRECT INPUTS

The following sections present the direct inputs used to perform the criticality FEPs screening analysis. Use of these data is justified as they are extracted from qualified project sources and their application is compatible with their developed purpose and limitations.

4.1.1 Configuration Generator Event Trees

This report utilizes event tree structures from the *Configuration Generator Model* (BSC 2004 [DIRS 168552]) to perform probability evaluations to support the criticality FEPs screening analysis. The qualified data necessary to develop the event tree probability values are presented throughout Section 4.1. The probability values are developed and evaluated in Sections 6.3 through 6.6. Documentation of the event tree structures used in the criticality FEPs screening analysis is provided in Section 6.2 and Appendix B.

4.1.2 Seepage Rate Information

The seepage rate is determined from the inputs discussed in the *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1, [TBV-6630]). The seepage flux is a function of three parameters: capillary strength ($1/\alpha$), permeability (k), and adjusted percolation flux ($q_{perc,ff}$). The values for each of these parameters will be discussed.

Capillary strength ($1/\alpha$) is developed into two separate distributions, one to account for spatial variability and the second to account for uncertainty (BSC 2004 [DIRS 169131], Section 6.7.1.1, [TBV-6630]). The spatial variability follows a uniform distribution with a mean of 591 Pa, a lower bound of 402 Pa, and an upper bound of 780 Pa. The uncertainty [$\Delta(1/\alpha)$] is represented by a triangular distribution with a mean of 0.0 Pa, a lower bound of -105 Pa, and an upper bound of 105 Pa. These distributions are applicable for all geologic repository zones.

Permeability (k) is developed into two separate distributions, one to account for spatial variability and the other to account for uncertainty. The spatial variability for permeability was statistically analyzed using log-transformed data and found to follow a lognormal distribution (in log 10) (BSC 2004 [DIRS 169131], Section 6.7.1.1, [TBV-6630]). The uncertainty (*Δk*) follows a triangular distribution. Depending on the geologic repository zone, there are different values for the lognormal distribution and the triangular distribution (BSC 2004 [DIRS 169131], Section 6.7.1.1, [TBV-6630]).

Lithophysal zone:
Lognormal distribution mean is -11.5 and standard deviation is 0.47 (in log 10).
Triangular distribution mean is 0.0, lower bound is -0.92, and upper bound is 0.92.

Nonlithophysal zone:
Lognormal distribution mean is -12.2 and standard deviation is 0.34 (in log 10).
Triangular distribution mean is 0.0, lower bound is -0.68, and upper bound is 0.68.

The percolation flux for the glacial transition climate used in this analysis is from DTN: LB0310AMRU0120.002 [DIRS 166116] and is based on the percolation in the repository area only (BSC 2004 [DIRS 169131], Figure 6.6-10, [TBV-6630]). The percolation flux for the glacial transition climate is described using three different scenarios (i.e., lower bound, mean, and upper-bound), which are used in this analysis. The probability associated with the three different percolation flux scenarios are 0.24, 0.41, and 0.35 for the lower bound, mean, and upper bound, respectively (BSC 2003 [DIRS 165991], Section 7, Table 7-1). These probabilities are based on the glacial transition climate excluding the contingency area.

The seepage rate at the drift is then determined from lookup tables based on the three key parameters discussed above. The seepage rates are obtained through interpolation given a capillary strength ($1/\alpha$), permeability (k), and adjusted percolation flux ($q_{perc,ff}$). The seepage rates are from DTN: LB0304SMDCREV2.002 [DIRS 163687] for nondegraded drifts and DTN: LB0307SEEPDRCL.002 [DIRS 164337] for degraded drifts. The seepage rates are adjusted to account for uncertainty. The uncertainty is a factor that follows a uniform distribution having a mean of 0.0 with lower- and upper bound values of ($\mp\sqrt{3}$), respectively.

4.1.3 Mean Annual Seismic Exceedance Frequency Range and Time of Seismic Event

The range of mean annual seismic exceedance frequencies is obtained from DTN: MO0409SPACALSS.005, [DIRS 171833], [TBV-6787], which follows a log-uniform distribution. The mean annual seismic exceedance frequency of concern to the criticality FEPs analysis ranges from 10^{-8} to 10^{-4} per year. The time of occurrence of a seismic event ranges from repository closure through the regulatory period. This range is uniformly distributed from 1 year to 10,000 years (DTN: MO0409SPACALSS.005, [DIRS 171833], [TBV-6787]).

4.1.4 Reserved for Future Use

4.1.5 Reserved for Future Use

4.1.6 Reserved for Future Use

4.1.7 Waste Package and Drip Shield Fabrication Error Probabilities

Waste package and drip shield fabrication and closure process error probabilities have been obtained from *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2004 [DIRS 170024], Table 22). The waste package and drip shield fabrication and closure process error probabilities used in this analysis are presented in Table 4.1-1.

Table 4.1-1. Defect Types to Consider for Waste Package and Drip Shield Performance

Waste Package Defect Type	**Evaluation of Probability per Waste Package**
Weld flaws	See Table 11 through Table 13 of *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2004 [DIRS 170024])
Improper heat treatment grouped with improper laser peening and waste package damaged by mishandling	Lognormal distribution: Median = 7.2×10^{-6} per waste package Mean = 2.8×10^{-5} per waste package error factor = 15 upper truncation value = 7.44213×10^{-3} per waste package
Drip Shield Defect Type	**Main Characteristics**
Weld flaws	Mean number of flaws: 4.1 per drip shield Mean size of flaw: 1.3 mm
Base metal flaws	See Table 18 of *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2004 [DIRS 170024])
Improper heat treatment	Mean probability: 1.3×10^{-5} per drip shield
Damage by mishandling	Mean probability: 4.8×10^{-7} per drip shield

Source: Analysis of Mechanisms for Early Waste Package/Drip Shield Fairlure (BSC 2004 [DIRS 170024], Table 22)

NOTES: Itemized drip shield fabrication defects have non-zero rate and probability values assigned but such defects have no consequences with respect to criticality. No advective flow onto waste packages results from such defects (Section 6.3.3.1.3).

It should be noted that one of the recommendations for modeling waste package damage due to improper heat treatment (grouped with improper laser peening and waste package damaged by mishandling) is to consider the entire waste package surface to be affected (BSC 2004 [DIRS 170024], Section 6.4.8).

Defect probabilities as given in Table 4.1-1 have been translated in failure probabilities through degradation analyses in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2004 [DIRS 169996]). This analysis calculated a probability of 0.17 of having at least one early waste package failure (BSC 2004 [DIRS 169996], Section 6.4.12).

4.1.8 Emplacement Drift Information

Emplacement drift information is required to properly assign seepage information to the two geologic zones – lithophysal and nonlithophysal. The lithophysal and nonlithophysal fractional areas are calculated by dividing the emplacement drift area of both geological zones by the total drift area. The drift emplacement area by geological unit is found in Table 8 of *D&E / PA/C IED Subsurface Facilities* (BSC 2004 [DIRS 168370]). This information is summarized in Table 4.1–2.

Table 4.1-2. Drift Emplacement Area by Geological Unit

Geological Unit	Drift Emplacement Area (square meters)	Reference
Tptpul (lithophysal)	224,398	BSC 2004 [DIRS 168370], Table 8
Tptpmn (nonlithophysal)	616,003	BSC 2004 [DIRS 168370], Table 8
Tptpll (lithophysal)	4,013,268	BSC 2004 [DIRS 168370], Table 8
Tptpln (nonlithophysal)	129,483	BSC 2004 [DIRS 168370], Table 8
Total Lithophysal	4,237,666	sum of rows 1 and 3
Total Nonlithophysal	745,486	sum of rows 2 and 4
TOTAL	4,983,152	sum of rows 5 and 6

Source: *D&E / PA/C IED Subsurface Facilities (*BSC 2004 [DIRS 168370], Table 8)

4.1.9 Waste Package Population

Table 4.1-3 presents the percent breakdown of waste package by type for the 70,000 MTHM limit established for disposal in the MGR. This information is obtained from *Configuration Generator Model* (BSC 2004 [DIRS 168552], Table 6-2, [TBV-6629]). It forms the basis for the assignment of the basic event values for the waste form and waste package type fractions of event tree “WP_TYPE” (Appendix B).

4.1.10 Drip Shield Emplacement Error

Drip shield emplacement errors have been obtained from *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2004 [DIRS 170024], Sections 6.3.7). The sequence of events and their products follow a log-normal distribution. The calculation shows that, although an improperly placed drip shield in the repository to be a probable event, it does not result in an advective flow path through the drip shield and onto the waste package (BSC 2004 [DIRS 170024], Section 6.4.7). The emplacement error probabilities used in this analysis are presented in Table 4.1-4.

Table 4.1-3. Breakdown of 70,000 MTHM Emplacement Inventory by Waste Package Type

Waste Package Number	Waste Package Type	Number of Waste Packages [a]	Fraction of Total Inventory	Number of Waste Packages	Fraction of Total Inventory	Number of Waste Packages	Fraction of Total Inventory
1	21-PWR AP [c]	4,299	0.3821	4,557	0.4051	7,472	0.66418
2	21-PWR CR [d]	95	0.0084				
3	12-PWR AP [e]	163	0.0145				
4	44-BWR AP [f]	2,831	0.2516	2,915	0.2591		
5	24-BWR AP [g]	84	0.0075				
6	DOE1-S [h,s]	5	0.0004	66	0.0059	3,478	0.30916
7	DOE1-L [h,t]	61	0.0054				
8	DOE2-S [i,s]	165	0.0147	165	0.0147		
9	DOE3-S [j,s]	16	0.0014	240	0.0213		
10	DOE3-L [j,t]	4	0.0004				
11	DOE3-MCO [j,u]	220	0.0196				
12	DOE4-S [k,s]	655	0.0582	697	6.0020		
13	DOE4-L [k,t]	42	0.0037				
14	DOE5-S [m,s]	20	0.0018	93	0.0083		
15	DOE5-L [m,t]	73	0.0065				
16	DOE6-L [n,t]	605	0.0538	605	0.538		
17	DOE7-S [o,s]	1,226	0.1090	1,227	0.1091		
18	DOE7-L [o,t]	1	0.0001				
19	DOE8-S [p,s]	14	0.0012	33	0.0029		
20	DOE8-L [p,t]	19	0.0017				
21	DOE9-S [q,s]	8	0.0007	352	0.0313		
22	DOE9-L [q,t]	344	0.0306				
23	NNPP-S [r,s]	144	0.0128	300	0.0267	300	0.02667
24	NNPP-L [r,t]	156	0.0139				
Totals		11,250	1.0000	11,250	1.0000	11,250	1.00000

Source: [a] Configuration Generator Model (BSC 2004 [DIRS 168552, Table 6-2, [TBV-6629])
[b] Reserved for future use

NOTES:
[c] 21-PWR AP – 21-PWR Absorber Plate waste package type
[d] 21-PWR CR – 21-PWR Control Rod waste package type
[e] 12-PWR AP – 12-PWR Absorber Plate waste package type
[f] 44-BWR AP – 44-BWR Absorber Plate waste package type
[g] 24-BWR AP – 24-BWR Absorber Plate waste package type
[h] DOE1 – Mixed Oxide (MOX) DOE SNF; representative fuel type – Fast Flux Test Facility (FFTF)
[i] DOE2 – Uranium-Zirconium Hydride (UzrH) DOE SNF; representative fuel type – TRIGA
[j] DOE3 – Uranium Metal (U-Metal) DOE SNF; representative fuel type – N Reactor
[k] DOE4 – High-Enriched Uranium Oxide (HEU Oxide) DOE SNF; representative fuel type – Shippingport PWR
[m] DOE5 – Uranium/Thorium Oxide (U/Th Oxide) DOE SNF; representative fuel type – Shippingport LWBR
[n] DOE6 – Uranium/Thorium Carbide (U/Th Carbide) DOE SNF; representative fuel type – Fort St. Vrain
[o] DOE7 – Aluminum Based DOE SNF; representative fuel type – Advanced Test Reactor (ATR)
[p] DOE8 – Uranium-Zirconium/Uranium-Molybdenum (U-Zr/U-Mo) Alloy DOE SNF; representative fuel type – Enrico Fermi
[q] DOE9 – Low-Enriched Uranium Oxide (LEU Oxide) DOE SNF; representative fuel type – Three Mile Island II (TMI II)
[r] NNPP – Naval Nuclear Propulsion Program
[s] 5-DHLW/DOE Short waste package type
[t] 5-DHLW/DOE Long waste package type
[u] 2-MCO/2-DHLW waste package type

Table 4.1-4. Probability of Drip Shield Emplacement Error

Event	Event Probability
Failure to properly interlock adjacent drip shields	Mean = 3.75×10^{-3} Median = 3.0×10^{-3} Error factor = 3
Operator fails to detect gap between two improperly placed drip shields	Mean = 2.50×10^{-3} Median = 2.0×10^{-3} Error factor = 3
Combined probability per drip shield	Mean = 9.3×10^{-6} Median = 6.0×10^{-6} Error factor = 4.7 5th percentile = 1.3×10^{-6} 95th percentile = 12.8×10^{-5}

Source: Analysis of Mechanisms for Early Waste Package/Drip Shield Failure (BSC 2004 [DIRS 170024], Section 6.3.7)

4.1.11 Probability of Igneous Events

Eruptive and intrusive igneous events occur with a probability distribution characterized by a mean frequency of 1.7×10^{-8}/yr as stated in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Table 7-1, [TBV-6652]). Given an igneous intrusion into the repository, the conditional probability that one or more eruptive centers will form within the repository boundary is estimated as 0.78 (BSC 2004 [DIRS 169989], Table 7-1, [TBV-6652]), or a frequency of 1.3×10^{-8} per year. The number of eruptive centers of intersecting the repository ranges from zero to 13 with one being the most probable number (BSC 2004 [DIRS 169989], Table 6-11, [TBV-6652]).

The number of waste packages damaged by a system of eruptive conduits is treated as a joint probability, dependent on both the number of conduits and the diameter of the conduits in *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2004 [DIRS 170001], Section 6.4, [TBV-6691]). This analysis concludes that the median number of waste packages hit by conduits is approximately six (BSC 2004 [DIRS 170001], Section 7.2, [TBV-6691]). The median number of waste packages damaged is 1612 (BSC 2004 [DIRS 170001], Table 5, [TBV-6691]).

4.1.12 Longevity of Invert Material

A majority of the drift and invert non-tuff structures are either carbon or alloy steel (BSC 2004 [DIRS 169776]) that have a high corrosion rate. Corrosion tests in humid-air environments indicated that the longevity of these materials could be on the order of 300 years (BSC 2001 [DIRS 155667], Section 7.2), depending upon the thickness of the corrosion-allowance material. The actual longevity of the invert material is assumed to be 1000 years (Assumption 5.2.5) since not filling voids in the invert with corrosion products is conservative.

4.1.13 Probabilities for Waste Package/Waste Form Handling Errors

A waste paeckag selection error during loading operations can occur where a 21–PWR Control Rod waste package is utilized in place of a 21–PWR Absorber Plate waste package since both waste package types are identical in size and configuration. The only difference between them is that the basket assembly of the 21–PWR Control Rod waste package does not contain any neutron absorber material. Misloading errors can occur by incorrectly placing waste form into a waste package (or DOE standardized SNF canister) not designed for that waste form during the preclosure loading process. The probability values assigned to these errors are listed in Table 4.1-5.

Table 4.1-5. Probability of Waste Package Handling Errors

Waste Package Type	Event	Event Probability
21-PWR Absorber Plate Waste Package 21-PWR Control Rod Waste Package[a]	Improper Waste Package Selection	1.394×10^{-6}
21-PWR Absorber Plate Waste Package[b]	Misload	1.18×10^{-5}
21-PWR Control Rod Waste Package[c]	Misload	4.374×10^{-8}
44-BWR Absorber Plate Waste Package[d]	Misload	1.73×10^{-5}
12-PWR Absorber Plate Waste Package[e]	Misload	0.0
24-BWR Absorber Plate Waste Package[e]	Misload	0.0

Source: *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316]):
[a] Table 11, Sequences 13C and 24C
[b] Table 41
[c] Table 11, Sequences 18C, 20C, 29C, and 31C
[d] Table 41
[e] Section 7

4.1.14 Probability for Selection of Improper Material

The possibility exists that the manufacturer could inadvertently select a material that does not have any neutron absorbing properties during the manufacturing of the neutron absorber material for the waste form container (either a waste package or a DOE standardized SNF canister). Analysis of similar type events has been performed for weld and base metal materials in *Analysis of Mechanisms of Early Waste Package/Drip Shield Failure* (BSC 2003 [DIRS 170024], Section 6.2.3). The results of this evaluation were that that use of improper materials followed a log–normal distribution with a median probability of 3.5×10^{-5} and an error factor of 2.3.

4.1.15 Probability of Human Error

Human factor errors have been estimated in *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report* (Swain and Guttmann 1983 [DIRS 139383]). The relevant ones for this FEP screening process are as follows: (1) selection of the wrong basket material, (2) mislabeling of the waste package prior to shipping, (3) failure to correctly perform field measurements of material composition prior to the loading of the waste form, (4) failure to insert the neutron absorber materials for either commercial PWR SNF or

DOE standardized SNF canisters, (5) failure to identify missing neutron absorber materials as the waste form is loaded and the container sealed, and (6) failure to identify misloaded DOE standardized SNF canisters prior to sealing the canisters. The probabilities associated with these errors are given in Table 4.1-6.

Table 4.1-6. Probability of Occurrence for Human Factor Errors

Potential Error Description	Error Category	Probability/Error Factor
Select the wrong basket material	Select wrong control identified by labels only[a]	Median = 3.0×10^{-3} Error Factor = 3.0
Mislabel the waste package prior to shipping	Error in reading and recording quantitative information[b]	Median = 1.0×10^{-3} Error Factor = 3.0
Incorrectly perform field measurements of waste form composition prior to the loading container	Failure to correctly read digital readout[c]	Median = 1.0×10^{-3} Error Factor = 3.0
Failure to insert the neutron absorber materials as required	Failure to correctly follow procedure without a checkoff list or long list used incorrectly[d]	Median = 1.0×10^{-2} Error Factor = 3.0
Failure to identify missing neutron absorber materials as the waste form is loaded and the container sealed	Failure to correctly read digital readout[c]	Median = 1.0×10^{-3} Error Factor = 3.0
Failure to identify misloaded DOE standardized SNF canisters prior to sealing	Failure to correctly read digital readout[c]	Median = 1.0×10^{-3} Error Factor = 3.0

Source: *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report* (Swain and Guttmann 1983 [DIRS 139383]):

[a] Table 20-12, Item 2
[b] Table 20-10, Item 9
[c] Table 20-10, Item 2
[d] Table 20-7, Item 4

4.2 CRITERIA

This section addresses the criteria relevant to the FEP screening process. These criteria stem from the applicable regulations of 10 CFR Part 63 [DIRS 156605], as identified in the *Project Requirements Document* (PRD) (Canori and Leitner 2003 [DIRS 166275]). These criteria are expanded upon and expressed as specific NRC acceptance criteria in *Yucca Mountain Review Plan, Final Report* (NRC 2003, [DIRS 163274], Sections 2.2.1.2.1.3 and 2.2.1.2.2.3).

4.2.1 Projects Requirements Document

The *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275]) documents and categorizes the regulatory requirements and other project requirements and provides a crosswalk to the various YMP organizations that are responsible for ensuring that the criteria have been addressed in the License Application. The regulatory requirements include criteria relevant to performance assessment activities, in general, and to FEP-related activities as they pertain to performance assessment, in particular. Table 4.2-1 provides a listing of the requirements from *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275]) that are applicable to the criticality FEPs screening analysis and how this document addresses these requirements.

4.2.2 Yucca Mountain Review Plan (YMRP)

The bases for the NRC review of the License Application and its acceptance are described in *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]). The FEP-related acceptance criteria and how this document addresses these criteria are presented in Table 4.2-2. The acceptance criteria for FEP screening echo the regulatory screening criteria of low probability and low consequence, but also allow for exclusion of a FEP if the process is specifically excluded by the regulations (refer to Section 4.2.3).

Table 4.2-1. Applicable Project Requirements

Requirement Number and Title	Requirement Text	Rationale for Requirement	How Requirement Addressed
PRD-002/T-015[a] Requirements for Performance Assessment	For complete requirement text, refer to 10 CFR 63.114 [DIRS 156605]	Regulation 10 CFR 63.114 [DIRS 156605] specifies technical requirements to be used in a performance assessment to demonstrate compliance to 10 CFR 63.113 [DIRS 156605]. It includes requirements for calculations, including data related to site geology, hydrology, and geochemistry; the need to account for uncertainties and variabilities in model parameters; the need to consider alternative conceptual models; and technical bases for inclusion or exclusion of specific features, events, and processes (FEPs); deterioration or degradation processes of engineered barriers; and all the models used in the performance assessment. The Performance Assessment organization is responsible for developing and using TSPA calculations, methods, models, and processes that comply with the requirements of this section.	This report provides the technical bases for excluding criticality FEPs. The technical basis is provided in Section 6.8.
PRD-002/T-034[b] Limits on Performance Assessments	For complete requirement text, refer to 10 CFR 63.342 [DIRS 156605]	This section states that the license applicant's performance assessments should not include very unlikely FEPs, defined as those that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal. Furthermore, this section states that the performance assessments need not evaluate the impacts of sequences of FEPs with a higher chance of occurrence if the results of the earlier performance assessments would not be changed significantly. The Performance Assessment organization is responsible for incorporating these limits on performance assessments into its analytical models, methods, and activities.	This report provides the screening so as to not include very unlikely FEPs, defined as those that are estimated to have less than one chance in 10,000 of occurring within 10,000 years after closure, in the performance assessments. The screening is provided in Section 6.8.
PRD-013/T-016[c] DOE SNF Canister Criticality Potential Postclosure	The methodology defined in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]) shall be used to demonstrate acceptable criticality control for canisters and the waste packages in which they are disposed.	This requirement specifies the method by which acceptable criticality control is demonstrated for the [DOE standardized SNF] canisters and the waste packages for postclosure.	This report documents the partial implementation of the methodology from *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). The complete methodology is not used because the partial application excludes criticality. The implementation is provided in Sections 6.2 through 6.7

Table 4.2-1. Applicable Project Requirements (Continued)

PRD-013/T-023[d] Naval SNF Canister Criticality Potential Postclosure	The methodology defined in the NNPP addendum (Mowbray 1999 [DIRS 149585]) to the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]) shall be used to demonstrate acceptable criticality control for canisters and the waste packages in which they are disposed.[f]	The methodology in the NNPP addendum demonstrates the method by which acceptable postclosure criticality control is demonstrated for the waste packages with NNPP canisters. NNPP is directly responsible for completing the postclosure in-package criticality analysis of naval SNF waste packages and supplying the results to DOE. NNPP will also provide the results of the fissile material loss from waste packages source term calculations to the DOE for any out-of-package criticality analyses that may be needed.	The methodology in the NNPP Technical Support Document for the License Application (Mckenzie 2004 [DIRS 170742]) applies to naval SNF in lieu of the methodology provided in this report.”
PRD-013/T-038[e] Disposable Commercial- Origin DOE SNF Canister Criticality Potential Postclosure	The methodology defined in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]) shall be used to demonstrate acceptable criticality control for canisters and the waste packages in which they are disposed.	The methodology in the Topical Report demonstrates the method by which acceptable postclosure criticality control is demonstrated for canisters and waste packages in a repository.	This report documents the partial implementation of the methodology from *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). The complete methodology is not used because the partial application excludes criticality. The implementation is provided in Sections 6.2 through 6.7

Source: Canori and Leitner 2003 [DIRS 166275]

NOTES:

[a] Requirement basis is 10 CFR 63.114 and 63.113 [DIRS 156605] and YMP-RD 3.3.4.19 (YMP 2001 [DIRS 156713])

[b] Requirement basis is 10 CFR 63.342 [DIRS 156605]

[c] Requirement basis is WASRD 4.3.12.B (DOE 2002 [DIRS 158873])

[d] Requirement basis is WASRD 4.4.13.B (DOE 2002 [DIRS 158873])

[e] Requirement basis is WASRD 4.5.13.B (DOE 2002 [DIRS 158873])

[f] Although “Requirement Text” references the NNPP addendum (Mowbray 1999 [DIRS 149585]), this document is to be superceded by NNPP’s Technical Support Document for the License Application (McKenzie 2004 [DIRS 170742])

Table 4.2-2. Relevant Yucca Mountain Review Plan Acceptance Criteria

YMRP Section	Acceptance Criterion	Description	How Addressed in this Analysis Report
Scenario Analysis and Event Probability: Scenario Analysis (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3)	**Acceptance Criterion 1:** The Identification of a List of Features, Events, and Processes Is Adequate.	(1) The Safety Analysis Report contains a complete list of features, events and processes, related to the geologic setting or the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers) that have the potential to influence repository performance. The list is consistent with the site characterization data. Moreover, the comprehensive features, events, and processes list includes, but is not limited to, potentially disruptive events related to igneous activity (extrusive and intrusive); seismic shaking (high-frequency-low-magnitude, and rare large-magnitude events); tectonic evolution (slip on existing faults and formation of new faults); climatic change (change to pluvial conditions); and criticality.	(1) The list of criticality FEPs and FEP descriptions are provided in Section 1.2. See Section 6.1.1 of this analysis report for a description and origin of the criticality FEP list and descriptions. This analysis report does not address climatic change.
	Acceptance Criterion 2: Screening of the List of Features, Events, and Processes Is Appropriate.	(1) The U.S. Department of Energy has identified all features, events, and processes related to either the geologic setting or to the degradation, deterioration, or alteration of engineered barriers (including those processes that would affect the performance of natural barriers) that have been excluded	(1) See Table 7.2-1 for a list of excluded criticality FEPs.
		(2) The U.S. Department of Energy has provided justification for those features, events, and processes that have been excluded. An acceptable justification for excluding features, events, and processes is that either the feature, event, and process is specifically excluded by regulation; probability of the feature, event, and process (generally an event) falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment; and	(2) See the method and approach discussion provided in Section 6.1.2 and the individual justification (by regulation, low probability, low consequence) for excluding FEPs. The justification is also included in Table 7.2-1.
		(3) The U.S. Department of Energy has provided an adequate technical basis for each feature, event, and process, excluded from the performance assessment, to support the conclusion that either the feature, event, or process is specifically excluded by regulation; the probability of the feature, event, and process falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment.	(3) See Section 6.8 for discussion of the individual FEP screening arguments and supporting technical bases.

Table 4.2-2. Relevant Yucca Mountain Review Plan Acceptance Criteria (Continued)

YMRP Section	Acceptance Criterion	Description	How Addressed in this Analysis Report
Scenario Analysis and Event Probability: Identification of Events with Probability Greater than 10^{-8} per Year (NRC 2003 [DIRS 163274], Section 2.2.1.2.2.3)	**Acceptance Criterion 1:** Events Are Adequately Defined.	(1) Events or event classes are defined without ambiguity and used consistently in probability models, such that probabilities for each event or event class are estimated separately; and.	(1) See the FEP description provided for each FEP in Section 6.8.
		(2) Probabilities of intrusive and extrusive igneous events are calculated separately. Definitions of faulting and earthquakes are derived from the historical record, paleoseismic studies, or geological analyses. Criticality events are calculated separately by location.	(2) Probabilities associated with seismic and igneous disruptive events are taken into account in the criticality FEPs analyses of Sections 6.4 and 6.6, respectively.
	Acceptance Criterion 2: Probability Estimates for Future Events Are Supported by Appropriate Technical Bases.	(1) Probabilities for future natural events have considered past patterns of the natural events in the Yucca Mountain region, considering the likely future conditions and interactions of the natural and engineered repository system. These probability estimates have specifically included igneous events, faulting and seismic events, and criticality events.	(1) Probabilities associated with seismic and igneous disruptive events (including faulting) are taken into account in the criticality FEPs analyses of Sections 6.4 and 6.6, respectively.
	Acceptance Criterion 5: Uncertainty in Event Probability Is Adequately Evaluated	(1) Probability values appropriately reflect uncertainties. Specifically: (a) The U.S. Department of Energy provides a technical basis for probability values used, and the values account for the uncertainty in the probability estimates; and (a) The uncertainty for reported probability values adequately reflects the influence of parameter uncertainty on the range of model results (i.e., precision) and the model uncertainty, as it affects the timing and magnitude of past events (i.e., accuracy).	(1) The report addresses uncertainty in probability values by accounting for uncertainty in the model outputs used to develop the probability values. The uncertainty in model outputs used to develop probabilities is discussed in Section 6.4. Specifically: (a) The report provides a technical basis for probability values used (Sections 6.3 through 6.6 and Appendix C), and the values account for the uncertainty in the probability estimates (b) The uncertainties are not reported separately for probability values. The probability values are based on results that incorporate the parameter uncertainty from the model results and model uncertainty.

4.2.3 FEPs Screening Criteria

The criteria for determining low probability, low consequence, or by regulation exclusions are described below.

4.2.3.1 Low Probability

The low-probability criterion is stated in 10 CFR 63.114(d) [DIRS 156605]:

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

and supported by 10 CFR 63.342 [DIRS 156605]:

> The Department of Energy's (DOE) performance assessments shall not include consideration of very unlikely features, events, or processes, i.e., those that are estimated to have less than one chance in 10,000 of occurring within 10,000 years of disposal.

As noted in Assumption 5.1.18, the low-probability criterion for very unlikely events corresponds to an annual exceedance probability of 10^{-8} over the 10,000-year regulatory period for naturally occurring, time-independent FEPs. For time-dependent FEPs, such as criticality, the regulation [10 CFR 63.114(d)] is also expressed as a total probability criterion equivalent to 10^{-4} for the 10,000-year regulatory period.

4.2.3.2 Low Consequence

The low consequence criterion is stated in 10 CFR 63.114 (e and f) [DIRS 156605]:

> (e) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes in the performance assessment. Specific features, events, and processes must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, 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 radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, would be significantly changed by their omission.

and supported by 10 CFR 63.342 [DIRS 156605]:

> DOE's performance assessments need not evaluate the impacts resulting from any features, events, and processes or sequences of events and processes with a higher chance of occurrence if the results of the performance assessments would not be changed significantly.

Some FEPs have a beneficial effect on the TSPA, as opposed to an adverse effect. As identified in 10 CFR 63.102(j) [DIRS 156605], the concept of a performance assessment includes that:

> The features, events, and processes considered in the performance assessment should represent a wide range of both beneficial and potentially adverse effects on performance (e.g., beneficial effects of radionuclide sorption; potentially adverse effects of fracture flow or a criticality event). Those features, events, and processes expected to materially affect compliance with 10 CFR 63.113(b) [DIRS 156605] or be potentially adverse to performance are included, while events (event classes or scenario classes) that are very unlikely (less than one chance in 10,000 over 10,000 years) can be excluded from the analysis. …

The *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1), states that:

> In many regulatory applications, a conservative approach can be used to decrease the need to collect additional information or to justify a simplified modeling approach. Conservative estimates for the dose to the reasonably maximally exposed individual may be used to demonstrate that the proposed repository meets U.S. Nuclear Regulatory Commission regulations and provides adequate protection of public health and safety. …The total system performance assessment is a complex analysis with many parameters, and the U.S. Department of Energy may use conservative assumptions to simplify its approaches and data collection needs. However, a technical basis … must be provided.

On the basis of these statements, those FEPs that are demonstrated to have only beneficial effects on the radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, can be excluded on the basis of low consequence because they have no adverse effects on performance.

4.2.3.3 Regulation

Yucca Mountain Review Plan, Final Report (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3, Acceptance Criterion 2) allows for exclusion of a FEP if the process is specifically excluded by the regulations. To wit:

> The DOE has provided justification for those FEPs that have been excluded. An acceptable justification for excluding FEPs is that either the FEP is specifically excluded by regulation; probability of the FEP (generally an event) falls below the regulatory criterion; or omission of the feature, and process does not significantly change the magnitude and time of the resulting radiological exposures to the

reasonably maximally exposed individual, or radionuclide releases to the accessible environment.

4.3 CODES AND STANDARDS

The following codes have been cited in this analysis:

- 10 CFR Part 63 [DIRS 156605]. Energy: *Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada*.

The following standards are applicable to criticality FEPs screening evaluations:

- ASTM B 932-04. 2004 [DIRS 168403]. Standard Specification for Low-Carbon Nickel-Chromium-Molybdenum-Gadolinium Alloy Plate, Sheet, and Strip.

The following standard, ASTM B 932-04, is used in addition to the those identified in *Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002* (BSC 2004 [DIRS 166964] because of the TMRB-2004-009 (BSC 2004 [DIRS 169959]) baseline change after issuance of BSC 2004 [DIRS 166964].

5. ASSUMPTIONS

5.1 GENERAL CRITICALITY FEPS ANALYSIS ASSUMPTIONS

The following general assumptions are used in the development of inputs for the criticality FEPs screening analysis.

5.1.1 Waste Package Localized Corrosion Failures

Assumption: It is assumed that 10 percent of the waste packages fail due to localized corrosion processes.

Rationale: Drip shield failure is defined as drip shield damage, which results in an advective flow path through the drip shield and onto the waste package outer barrier. Waste package failure is defined as any breach of a waste package, regardless of the mechanism, that can result in either a diffusive or advective flow path through the waste package outer barrier.

The chemistry required to induce localized corrosion, low pH combined with high chloride concentrations, is unlikely to exist in large quantities in the repository. These chemistries can exist on the waste package by direct seepage onto the waste package or by the presence of dust with soluble salts on the waste package, which can cause water condensation. For direct seepage onto the waste package, there must be drip shield separation, which only occurs from fault displacement during a seismic event. The nominal seepage and dust chemistries are not severe enough to cause localized corrosion, as shown in Figures 6.13-4 through 6.13-12 for seepage and Figures 6.13-20 through 6.13-23 for dust in *Engineered Barriers System: Physical and Chemical Environment Model* (BSC 2004 [DIRS 170905]). *Engineered Barriers System: Physical and Chemical Environment Model* (BSC 2004 [DIRS 170905], Table 6.13-1) indicates that bin 1 and 2, the most extreme bins, will not seep into the repository, and bin 3, which has the next most extreme chemistry, has less than a 1% probability of occurring. The remaining situation that could cause localized corrosion is if the chloride and nitrate from seepage waters were to separate as the seepage runs down the outside of the waste package. For such separation to occur, the relative humidity (RH) must be below 77% (BSC 2004 [DIRS 170905], Section 6.11.2). However, once the drift wall has cooled to 100ºC such that water can seep into the drift, the RH surrounding the vast majority of the waste packages is well above 77% as shown in *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565], Section 6.3.13). Therefore, though the choice of 10% of the waste packages is somewhat arbitrary, it is likely that the vast majority of waste packages will not fail due to localized corrosion.

Confirmation Status: The actual number of failed waste package outer barriers from localized corrosion must be determined from TSPA-LA analyses. Confirmation of this assumption will be accomplished through completion and verification of the TSPA-LA analyses that calculate the localized corrosion effects on the waste package outer barrier system.

Use in the Analysis: This assumption is used in Sections 6.3.3.1.3, 6.3.3.1.5, 6.3.3.1.10, 6.4.1.1.1, 6.4.2.1.10, 6.8.2, 6.8.3, 6.8.4, 6.8.10, and 7.3.2.

5.1.2 Loading Curves for Commercial SNF Waste Packages

Assumption: It is assumed that loading curve evaluations for the 21–PWR Control Rod, 12-PWR Absorber Plate, and 24–BWR Absorber Plate waste package design variants will demonstrate results similar to those obtained for the 21–PWR Absorber Plate and 44–BWR Absorber Plate design variants.

Rationale: A basic waste package design is used for all commercial waste forms anticipated for disposal in the repository, but has a number of variants to accommodate particular waste forms (BSC 2004 [DIRS 169472]). The three referenced waste package types are designed to prevent criticality for intact and degraded in-package conditions.

Confirmation Status: This assumption requires confirmation to be provided through completion of waste form loading curve evaluations. Demonstration of the no-criticality potential for the waste package design variations is through the performance of the loading curve evaluations.

Use in the Analysis: This assumption is used in Section 6.2.

5.1.3 Design of Control Rods for the 21–PWR Control Rod Waste Package

Assumption: It is assumed that the 21–PWR Control Rod waste package will use zirconium clad, boron carbide (B_4C) control rods for reactivity control as described in *Determination of Waste Package Design Configurations* (CRWMS M&O 1997 [DIRS 100224], Section 7.3.2).

Rationale: The control rod design is similar to the referenced zirconium clad B_4C rods that exhibit low corrosion rates and adequate control characteristics.

Confirmation Status: This assumption requires confirmation to be provided through completion of waste package design.

Use in the Analysis: This assumption is used in Sections 5.1.6, 6.3.3.1.8, and 7.3.1.

5.1.4 Probability of Human Error in Waste Package Fabrication

Assumption: It is assumed that the use of generic human reliability analysis values for evaluating fabrication errors, e.g., neutron absorber misloads, generate more limiting (i.e., higher probability of failure) results than are expected during actual waste package fabrication.

Rationale: Generic human reliability analyses, of necessity, include sample distributions in their studies of the performance of basic operations that are drawn from a general population. Thus, the samples likely include a number of individuals with little or no training on the particular processes or operations. Fabrication processes for QA or any other type of manufacturing control require training on the processes. Thus, in general, the rate of operational errors for such specialized processes are likely to be lower than rates from operations performed by generic populations.

Confirmation Status: This assumption requires confirmation to be provided from fabrication and operational training requirements.

Use in the Analysis: This assumption is used in Section 6.3.3.1.8.

5.1.5 Receipt of Fabricated Waste Package Components

Assumption: It is assumed that hardware suppliers may obtain contracts to manufacture both the 21–PWR Absorber Plate and 21–PWR Control Rod waste packages. It is further assumed that these waste packages will contain the basket assembly within the waste package when received at the repository.

Rationale: Because procurement requirements may not allow segregation of bidders by waste package type, it is possible that a manufacturer could fabricate both 21-PWR Absorber plate and 21-PWR Control rod waste packages. Likewise, in such cases, cost as well as shipping logistics would likely be minimized by assembling the internal structures of these waste packages prior to shipping. With the same manufacturer fabricating both waste packages, potential misload situations can develop through human error and non-recovery processes during the manufacturing process.

Confirmation Status: This assumption requires confirmation to be obtained from procurement activities.

Use in the Analysis: This assumption is used in Section 6.3.3.1.8.

5.1.6 Degradation of Neutron Absorber Material in the 21–PWR Control Rod Waste Package

Assumption: It is assumed that the neutron absorber material in the 21–PWR Control Rod waste package will not degrade during the regulatory period.

Rationale: The 21–PWR Control Rod waste package is designed for PWR commercial SNF that does not meet the loading curve criteria for placement in the 21–PWR Absorber Plate waste package. The 21–PWR Control Rod waste package uses zirconium clad, boron carbide (B_4C) control rods for reactivity control (CRWMS M&O 1997 [DIRS 100224], Section 7.3.2) (Assumption 5.1.3). These control rods are to be inserted into each assembly guide tube location prior to waste package loading. The zirconium cladding of the control rods is the same as the Zircaloy used for the manufacturing of fuel rod cladding. Under normal conditions, Zircaloy-clad fuel rods remain intact beyond the regulatory period because Zircaloy cladding is highly resistant to corrosion (Hillner, et al. 1998 [DIRS 100455], Abstract). Because the zirconium cladding of the control rods is unirradiated and is thicker than the fuel rod cladding, its durability and corrosion resistance is expected to be even greater than that of the Zircaloy cladding of the fuel rods. In addition, because the zirconium control rod cladding is expected to be thicker than fuel pin cladding and the controls are protected by the fuel assembly guide tubes, it is unlikely that the control rod cladding is damaged during seismic events. Therefore, it is assumed that the neutron absorber materials of the 21–PWR Control Rod waste package cannot be flushed from the waste package during the regulatory period.

Confirmation Status: This assumption requires confirmation from analyses that include the 21–PWR Control Rod waste package.

Use in the Analysis: This assumption is used in Section 5.1.10 and 7.3.1.

5.1.7 Waste Form Misload Criticality Potential

Assumption: It is assumed that the waste package configuration resulting from a waste form misload has a criticality potential. The criticality potential of DOE SNF misloads is assumed to be 1.00. The criticality potential of commercial SNF misloads is based on the evaluations of the possible waste package misload scenarios.

Rationale: The resulting increase in fissile material that results from the misload of a waste form will increase the reactivity of a waste package system. The resulting increase in reactivity will increase the potential for criticality of the resulting configuration. Two waste form/waste package types have been identified as having the potential for misload – the 21-PWR Absorber Plate (BSC 2004 [DIRS 171414]) and the 5-DHLW/DOE Long with MOX DOE SNF (CRWMS M&O 1999 [DIRS 125206]).

Confirmation Status: This assumption requires confirmation to be obtained by completion of evaluations of misload potential.

Use in the Analysis: This assumption is used in Sections 6.4.2.2.10 and 6.4.2.3.6.

5.1.8 Waste Package Quality Control Inspection

Assumption: It is assumed that quality control inspections will be performed on fabricated components as they arrive at the repository site. These inspections are assumed to include examinations, e.g., X-ray spectroscopy, that have the capability for performing quick field measurements of material composition.

Rationale: Although the waste package fabrication processes will be under a quality control procedure, there is still the possibility of failures to perform the operations correctly. The quality control inspection at the point of receipt will help minimize the probability of incorrect material and component usage.

Confirmation Status: This assumption requires confirmation that will be done when the operational procedures are finalized.

Use in the Analysis: This assumption is used in Section 6.3.3.1.8.

5.1.9 Corrosion Rate of Neutron Absorbing Material

Assumption: It is assumed that the corrosion rates for the neutron absorbing material, Ni-Gd alloy (UNS N06464) (ASTM B 932-04 2004 [DIRS 168403]) are similar to Ni-Cr alloy (UNS N06455).

Rationale: The composition of the principal constituents of the Ni-Gd alloy (ASTM B 932-04 2004 [DIRS 168403], Table 1) is similar to that of Ni-Cr alloy (UNS N06455). Thus, the general corrosion characteristics are expected to be similar. The major difference is the possible behavior of the gadolinium (Gd). Short term tests (~1 year) indicate that gadolinium degrades preferentially if present in the alloy as a connected matrix (BSC 2004 [DIRS 169959]). However, fabrication specifications (BSC 2004 [DIRS 169959]) require the gadolinium to be in a non-connected matrix to prevent such preferential degradation.

Confirmation Status: This assumption requires confirmation to be obtained from testing and fabrication specifications.

Use in the Analysis: This assumption is used in Sections 6.3, 6.4.2.2.3, 6.4.2.2.5, 6.4.2.2.6, 6.4.2.3.4, 6.4.2.4.1, 6.8.2 and 6.8.3.

5.1.10 Loading of Control Rods in Assemblies for the 21–PWR Control Rod Waste Package

Assumption: It is assumed that B_4C control rods (Assumption 5.1.3) are included in all assemblies identified for loading into the 21–PWR Control Rod waste package.

Rationale: PWR assemblies that do not meet the reactivity criteria for loading into the 21–PWR Absorber Plate waste package are designated for loading into the 21–PWR Control Rod waste package. Placement of control rods in all assemblies is potentially a requirement since the criticality potential of this waste package/waste form has not been determined.

Confirmation Status: This assumption requires confirmation to be obtained from analyses of the 21–PWR Control Rod waste package.

Use in the Analysis: This assumption is used in Section 6.3.3.1.8.

5.1.11 RESERVED FOR FUTURE USE

5.1.12 No Drip Shield or Waste Package Failures from Generalized Corrosion or Stress Corrosion Cracks within Regulatory Period

Assumption: It is assumed that there will be no failures due to generalized corrosion or stress corrosion cracks of either the drip shield or waste package outer barrier material that could allow advective flow during the 10,000-year period of regulatory concern.

Rationale: For general corrosion, from *General Corrosion and Localized Corrosion of the Waste Package Outer Barrier* (BSC 2004 [DIRS 169984], Section 8.1), a bounding analysis clearly demonstrates that the waste package performance in the repository is not limited by general corrosion. For stress corrosion cracks, a bounding analysis (BSC 2004 [DIRS 169985], Section 8.3), shows that the final closure lid weld stress mitigated layer is deep enough to extend the lifetime of the waste package well beyond 10,000 years. (See definition of drip shield and waste package failure in Section 5.1.1)

Confirmation Status: Confirmation of this assumption is required and will be obtained through the completion and verification of the TSPA-LA model that calculates the effects of general corrosion and stress corrosion cracking of the drip shield and waste package outer barrier.

Use in the Analysis: This assumption is used in Sections 6.3.3.1.3, 6.3.3.1.5, 6.4.2.1.3, 6.4.2.1.5, and 7.3.2.

5.1.13 Misload Probability for DOE SNF Waste Forms

Assumption: It is assumed that the misload probability for DOE SNF waste forms in the DOE standardized SNF canister will not exceed the probability calculated for commercial SNF waste package types.

Rationale: The probability of a waste form misload is proportional, among other things, to the number of units placed into a waste package. The maximum misload probability assigned to commercial SNF waste package types is 1.18×10^{-5} for the 21–PWR Absorber Plate waste package (Table 4.1-9). Thus, the misload probability for the MOX DOE SNF (the only DOE waste form with misload potential) waste form in the DOE standardized SNF canister is set at 1.18×10^{-5}. This assumption is conservative.

Confirmation Status: This assumption does not require confirmation.

Use in the Analysis: This assumption is used in Section 6.3.3.1.9.

5.1.14 RESERVED FOR FUTURE USE

5.1.15 Waste Package Verification Inspection

Assumption: It is assumed that a separate independent verification inspection will be performed prior to waste package loading to confirm that the correct waste package configuration type is selected for loading.

Rationale: Independent verification inspections are common practice for nuclear quality assurance operational procedures.

Confirmation Status: This assumption requires confirmation to be obtained when operational procedures are finalized.

Use in the Analysis: This assumption is used in Section 6.3.3.1.8.

5.1.16 Neutron Absorber Material Misload Criticality Potential

Assumption: Waste package configurations with neutron absorber material misloads are assumed to have a probability of 1.0 of having criticality potential.

Rationale: It is conservative to assume that waste package configurations with neutron absorber material misloads have criticality potential with a probability of 1.0.

Confirmation Status: This assumption does not require confirmation.

Use in the Analysis: This assumption is used in Sections 6.4.2.2.10, 6.4.2.3.6, and 6.6.2.4.7.

5.1.17 RESERVED FOR FUTURE USE

5.1.18 Low Probability Screening Criterion

Assumption: For naturally occurring, time-independent FEPs, it is assumed that regulations expressed as a probability criterion can be expressed as an annual-exceedance probability, which is defined as the probability that a specified value (such as for ground motions or fault displacement) will be exceeded during one year. More specifically, the stated probability screening criterion of one chance in 10,000 in 10,000 years ($10^{-4}/10^{4}$ yr) criterion is assumed equivalent to a 10^{-8} annual-exceedance probability over the 10,000-year regulatory period.

Rationale: The definition of annual exceedance probability is taken from *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (BSC 2004 [DIRS 168030], Glossary). The assumption of equivalence of annual-exceedance probability is appropriate if the possibility of an event is equal for any given year. This satisfies the definition of a Poisson distribution as "…a mathematical model of the number of outcomes obtained in a suitable interval of time and space, that has its mean equal to its variance…" (Merriam-Webster 1993 [DIRS 100468], p. 899). This is inferred to mean that naturally occurring, infrequent, and independent events, can be represented as stochastic processes in which distinct events occur in such a way that the number of events occurring in a given period of time depends only on the length of the time period. The use of this assumption is justified in *Characterize Framework for Seismicity and Structural Deformation at Yucca Mountain, Nevada* (BSC 2004 [DIRS 168030], Section 6.4.2), which indicates that assuming that the behavior of the earth is generally Poissonian or random is the underlying assumption in all probabilistic hazard analyses.

Although there may be cases where sufficient data and information exist to depart from this assumption, the Poissonian model is generally an effective representation of nature and represents a compromise between the complexity of natural processes, availability of information, and the sensitivity of results of engineering relevance. Consequently, for geologic processes that occur over long time spans, assuming annual equivalence over a 10,000-year period (a relatively short time span for geologic-related events) is reasonable and consistent with the basis of probabilistic hazard analyses. Therefore, no further confirmation is required.

For time-dependent events, such as criticality, an annual exceedance probability criterion is unrealistic as the initiating events required to cause a criticality event are equally likely to occur in year one as in year ten thousand. For a criticality initiating event occurring in year 10,000, an annual probability value of zero would be calculated for the first 9999 years and an annual probability of one calculated for the year 10,000. This would violate the annual exceedance probability criterion of 10^{-8} in year 10,000.

Therefore, for time-dependent FEPs, the use of a total probability criterion, not to be exceeded over the entire regulatory period, is more applicable. The total probability criterion is 10^{-4} for the 10,000-year regulatory period.

Confirmation Status: This assumption does not require confirmation.

Use in the Analysis: This assumption is used in Section 4.2.3.1.

5.2 SEISMIC CRITICALITY FEPS ANALYSIS ASSUMPTIONS

The following assumptions are used in the development of inputs for the criticality FEPs screening analysis of the seismic disruptive event.

5.2.1 RESERVED FOR FUTURE USE

5.2.2 RESERVED FOR FUTURE USE

5.2.3 RESERVED FOR FUTURE USE

5.2.4 Condensation Flux From Drip Shields

Assumption: It is assumed that any condensation flux within the drip shield region is a negligible contributor to waste package flooding.

Rationale: In the absence of seepage, the only sources of water are condensation and atmospheric humidity. *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565], Sections 5.6 and 6.3.3) indicates that, because of the fracture density, drainage from the drift is not significantly impeded, inferring that pooling in the invert thus cannot occur.

Condensation on the underside of the drip shield may occur, as discussed in *In-Drift Convection and Condensation Model* (BSC 2004 [DIRS 164327], Section 8.3). However, from the geometry of the drip shield/waste package system, only a small fraction (on the order of 10%) of condensate liquid present on the underside of the drip shield can drip onto the waste packages since the source must originate near the drip shield crown to affect the waste packages. Furthermore, source locations of condensation do not correlate with failure locations on the waste package outer barrier. Therefore, condensation represents a minor contributor to any liquid that might drip into breached waste packages, relative to seepage flux. This conclusion is also consistent with *Engineered Barrier System Features, Events, and Processes* (BSC 2004 [DIRS 169898], Section 6.2.41) which states that condensate waters present on the underside of the drip shield have a small potential to drip onto exposed waste packages.

Where seepage or condensation does occur, the flux into a failed waste package is only of concern for those waste packages that have potential for criticality, a majority of which are CSNF waste packages. These latter waste packages also have the largest decay heat sources to support evaporation, increasing the seepage flux required to flood these waste packages. This minimizes the contribution of very low seepage rates to the overall criticality potential.

Confirmation Status: This assumption requires confirmation to be obtained by completion of analysis.

Use in the Analysis: This assumption is used in Sections 6.3.3.1.4 and 6.4.2.1.4.

5.2.5 Drift Material Degradation

Assumption: It is assumed that the drift material, e.g., grids, rails, etc., are degraded by 1000 years.

Rationale: A majority of the drift and invert non-tuff structures are either carbon or alloy steel that have a high corrosion rate. Corrosion tests in humid-air environments indicated that the longevity of these materials could be on the order of 300 years (BSC 2001 [DIRS 155667], Section 7.2). Using 1000 years for the longevity of carbon steel is conservative as it allows for a longer period before voids in the invert are filled with corrosion products that will prevent significant accumulation of released fissile materials from breached waste packages.

Confirmation Status: This assumption does not require further confirmation.

Use in the Analysis: This assumption is used in Sections 6.4.2.8.4 and 6.6.2.8.4.

5.2.6 RESERVED FOR FUTURE USE

5.2.7 Probability of Waste Package Failures Forming a Bathtub

Assumption: It is assumed that all waste package failure conditions associated with localized corrosion mechanisms allowing for advective flow will result in the formation of a bathtub configuration.

Rationale: There are two waste package failure modes that allow for advective flow – bathtub and flow-through (see Section 6.1.1 for description of configurations). The flow-through mode results in an under-moderated configuration that has a small possibility of in-package criticality, but increases the potential for external criticality by providing a more direct pathway for the transport of fissile material to the near-field and far-field environments. A bathtub mode will result in a higher likelihood of in-package critical configuration formation due to its higher neutron moderation capability. Information is currently not available for the determination of the formation and duration of bathtub and flow-through configurations during the regulatory period.

Although waste package damage initiated by seismic events is expected to occur over the entire surface of the waste package, it is conservative to assume that the damage on other than the top surface remains in a diffusive mode or becomes plugged with corrosion products, effectively limiting the waste package failure to a bathtub mode.

Eventually, however, the bathtub configuration will transition to a flow-through configuration as the bottom surface fails due to corrosion mechanisms. The formation of a flow-through configuration limits the duration of the bathtub configuration and, thus, limits the potential for internal criticality. However, formation of the flow-through configuration increases the potential for external criticality by providing a more direct path for the transport of fissile material to the near-field and far-field environments.

Confirmation Status: This assumption does not require confirmation since assuming that damage to waste packages from seismic events results in bathtub configurations is a conservative approach. Waste package failures from seismic activity are only predicted for fault displacement events that are expected to damage both top and bottom surfaces of the waste package, in which event, bathtub configurations would be precluded.

Use in the Analysis: This assumption is used in Sections 6.4.2.1.6, 6.4.2.1.7, and 6.4.2.2.8.

5.3 ROCK FALL CRITICALITY FEPS ANALYSIS ASSUMPTIONS

No assumptions are required to evaluate the rock fall disruptive event criticality FEPs.

5.4 IGNEOUS CRITICALITY FEPS ANALYSIS ASSUMPTIONS

The following assumptions are used in the development of inputs for the criticality FEPs screening analysis of the igneous disruptive event.

5.4.1 RESERVED FOR FUTURE USE

5.4.2 RESERVED FOR FUTURE USE

5.4.3 RESERVED FOR FUTURE USE

5.4.4 RESERVED FOR FUTURE USE

5.4.5 Characterization of Igneous Events

Assumption: *It is assumed that any eruptive igneous event that intersects the repository has both effusive and pyroclastic phases lasting throughout the duration of the event erupting volcanic tephra in a range of sizes from large clasts to very fine grained material.*

Rationale: Volcanic activity typically consists of gas and effusive Strombolian and violent Strombolian phases. Strombolian activity is characterized by short-duration bursts that throw relatively coarse fragments of melt out of the vent on ballistic trajectories, where most of the fragments are deposited immediately around the vent with only a small fraction of finer particles rising higher and being dispersed by wind to form minor fallout sheets (BSC 2004 [DIRS 169980], Section 6.3.3.6.1). In contrast, the most violent type of Strombolian activity is characterized by vertical eruption of a high-speed jet of a gas-clast mixture and fragments or clasts tend to be finer gained. The near-vent ballistic component is small and tephra dispersal in a wind-blown convective plume dominates, according to the conceptual model (Jarzemba, et al. 1997 [DIRS 100987], p. 2−1) used for ASHPLUME (BSC 2004 [DIRS 170026], Section 6.5). This assumption maximizes the dispersal for contaminants for Strombolian activity. This assumption is part of the assumptions incorporated in the ASHPLUME model of igneous events (BSC 2004 [DIRS 170026], Section 5.1.1).

Confirmation Status: This assumption does not require further confirmation.

Use in the Analysis: This assumption is used in Section 6.6.

5.4.6 Interaction of Eruptive Igneous Events with Waste Packages

Assumption: It is assumed that the waste packages adjacent to an eruptive conduit will remain in place in the magma-filled drift and will not be captured by the ascending magma in the eruption conduit (BSC 2004 [DIRS 170001] Section 5.3). This assumption applies only to non-vitrified waste.

Rationale: The waste packages are expected to deform rather than disintegrate in the presence of magma (BSC 2004 [DIRS 170028], Section 6.4.8.1). The waste packages have a greater density than the magma {waste package mean density is in the range of 2940-4280 kg/m^3 (BSC 2004 [DIRS 169472], Table 1) whereas molten magma has a density ranging from 2474 to 2663 kg/m^3 (BSC 2004 [DIRS 169980], Table 6-4)}. It is thus reasonable to assume that the waste packages that are adjacent to the conduit will most likely remain in place in the magma-filled drift and will not be captured by the ascending magma in the eruption conduit as a result of drain back or melt (BSC 2004 [DIRS 170028], Section 6.4.8.2).

Confirmation Status: This assumption does not require further confirmation.

Use in the Analysis: This assumption is used in Section 6.6.

5.4.7 Magmatic Intrusion into Impacted Waste Packages

Assumption: It is assumed that intrusive magma flowing around a waste package will not significantly flood or flush through the waste package.

Rationale: Intact waste packages are not expected to rupture from internal pressure due to heating from the magma (CRWMS M&O 1999 [DIRS 121300]). Rather, they are expected to deform and slump downward (BSC 2004 [DIRS 170028], Section 6.4.8.1). It is expected that the width of any crack opening on the outer surface will be on the order of several millimeters, but could possibly range from 0.1 mm to 10 mm wide, extending a meter or more in length, and penetrate the waste package outer barrier (BSC 2004 [DIRS 170028], Section 6.4.8.1).

Even if magma were to penetrate a waste package, the magma outside of the waste package is expected to stagnate once the drift has filled {on the order of 1000 seconds (BSC 2004 [DIRS 170028, Section 6.4.7.5)} so that there are not likely to be driving forces that would result in flow through a waste package. Thus it can be concluded that, in the absence of a major failure of a waste package, significant amounts of magma will not flow through the waste package, and that the waste form will remain in place (BSC 2004 [DIRS 170028], Section 6.4.8.1).

Confirmation Status: This assumption does not require further confirmation.

Use in the Analysis: This assumption is used in Sections 6.6.2.2.3 and 6.6.2.4.4.

5.4.8 RESERVED FOR FUTURE USE

5.4.9 RESERVED FOR FUTURE USE

5.4.10 Waste Form Pulverized

Assumption: In a violent Strombolian eruption, the waste packages within the conduit are assumed to be destroyed and the waste form pulverized (BSC 2004 [DIRS 170026], Section 5.2.4).

Rationale: Waste interaction has been evaluated in two stages. The first addresses the performance of the waste package in an igneous event and the second addresses the assumptions for waste materials fragmentation when exposed during an igneous event.

Dike/Drift Interactions (BSC 2004 [DIRS 170028], Section 6.4.9) evaluated the impact of magma on the waste package. Because of the limited data available, the report stated that: "it would be proper to adopt the conservative position that all waste packages and associated drip shields that come in contact with basalt magma immediately and totally fail."

The rationale for estimating the waste-particle size is given in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2004 [DIRS 170026], Section 5.2.4). "Experimental evidence is lacking for processes capable of fragmenting spent nuclear fuel in a volcanic eruption. … From the foregoing, and in the absence of data that more specifically represents interaction of magma with spent fuel, the Ashplume [sic] model assumes that fuel in the affected waste packages is available for entrainment in the ash plume as finely-divided particles with diameters in the range of 1 to 500 micrometers, with a mean of 20 micrometers."

Confirmation Status: This assumption does not require further confirmation.

Use in the Analysis: This assumption is used in Section 6.6.2.2.1.

5.4.11 RESERVED FOR FUTURE USE

5.4.12 Post-Igneous Near-field Fissile Material Accumulation

Assumption: It is assumed that after an igneous event, seepage water is expected to be reestablished and flow through repository contacting the basalt, and undergo chemical interactions with the basalt (BSC 2004 [DIRS 170028], Section 6.8). No known mechanism exists for fissile material accumulation in this process.

Rationale: The chemistry of water seeping into the magma-filled drifts after cool down to less than boiling conditions is considered to be unaltered but could be affected by basalt-water as the seepage of water passes the magma in the drift (BSC 2004 [DIRS 170028], Section 6.8). As water moves from the tuff into the cooled basalt, the environment is likely to become more reducing. The impact of this on the waste form is unknown. As given in Assumption 5.5.3, there are no mechanisms in the external fields that can cause appreciable precipitation of fissile material. Thus, the post-igneous environment is not considered to support appreciable precipitation of fissile material.

In the presence of magma, chemical interactions between waste forms and the magma, and the waste forms and the metal of the waste canisters or assemblies and cladding could occur. Because the extent of development of mineral phases is unknown, the waste is considered chemically unchanged. If the waste were to react with the magma and cladding, the resulting phases would be less soluble than unaltered waste.

Confirmation Status: This assumption does not require further confirmation.

Use in the Analysis: This assumption is used in Sections 6.6.2.6.2, 6.6.2.6.3, 6.6.2.6.4, 6.6.4, and 6.8.15.

5.5 EXTERNAL CRITICALITY FEPS ANALYSIS ASSUMPTIONS

The following fissile material accumulation assumptions are used in the development of inputs for the in the external (near-field and far-field) criticality FEPs screening analyses for the seismic and igneous disruptive events.

5.5.1 Franklin Lake Accumulation

Assumption: It is assumed that, over the period of regulatory concern, insufficient fissile material could be transported and accumulated in the organic-rich zones of the Franklin Lake region to result in a potentially critical configuration.

Rationale: This is a reasonable assumption based on the following evaluation of: (1) transport distance from Yucca Mountain to Franklin Lake; and (2) groundwater dilution along the flow path.

Czarnecki (1997 [DIRS 158810]) shows the potentiometric surface in the Amargosa Desert that indicates a continuous flow system in the Alluvial Aquifer from Fortymile Wash near the Yucca Mountain accessible environment to the discharge area at Franklin Lake. Using the flow field of Czarnecki (1997 [DIRS 158810]) there is a flow path from the Yucca Mountain repository to Franklin Lake Playa. Such a flow path would pass through the alluvium of the Amargosa Desert for about 45 km from a point near the boundary of the Yucca Mountain accessible environment to Franklin Lake Playa. Using the groundwater specific discharge in the alluvium at the accessible environment which ranges from 1.2 to 9.4 m/yr and the range of effective porosity of 0.0 to 0.35 (BSC 2004 [DIRS 170042], Section 6.5.2), the range in groundwater velocity is 4.3 to 1.8×10^2 m/yr. The corresponding travel time for 45 km ranges from 3.8×10^2 to 1.0×10^4 years. Of the radionuclides that potentially could migrate along the flow path, consider the potential for uranium and plutonium with mean values of sorption coefficients of 4.6 and 100 ml/g, respectively (DTN: LA0310AM831341.002, [DIRS 165891]). Their retardation coefficients (using bulk density of 1.9 g/ml and total porosity of 0.3) range from a low of 30 for uranium to a high of 6.3×10^2 for plutonium. Their travel times range from 1.1×10^4 to 6.6×10^6 years, which exceed the 10,000-year compliance period.

A large amount of dilution would also be expected to occur over that 45 km flow path. Using equation 9.7 of Freeze and Cherry (1979, p 395) with a longitudinal dispersivity of 100 m and transverse dispersivities defined in the saturated zone (SZ) site-scale transport model abstraction (BSC 2004 [DIRS 170042]), the concentrations are estimated to decrease by more than 8 orders of magnitude along the flow path.

Confirmation Status: This assumption does not require confirmation.

Use in the Analysis: This assumption is used in Sections 5.5.2, 6.4.2.12.8, 6.4.2.12.9, 6.6.2.11.8, 6.6.2.11.9, 6.6.4, 6.8.4, 6.8.8, 6.8.12, and 6.8.16.

5.5.2 TSbv Accumulation

Assumption: It is assumed that there are no known fissile material accumulation mechanisms in the altered TSbv (Topopah Spring basal vitrophyre).

Rationale: This is a subcase of Assumption 5.5.3.

Confirmation Status: This assumption requires confirmation that will be obtained upon completion of analyses.

Use in the Analysis: This assumption is used in Sections 6.4.2.10.7, 6.4.2.11.3, 6.4.2.11.6, 6.6.2.9.7, 6.6.2.10.3, 6.6.2.10.6, 6.6.4, 6.8.4, 6.8.8, 6.8.12, and 6.8.16.

5.5.3 Precipitation of Fissile Material in the Unsaturated and Saturated Zones

Assumption: It is assumed that there are no mechanisms in either the unsaturated or saturated zones below the repository that would cause an appreciable precipitation and/or accumulation of fissile material.

Rationale:

Precipitation of Fissile Material in the Unsaturated Zone - The effects of solubility on potential precipitation of uranium and plutonium in the unsaturated zone (UZ) were evaluated using the ranges of temperature, pH, and pCO_2 [log (partial pressure by volume)] expected during the performance period.

The effects of temperature are discussed in *Dissolved Concentration Limits of Radioactive Elements* (BSC 2004 [DIRS 169425], Section 6.3.3.3) where it is stated that uranium and plutonium are expected to have solubilities that increase with decreasing temperature. Hence, radionuclides moving from the repository to cooler environments will tend to keep the radionuclides in solution.

Another factor that will tend to keep these elements in solution is that as the radionuclides move away from the repository, they will mix in water of lower elemental concentrations leading to a dilution effect.

Figures 6.4-16 and 6.4-17 of *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2004 [DIRS 169866]) show the expected variations in pCO_2 and pH, respectively between the repository and the water table. Generally speaking, pCO_2 ranges from a minimum of 3 near the repository to a maximum value of 4.5. The variations in pH are found to be from about 8 near the repository to a minimum values of 7.

For plutonium, the solubility variations going from a pH of 8 and a pCO_2 of 3 at the repository to a pH of 7 and pCO_2 of 4.5 gives the following:

Repository (mg/L)		UZ (mg/L)	
uranium:	40	1	(BSC 2004 [DIRS 169425], Table 6.7-3)
plutonium:	0.006	0.004	(BSC 2004 [DIRS 169425], Table 6.5-3)

As can be seen, plutonium solubility is almost flat spanning the full range of pH and pCO_2 conditions, so the effects of temperature and dilution are expected to keep plutonium in solution during transport through the UZ. However, the effects of pH and pCO_2 on uranium are much larger, showing a reduction in solubility of a factor of 40, which could lead to precipitation of uranium. If uranium precipitation should occur, the mass density of uranium in a precipitate zone may approach 7000 g/L, based on a maximum porosity of 0.35 (BSC 2004 [DIRS 170041], Table 6-3) and a density of solid uranium of 19 g/mL

Precipitation of Fissile Material in the Saturated Zone - Geochemical contrasts in Eh (equilibrium redox potential in volts) in the SZ have the potential for causing precipitation of uranium or plutonium. However, observations in groundwater wells in the Yucca Mountain area indicate that precipitation and accumulation of fissile material in the SZ would not be significant. If significant precipitation of redox sensitive species (such as natural uranium) had occurred in the groundwater system in the past, this would indicate the potential for such accumulation of contaminants from the repository in the future. Specifically, accumulations of natural uranium in the past in the SZ would be observed as anomalies in gamma geophysical borehole logs. No gamma log anomalies indicative of significant natural uranium accumulation have been observed in well logs along the inferred flow path from the repository out to the boundary of the accessible environment (including gamma logs from Nye Co. Early Warning Drilling Program wells EWDP-10P, 10S, 22PA, 22S, 19D, and 19P). Significantly high gamma log readings have been observed in Nye Co. wells EWDP-3D and 3S; however, this well is not along the flow path from Yucca Mountain.

Confirmation Status: This assumption requires confirmation that will be obtained upon completion of analyses.

Use in the Analysis: This assumption is used in Sections 5.4.12, 6.4.2.10.4, 6.4.2.12.2, 6.4.2.12.4, 6.6.2.9.4, 6.6.2.11.2, 6.6.2.11.4, 6.6.4, 6.8.4, 6.8.8, 6.8.12, and 6.8.16.

5.5.4 Sorption of Fissile Material on Clays and Zeolites in the Unsaturated Zone

Assumption: It is assumed that the known quantities of clays and zeolites in the unsaturated zone are insufficient to result in appreciable sorption and accumulation of fissile materials.

Rationale: This is a subcase of Assumptions 5.5.3 and 5.5.5.

Confirmation Status: This assumption requires confirmation that will be obtained upon completion of analyses.

Use in the Analysis: This assumption is used in Sections 6.4.2.10.6, 6.4.2.11.5, 6.6.2.9.6, 6.6.2.10.5, 6.6.4, 6.8.4, 6.8.8, 6.8.12, and 6.8.16.

5.5.5 Accumulation of Fissile Material in Organic-Rich Reducing Zones

Assumption: It is assumed that any fissile material transported to organic-rich reducing zones in the saturated zone is precipitated and accumulates in these zones.

Rationale: It is reasonable to assume that significant accumulation of fissile material could occur in the SZ if organic-rich reducing zones are present. However, there are no observations of organic-rich zones in the SZ along the flow path from the repository (at least out to the boundary of the accessible environment). In addition, any such organic-rich zones in the SZ would have accumulated natural uranium from the groundwater system in the geologic past and would be identified in gamma geophysical borehole logs, as described above in Section 5.5.3.

Confirmation Status: This assumption does not require confirmation.

Use in the Analysis: This assumption is used in Sections 5.5.4, 6.4.2.12.5, 6.4.2.12.6, 6.6.2.11.5, 6.6.2.11.6, 6.6.4, 6.8.4, 6.8.8, 6.8.12, and 6.8.16.

6. SCIENTIFIC ANALYSIS DISCUSSION

The following sections discuss the criticality FEPs analyses. Section 6.1 discusses the methods and approach used for the FEPs screening. Section 6.2 discusses the SAPHIRE analysis used to establish the technical basis for the criticality FEPs screening. The SAPHIRE analysis (summarized in Section 6.2) used to organize the processes and event scenarios and to combine associated probabilities for the criticality FEPs screening analysis was developed specifically for this purpose in *Configuration Generator Model* (BSC 2004 [DIRS 168552]) and is consistent with the TSPA approach to satisfy the regulatory probability criterion and performance objectives. Additionally, these analyses are also appropriate because they address the NRC's acceptance criteria in *Yucca Mountain Review Plan* (NRC 2003 [DIRS 163274]) as previously discussed in Section 4.2, which are applicable to the FEPs discussions provided in Sections 6.3 through 6.8 of this analysis report. Section 6.3 provides the details and results of the base case criticality FEPs screening analysis. Section 6.4 provides the details and results of the seismic disruptive event criticality FEPs screening analysis. Section 6.5 provides the details and results of the rock fall disruptive event criticality FEPs screening analysis. Section 6.6 provides the details and results of the igneous disruptive event criticality FEPs screening analysis. Section 6.7 summarizes the results of Sections 6.3 through 6.6 and Section 6.8 provides the screening discussions for the criticality FEPs.

6.1 METHODS AND APPROACH

The identification and screening of a comprehensive list of FEPs potentially relevant to the postclosure performance of the Yucca Mountain repository is an ongoing, iterative process based on site-specific information, design, and regulations. FEP analysis uses the following definitions, as taken from NRC (2003, Glossary [DIRS 163274]):

feature –	An object, structure, or condition that has a potential to affect disposal system performance.
event –	A natural or human-caused phenomenon that has a potential to affect disposal system performance and that occurs during an interval that is short compared to the period of performance.
process –	A natural or human-caused phenomenon that has a potential to affect disposal system performance and that operates during all or a significant part of the period of performance.

FEP analysis for TSPA-LA is described in BSC (2004 [DIRS 168706]). It is summarized in the following subsections.

6.1.1 Feature Events and Processes Identification

The first step of FEP analysis is FEP identification and classification, which addresses Acceptance Criterion 1 of the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3). The TSPA-LA FEP identification and classification process is described in BSC (2004 [DIRS 168706], Section 3). It produced a version of the LA FEP List (DTN: MO0407SEPFEPLA.000 DIRS [170760]), used in this criticality FEP analysis. Aside from editorial corrections to FEP descriptions, any changes to the FEP list from the information shown in DTN: MO0407SEPFEPLA.000 ([DIRS 170760]) is discussed below.

Table 6.1-1 presents the list of 16 criticality FEPs for TSPA-LA from Table 1.2-1. The "In-package criticality (degraded configurations)" FEPs encompass the configuration classes identified in Figures 3-2a and 3-2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). Figure 3-2a defines in-package bathtub configuration classes (hole at top of waste package and waste package flooded). Figure 3-2b defines in-package flow-through configuration classes (hole at top and bottom of waste package and water flowing through and over waste package internals and waste form).

The "Near-field criticality" FEPs encompass the degraded configuration classes identified in Figure 3-3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]) and the "Far-field criticality" FEPs encompass the configuration classes of Figure 3-3b. The near-field environment is defined as external to the waste package and inside the drift wall (including any drift liner and the invert). The far-field environment is defined as the area beyond the drift wall (i.e., in the host rock of the repository).

Table 6.1-1. Criticality FEPs List to be Utilized in Criticality Screening Analysis

FEP Number	FEP Name	FEP Description
Base Case FEPs		
2.1.14.15.0A	In-package criticality (intact configuration)	The waste package internal structures and the waste form remain intact. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ. In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.1.14.16.0A	In-package criticality (degraded configurations)	The waste package internal structures and the waste form may degrade. If a critical configuration (sufficient fissile material and neutron moderator, lack of neutron absorbers) develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.1.14.17.0A	Near-field criticality	Near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.2.14.09.0A	Far-field criticality	Far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.
Seismic Disruptive Event FEPs		
2.1.14.18.0A	In-package criticality resulting from a seismic event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a seismic disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.

Table 6.1-1. Criticality FEPs List to be Utilized in Criticality Screening Analysis (Continued)

FEP Number	FEP Name	FEP Description
2.1.14.19.0A	In-package criticality resulting from a seismic event (degraded configurations)	Either during, or as a result of, a seismic disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.20.0A	Near-field criticality resulting from a seismic event	Either during, or as a result of, a seismic disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.10.0A	Far-field criticality resulting from a seismic event	Either during, or as a result of, a seismic disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
Rock Fall Disruptive Event FEPs		
2.1.14.21.0A	In-package criticality resulting from rock fall (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a rock fall event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ. 2.1.14.14.0A
2.1.14.22.0A	In-package criticality resulting from rock fall (degraded configurations)	Either during, or as a result of, a rock fall event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.23.0A	Near-field criticality resulting from rock fall	Either during, or as a result of, a rock fall event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.11.0A	Far-field criticality resulting from rock fall	Either during, or as a result of, a rock fall event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
Igneous Disruptive Event FEPs		
2.1.14.24.0A	In-package criticality resulting from an igneous event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after an igneous disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.

Table 6.1-1. Criticality FEPs List to be Utilized in Criticality Screening Analysis (Continued)

FEP Number	FEP Name	FEP Description
2.1.14.25.0A	In-package criticality resulting from an igneous event (degraded configurations)	Either during, or as a result of, an igneous disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.26.0A	Near-field criticality resulting from an igneous event	Either during or as a result of an igneous disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.12.0A	Far-field criticality resulting from an igneous event	Either during, or as a result of, an igneous disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Source: Table 1.2-1

6.1.2 Feature, Event, and Process Screening Process

The second step of FEP analysis is FEP screening, which addresses Acceptance Criterion 2 of the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.2.1.3). The TSPA-LA FEP screening process is described in BSC (2004 [DIRS 168706], Section 4).

For FEP screening, each FEP is screened against the specified exclusion criteria (refer to Section 4.2.3), summarized in the three following FEP screening statements:

1) FEPs having less than one chance in 10,000 of occurring over 10,000 years may be excluded (screened out) from the TSPA on the basis of low probability (as per 10 CFR 63.114(d) [DIRS 156605]).

2) FEPs whose omission would not significantly change the magnitude and time of the resulting radiological exposures to the RMEI, or radionuclide releases to the accessible environment, may be excluded (screened out) from the TSPA on the basis of low consequence (as per 10 CFR 63.114 (e and f) ([DIRS 156605])).

3) FEPs that are inconsistent with the characteristics, concepts, and definitions specified in 10 CFR Part 63 ([DIRS 156605]) may be excluded (screened out) from the TSPA by regulation.

A FEP need only satisfy one of the exclusion screening criteria to be excluded from TSPA. A FEP that does not satisfy any of the exclusion screening criteria must be included (screened in) in the TSPA-LA model.

This analysis report documents the screening decisions for the criticality FEPs. In cases where a FEP covers multiple technical areas and is shared with other FEP AMRs, this analysis report provides only a partial technical basis for the screening decision as it relates to criticality issues. The full technical basis for these shared FEPs is addressed, collectively, by all of the sharing FEP analysis reports.

Documentation of the screening for each FEP is provided in Section 6.8. The following standardized format is used.

> **Section 6.2.x FEP Name** (FEP Number)
>
> **FEP Description:** This field describes the nature and scope of the FEP under consideration.
>
> **Screening Decision:** Identifies the screening decision as one of:
>
> - "Included"
> - "Excluded – Low Probability"
> - "Excluded – Low Consequence"
> - "Excluded – By Regulation"
>
> In a few cases, a FEP may be excluded by a combination of two criteria (e.g., Low Probability and Low Consequence).
>
> **Screening Argument:** This field is used only for excluded FEPs. It provides the discussion for why a FEP has been excluded from TSPA-LA.
>
> **TSPA Disposition:** This field is used only for included FEPs. It provides the consolidated discussion of how a FEP has been included in TSPA-LA, making reference to more detailed documentation in other supporting technical AMRs, as applicable. For excluded FEPs, it is indicated as "Not Applicable."
>
> **Supporting Reports:** This field is only used for included FEPs. It provides the list of supporting technical AMRs that identified the FEP as an included FEP and contain information relevant to the implementation of the FEP within the TSPA-LA model. This list of supporting technical AMRs provides traceability of the FEP through the document hierarchy. For excluded FEPs, it is indicated as "Not Applicable."

6.1.3 Supporting AMRs and Inputs

Indirect inputs used for the criticality FEPs screening analyses are cited within each FEP discussion and use of these inputs has been documented per YMP procedural requirements. Where possible, the indirect inputs used in this analysis report to support the screening decisions were obtained from controlled source documents and references using the appropriate document identifiers or records system accession numbers. Sources of such inputs include, but are not limited to, analyses, models, technical reports, and other YMP documents and databases. As needed, indirect inputs were obtained from literature searches of peer-reviewed journals, other widely recognized scientific periodicals, results of review of YMP documents by external organizations, and other appropriate sources such as technical handbooks and textbooks. A listing of the indirect input used to support the criticality FEPs screening decisions are provided in Table 6.1-2.

Table 6.1-2. Indirect Inputs Used in the Criticality FEPs Screening Analyses

Reference Description	Reference Sections Used	Section Used in	Input Description
Evaluation of Codisposal Viability for MOX (FFTF) DOE-Owned Fuel (CRWMS M&O 1999 [DIRS 125206])	Entire	Table 6.2-1 Sections 5.1.7, 6.8.1 and 6.8.2	Reference to FFTF fuel criticality analyses
Evaluation of Codisposal Viability for UZrH (TRIGA) DOE-Owned Fuel (CRWMS M&O 2000 [DIRS 147650])	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to TRIGA fuel criticality analyses
Evaluation of Codisposal Viability for HEU Oxide (Shippingport PWR) DOE-Owned Fuel (CRWMS M&O 2000 [DIRS 147651])	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to Shippingport PWR fuel criticality analyses
Evaluation of Codisposal Viability for U-Zr/U-Mo Alloy (Enrico Fermi) DOE-Owned Fuel (CRWMS M&O 2000 [DIRS 151742])	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to Enrico Fermi fuel criticality analyses
Evaluation of Codisposal Viability for Th/U Oxide (Shippingport LWBR) DOE-Owned Fuel (CRWMS M&O 2000 [DIRS 151743])	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to Shippingport LWBR fuel criticality analyses
Evaluation of Codisposal Viability for U-Metal (N Reactor) DOE-Owned Fuel (CRWMS M&O 2001 [DIRS 154194])	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to N Reactor fuel criticality analyses
Evaluation of Codisposal Viability for Melt and Dilute DOE-Owned Fuel (BSC 2001 [DIRS 157733])	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to aluminum based fuel criticality analyses
Evaluation of Codisposal Viability for Th/U Carbide (Fort Saint Vrain HTGR) DOE-Owned Fuel (BSC 2001 [DIRS 157734])	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to Fort St. Vrain fuel criticality analyses
Intact and Degraded Mode Criticality Calculations for the Codisposal of TMI-2 Spent Nuclear Fuel in a Waste Package (BSC 2004 [DIRS 168935]).	Entire	Table 6.2-1 Sections 6.8.1 and 6.8.2	Reference to TMI-2 fuel criticality analyses
21-PWR Waste Package with Absorber Plates Loading Curve Evaluation (BSC 2004 [DIRS 171414])	Entire	Sections 5.1.7, 6.2, 6.3.3.1.8, 6.3.3.1.10, 6.4.2.1.10, 6.4.2.2.10, 6.4.2.3.6, 6.8.1, and 6.8.2	Reference to 21-PWR fuel assembly loading curve analyses
44 BWR Waste Package Loading Curve Evaluation (BSC 2004 [DIRS 169963])	Entire	Sections 6.2, 6.3.3.1.10, 6.4.2.1.10, 6.4.2.2.10, 6.4.2.3.6, 6.8.1, and 6.8.2	Reference to 44-BWR fuel assembly loading curve analyses

Table 6.1-2. Indirect Inputs Used in the Criticality FEPs Screening Analyses (Continued)

Reference Description	Reference Sections Used	Section Used in	Input Description
Disposal Criticality Analysis Methodology Topical Report (YMP 2003 [DIRS 165505])	Section 3.3	Section 6.2	Master Scenario List
	Sections 3.7.1.1 and 3.7.2	Section 6.3	Silica moderator
	Figures 3-2a through 3-3b	Tables 6.1-1, 6.3-1, 6.4-1, 6.5-1, and 6.6-1 Sections1.2, 6.1.1, 8.2, 8.3, 8.6, 8.8 8.10, 8.11, 8.12, 8.14, 8.15, and 8.16	Reference to degraded configurations
Criticality Model Report (BSC 2004 [DIRS 168553])	Section 6.3.1	Sections 6.2, 6.3, 6.8.1, and 6.8.2	Definition of critical limit
	Entire	Section 6.2	Reference to criticality model
WAPDEG Analysis of Waste Package and Drip Shield Degradation (BSC 2004 [DIRS 169996])	Sections 6.3.5 and 6.5.2; Figures 22, 23, 24 and 26	Sections 6.3.3.1.3, 6.3.3.1.5, and 6.3.3.2.2	General corrosion failure of the waste package and drip shield and stress corrosion cracking failure of the waste package
Dike/Drift Interactions (BSC 2004 [DIRS 170028])	Section 5.4.2	Section 6.6.2.4.2	Fracture density in basalt
	Sections 6.4.7.5, 6.4.8.1, 6.4.8.2, 6.7.1.2, 6.4.8.3	Sections 5.4.6, 5.4.7, 6.6, 6.6.2.3.1, 6.6.2.3.2; Table 6.1-2	Waste package failure; Tensile strength of the waste package and internal components; Magma temperature; Formation of Zr-Fe and Zr-Ni liquid eutectics; Mixed phases of waste and magma
	Sections 6.4.9, 6.6, 6.6.1, 6.6.5, 6.6.6, 6.7, 6.7.1.2, 6.8, 8.2.3, Appendix D	Sections 5.4.10, 6.6.1, 6.6.2.3.2, 6.8.13, 6.8.14; Table 6.1-2	Igneous impacts on waste packages in Zone 1 and Zone 2; possible impacts from thermal and volatile gases
	Section 6.4.7.5	Sections 6.6, 6.6.2.7.1; Table 6.1-2	Magma flows into drifts
	Section 6.4.7.5	Sections 5.4.7, 6.6, 6.6.2.7.1, 6.6.2.8.2, 6.6.2.8.5, 6.6.2.8.6	Magma levels in drift and time to fill drifts
Characterize Eruptive Processes at Yucca Mountain (BSC 2004 [DIRS 169980])	Sections 6.3.1.1, 6.3.2.2	Section 6.6	Roughly cylindrical conduit eruptions; water content of magma

Table 6.1-2. Indirect Inputs Used in the Criticality FEPs Screening Analyses (Continued)

Reference Description	Reference Sections Used	Section Used in	Input Description
Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain (BSC 2004 [DIRS 170026])	Section 6.5	Section 5.4.5	Reference to conceptual model for ASHPLUME
	Section 5.2.4	Sections 5.4.10, 6.6, 6.6.2.2.1, and 6.8.14	Sections 5.4.10, 6.6, 6.6.2.2.1, and 6.8.14
	Section 5.1.1	Sections 5.4.5 and 6.6	Description of igneous event
	Sections 6.6 and 6.7	Section 6.6.1	Mobility of volcanic gases between drifts
	Figures 1-1 and 7-3	Section 6.6.2.2.3	Dispersal area for eruption
Critical Mass Search Calculation in the Invert (BSC 2004 [DIRS 170060])	entire	Sections 6.1.3, 6.3.2 , and 6.4.3	minimum critical mass in invert
	Entire	Section 6.8.7	Supporting documentation
	entire	Sections 6.4.2.6.5, 6.4.2.7.3, and 6.4.2.8.7	calculated k-eff below the critical limit
Criticality Potential of Waste Packages Affected by Igneous Intrusion. (BSC 2004 [DIRS 171690])	Entire	Section 6.6.3	Criticality potential of waste packages affectied by igneous intrusion
Configuration Generator Model (BSC 2004 [DIRS 168552])	Entire	Executive Summary; Sections 1, 1.4, 4.1.1, 6, 6.2; Appendix B	Reference to Configuration Generator Model, configuration classes, and WP event trees
	Attachment I	Section 6.2, Figures 6.2-1 thru 6.2-5 and B-1 thru B-27	

6.1.4 Qualification of Unqualified Direct Inputs

Direct Inputs are listed in Section 4.1 and any unqualified data are identified by TBV number that documents their qualification.

6.1.5 Assumptions and Simplifications

For included FEPs, the TSPA Dispositions may include statements regarding assumptions made to implement the FEP within the TSPA-LA model. Such statements are descriptive of the manner in which the FEP has been included and are not used as the basis of the screening decision to include the FEP with the TSPA-LA model. Assumptions utilized in the criticality FEPs screening analysis are provided in Section 5.

Because of the individual FEPs are specific in nature, any discussion of applicable mathematical formulations, equations, algorithms, numerical methods, or idealizations or simplifications are provided within the individual FEP discussions in Section 6.2.

6.1.6 Intended Use and Limitations

The intended use of this analysis report is to provide FEP screening information for a project-specific FEP database, and to promote traceability and transparency regarding FEP screening. This analysis report is intended to be used as the source documentation for the FEP database described in BSC (2004, [DIRS 168706]). For included FEPs, this document summarizes and consolidates the method of implementation of the FEP in TSPA-LA in the form of TSPA Disposition statements, based on more detailed implementation information in the listed supporting technical AMRs. For excluded FEPs, this document provides the technical basis for exclusion in the form of Screening Arguments.

Inherent in this evaluation approach is the limitation that the repository is constructed, operated, and closed according to the design used as the basis for the FEP screening and in accordance with NRC license requirements. This is inherent in performance evaluation of any engineering project, and design verification and performance confirmation are required as part of the construction and operation processes. The results of the FEP screening presented herein are specific to the repository design evaluated in this analysis report for TSPA-LA.

Any changes in direct inputs listed in Section 4.1, in baseline conditions used for this evaluation, or in other subsurface conditions, will need to be evaluated to determine if the changes are within the limits stated in the FEP evaluations. Engineering and design changes are subject to evaluation to determine if there are any adverse manner impacts to safety as codified at 10 CFR 63.73 and in Subparts F and G ([DIRS 156605]). See also the requirements in 10 CFR 63.44 ([DIRS 156605]).

6.2 CRITICALITY FEPS SCREENING ANALYSIS

The criticality FEPs screening analysis utilizes the event tree process developed in *Configuration Generator Model* (BSC 2004 [DIRS 168552]) for the evaluation of the overall probability of criticality. The configuration generator identifies the possible pathways required for the development of waste package internal and external configuration classes, evaluates the probability of occurrence for the configuration classes, and provides the configuration class associated parameter ranges to determine the criticality potential of each configuration class.

The configuration classes represented by the event tree process of the *Configuration Generator Model* (BSC 2004 [DIRS 168552], Attachment I) are defined by the Master Scenario List in *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505], Section 3.3). These configuration classes represent flooded, i.e., bathtub, and flow-through waste package configurations, near-field and far-field configurations external to the waste package, and igneous configurations. The event trees of the configuration generator represent the events and processes, both internal and external to the waste package, which are necessary to achieve the configuration classes.

The configuration generator event tree starts with the different waste forms expected to be stored in the monitored geologic repository. The sequences for the various waste forms then transfer, respectively, to their specific configuration generating event trees. These event trees identify the specific waste form along with the degradation processes listed in sequential order, in order to provide the start to finish sequences for the degradation process. The top events on the event tree are the specific processes required for degradation. Branching under the top events (degradation processes) provides a traceable sequence to each configuration class. The different configuration classes are noted on the configuration generator event tree with their respective end states. Note that to reach a specific end state, the degradation-related processes in that sequence must occur.

The various end states of a configuration class are evaluated for their potential for criticality without necessarily quantifying the probability of achieving such a state. End states of a configuration class are marked as having potential for criticality if their essential parameters have values in the range that can support criticality. The sequences to those particular end states are then backtracked to assess the probabilities that the parameters can actually have the requisite values. Summing these probabilities is the method for estimating the probability of occurrence of a configuration class. The probability of criticality is set to zero for all end states of configuration classes that are not marked as having potential for criticality.

The waste package/waste form must degrade in some manner to achieve a potentially critical configuration. This is because intact, fully flooded waste package conditions are precluded from achieving criticality by design to satisfy a preclosure operations requirement that the repository provide means to ensure criticality control during SNF/HLW handling operations, including waste package loading (Curry 2004 [DIRS 170557], Requirement 1.1.6-4). If this requirement is satisfied, in situ criticality in an intact configuration (criticality FEPs 2.1.14.15.0A, 2.1.14.18.0A, 2.1.14.21.0A, or 2.1.14.24.0A) cannot occur.

It has been previously demonstrated through loading curve analyses for the 21–PWR Absorber Plate and the 44–BWR Absorber Plate waste package types that an intact, fully flooded waste package configuration cannot achieve criticality (BSC 2004 [DIRS 171414] and BSC 2004 [DIRS 169963], respectively). To satisfy Requirement 1.1.6-4 (Curry 2004 [DIRS 170557]), similar analyses must be performed for the remaining commercial SNF waste package types. Analyses have also been previously performed for all nine of the representative DOE SNF waste forms that demonstrate subcriticality of these waste package types for intact, fully flooded conditions. The references for these analyses are listed in Table 6.2-1. Future loading curve evaluations of the remaining three commercial SNF waste package types are expected to demonstrate similar results (Assumption 5.1.2).

The final logical evaluation point is to assess the criticality probability for each configuration class. Using the criticality model (BSC 2004 [DIRS 168553]) and the configuration class characteristics defined by the configuration generator evaluations, detailed criticality analyses are performed to determine the effective neutron multiplication factor (k_{eff}) for the range of parameters associated with each configuration class. If the calculated k_{eff} is below a prescribed critical limit (BSC 2004 [DIRS 168553], Section 6.3.1) for the entire range of parameters, the configuration class has no criticality potential. If the calculated k_{eff} is above a prescribed critical limit for some or all of the range of parameters, then the probability of achieving these parameter ranges is assessed. The probability of achieving these parameter ranges is the configuration class's criticality probability.

Table 6.2-1. DOE SNF Intact Configuration Criticality Analysis References

DOE SNF Waste Form Group	DOE SNF Representative Waste Form	Intact Configuration Criticality Analysis Reference
Mixed Oxide (MOX)	Fast Flux Test Facility (FFTF)	CRWMS M&O 1999 [DIRS 125206]
Uranium-Zirconium Hydride (U-Zr H_x)	Training, Research, Isotopes, General Atomics (TRIGA)	CRWMS M&O 2000 [DIRS 147650]
Uranium (U) Metal	N Reactor	CRWMS M&O 2001 [DIRS 154194]
High-Enriched Uranium (HEU) Oxide	Shippingport PWR	CRWMS M&O 2000 [DIRS 147651]
Uranium/Thorium (U/Th) Oxide	Shippingport LWBR	CRWMS M&O 2000 [DIRS 151743]
Uranium/Thorium (U/Th) Carbide	Fort St. Vrain	BSC 2001 [DIRS 157734]
Aluminum Based	Melt and Dilute	BSC 2001 [DIRS 157733]
Uranium-Zirconium/Uranium-Molybdenum (U-Zr/U-Mo) Alloy	Enrico Fermi	CRWMS M&O 2000 [DIRS 151742]
Low-Enriched Uranium (LEU) Oxide	Three Mile Island II	BSC 2004 [DIRS 168935]

The remainder of this section summarizes select event trees of the configuration generator used in the criticality FEPs screening analysis. The configuration generator consists of 48 event trees that represent the events and processes necessary for the formation of the configuration classes of the Master Scenario List (YMP 2003 [DIRS 165505], Section 3.3). A listing of these trees and a cross reference of their use in the criticality FEPs screening analysis is provided in Table 6.2-2. The event trees used in the criticality FEPs screening analysis are contained in the SAPHIRE file of Appendix G (a read-only CDROM).

Table 6.2-2. Listing of Configuration Generation Model Event Trees

Event Tree Name	Description	Use in Criticality FEPs Screening Analysis
WP-WF	Event tree for determination of waste package type fractions	Yes, for informational purposes only
WP01-21-PWR-AP	Initiating event tree for 21-PWR Absorber Plate waste package type	Yes, for all cases
WP02-21-PWR-CR	Initiating event tree for 21-PWR Control Rod waste package type	Yes, for all cases
WP03-12-PWR-AP	Initiating event tree for 12-PWR Absorber Plate waste package type	Yes, for all cases
WP04-24-BWR-AP	Initiating event tree for 24-BWR Absorber Plate waste package type	Yes, for all cases
WP05-44-BWR-AP	Initiating event tree for 44-BWR Absorber Plate waste package type	Yes, for all cases
WP06-DOE1-SHORT	Initiating event tree for MOX DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP07-DOE1-LONG	Initiating event tree for MOX DOE SNF in 5-DHLW/DOE Long waste package type	Yes, for all cases
WP08-DOE2-SHORT	Initiating event tree for U-Zr Hx DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP09-DOE2-SHORT	Initiating event tree for U-Metal DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases

WP10-DOE2-LONG	Initiating event tree for U-Metal DOE SNF in 5-DHLW/DOE Long waste package type	Yes, for all cases
WP011-DOE3-MCO	Initiating event tree for U-Metal DOE SNF in 2-MCO/2-DHLW waste package type	Yes, for all cases
WP12-DOE4-SHORT	Initiating event tree for HEU Oxide DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP13-DOE4-LONG	Initiating event tree for HEU Oxide DOE SNF in 5-DHLW/DOE Long waste package type	Yes, for all cases
WP14-DOE5-SHORT	Initiating event tree for U/Th Oxide DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP15-DOE5-LONG	Initiating event tree for U/Th Oxide DOE SNF in 5-DHLW/DOE Long waste package type	Yes, for all cases
WP16-DOE6-SHORT	Initiating event tree for U/Th Carbide DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP17-DOE7-SHORT	Initiating event tree for Aluminum Based DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP18-DOE7-LONG	Initiating event tree for Aluminum Based DOE SNF in 5-DHLW/DOE Long waste package type	Yes, for all cases

Table 6.2-2 Listing of Configuration Generation Model Event Trees (Continued)

Event Tree Name	Description	Use in Criticality FEPs Screening Analysis
WP19-DOE8-SHORT	Initiating event tree for U-Zr/U-Mo Alloy DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP20-DOE8-LONG	Initiating event tree for U-Zr/U-Mo Alloy DOE SNF in 5-DHLW/DOE Long waste package type	Yes, for all cases
WP21-DOE9-SHORT	Initiating event tree for LEU Oxide DOE SNF in 5-DHLW/DOE Short waste package type	Yes, for all cases
WP22-DOE9-LONG	Initiating event tree for LEU Oxide DOE SNF in 5-DHLW/DOE Long waste package type	Yes, for all cases
YMP-INIT-EVENTS	Event tree for directing Master Scenario List evaluation for base case and disruptive events	Yes, for all cases
MSL-ET	Event tree for determining bathtub or flow-through waste package configuration	Yes, for base, seismic, and rock fall cases
MSL-ET2	Continuation of event tree for determining bathtub or flow-through waste package configuration	Yes, for base, seismic, and rock fall cases
CONFIG-BATH	Event tree for initiating evaluation of waste package bathtub configurations IP-1, IP-2, and IP-3	Yes, for seismic case
CONFIG-NOBATH	Event tree for initiating evaluation of waste package flow-through configuration classes IP-4, IP-5, and IP-6	Not used in this analysis
CONFIG-IP2-D	Event tree for evaluating configuration class IP-2	Not used in this analysis
CONFIG-IP3	Event tree for evaluating configuration class IP-3	Not used in this analysis
CONFIG-IP3-G	Continuation of event tree for evaluating configuration class IP-3	Not used in this analysis

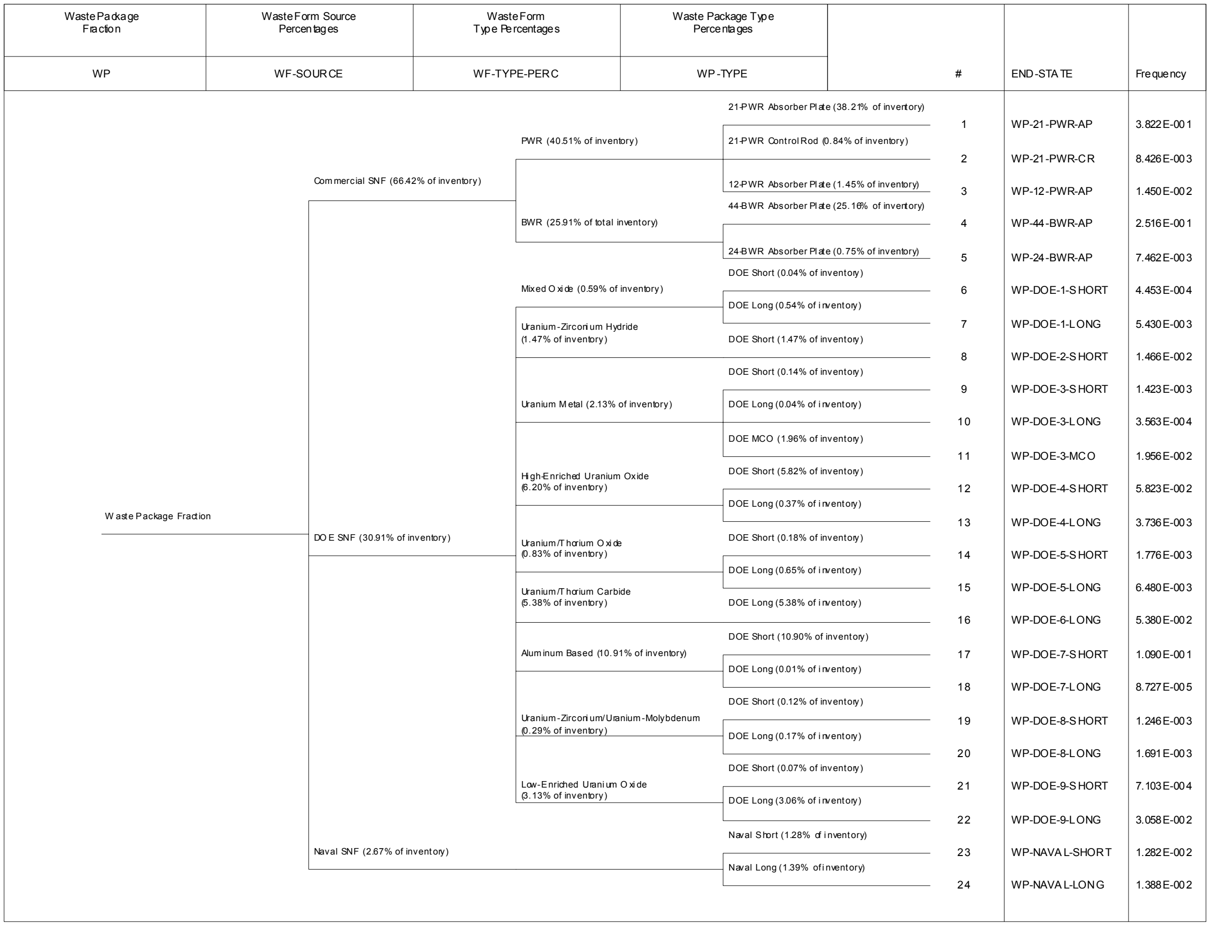
Table 6.2-2 Listing of Configuration Generation Model Event Trees (Continued)

Event Tree Name	Description	Use in Criticality FEPs Screening Analysis
CONFIG-IP4-A	Event tree for evaluating configuration class IP-4	Yes, for seismic case
CONFIG-IP5	Event tree for evaluating configuration class IP-5	Not used in this analysis
CONFIG-IP-6C	Event tree for evaluating configuration class IP-6	Not used in this analysis
CONFIG-NF-F	Event tree for initiating the evaluation of near-field configuration classes	Yes, for all cases
CONFIG-NF1	Event tree for evaluating configuration class NF-1	Yes, for all cases
CONFIG-NF2	Event tree for evaluating configuration class NF-2	Yes, for all cases
CONFIG-NF3	Event tree for evaluating configuration class NF-3	Yes, for all cases
CONFIG-NF4	Event tree for evaluating configuration classes NF-4 and NF-DD	Yes, for base, seismic, and rock fall cases
CONFIG-NF4-E	Continuation of tree for evaluating configuration class NF-4 TP E	Not used in this analysis
CONFIG-NF5-I	Event tree for evaluating configuration class NF-5 TP I	Not used in this analysis
CONFIG-FF-J	Event tree for evaluating configuration class FF-1	Yes, for seismic and igneous cases
CONFIG-FF-K	Event tree for evaluating configuration class FF-2	Yes, for seismic and igneous cases
CONFIG-FF3	Event tree for evaluating configuration class FF-3	Yes, for seismic and igneous cases
IGNEOUS	Event tree for initiating evaluation of igneous configuration class	Yes, for igneous case
IG-ERUPTIVE	Event tree for evaluating igneous eruptive scenarios – configuration classes IGE-1, IGE-2, and IGE-3	Yes, for igneous case
IG-INTRUSIVE	Event tree for evaluating igneous intrusion scenarios – configuration classes – IGI-4, IGI-5, and IGI-6	Yes, for igneous case
IG-INTRUSIVE2	Continuation of evaluation of igneous intrusion scenarios – configuration classes – IGI-1, IGI-2, and IGI-3	Yes, for igneous case

Source: *Configuration Generator Model.* CAL-DS0-NU-000002 REV 00A (BSC 2004 [DIRS 168552])

It is beyond the scope of this analysis to provide the details of each of these event trees. Only those event trees involved in initiating the criticality FEPs evaluation are discussed in this section. Detailed descriptions of the remaining trees and their inputs are presented in *Configuration Generator Model* (BSC 2004 [DIRS 168552]). Event descriptions and justification of the input values for the event trees that are utilized in the criticality FEPs screening analysis are provided in subsequent sections.

The first event tree from the configuration generator defines the fractional breakdown of the waste forms and waste package types proposed for disposal in the repository. This event tree, presented in Figure 6.2-1, is a stand-alone tree (i.e., none of its end states transfer to a sub-event tree). Its purpose is to graphically identify the fraction of total waste package inventory for each waste form and waste package type, including naval waste package types. The inventory fractions presented on this event tree are based on the information provided in Table 4.1-3.

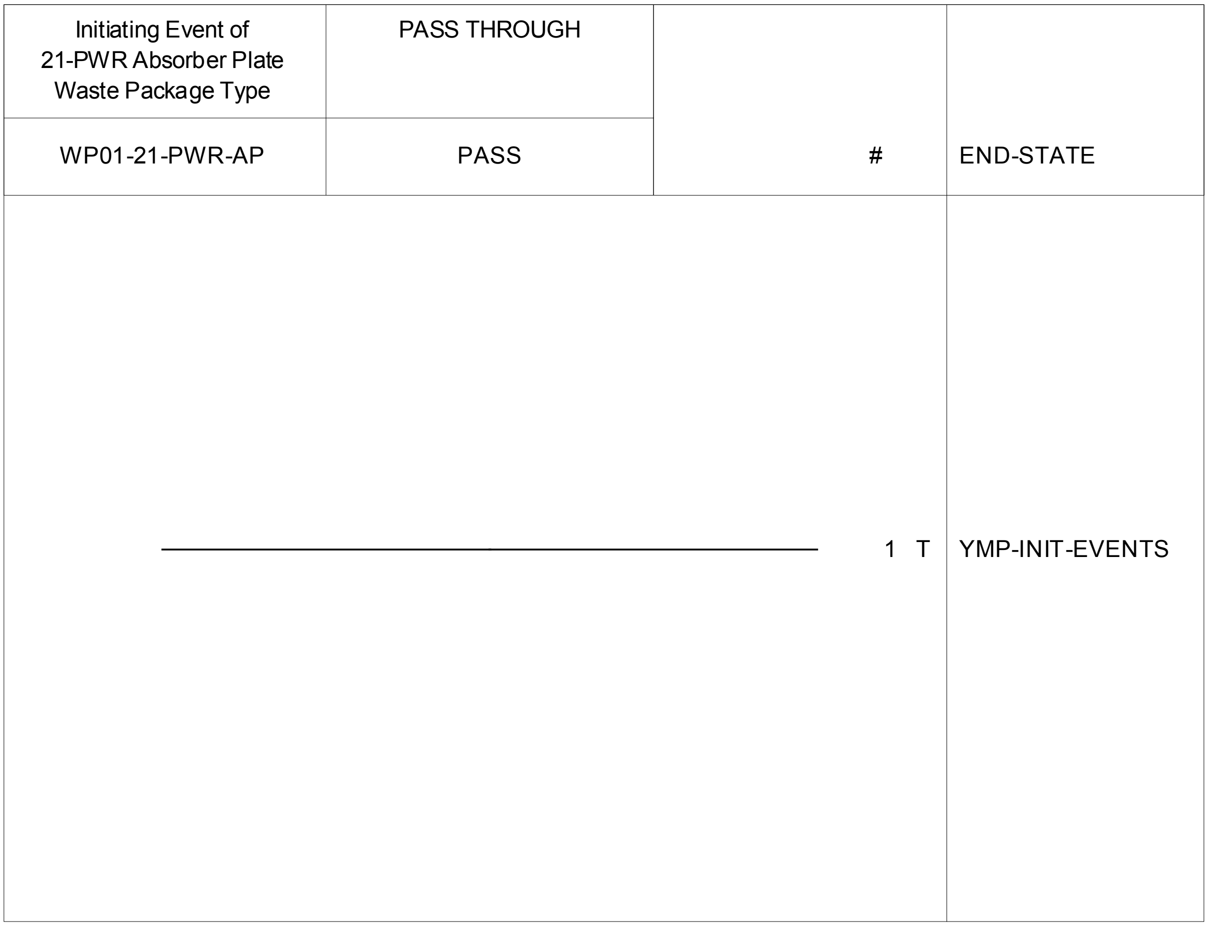


Source: BSC 2004 [DIRS 168552], Attachment I

Figure 6.2-1. Fraction of Waste Form and Waste Package Types Proposed for Disposal at the Repository

Although the Naval Nuclear Propulsion Program (NNPP) is responsible for assessing the criticality potential of the naval waste package types in their Technical Support Document for the License Application (McKenzie 2004 [DIRS 170742]), these waste package types are presented on this event tree for completeness.

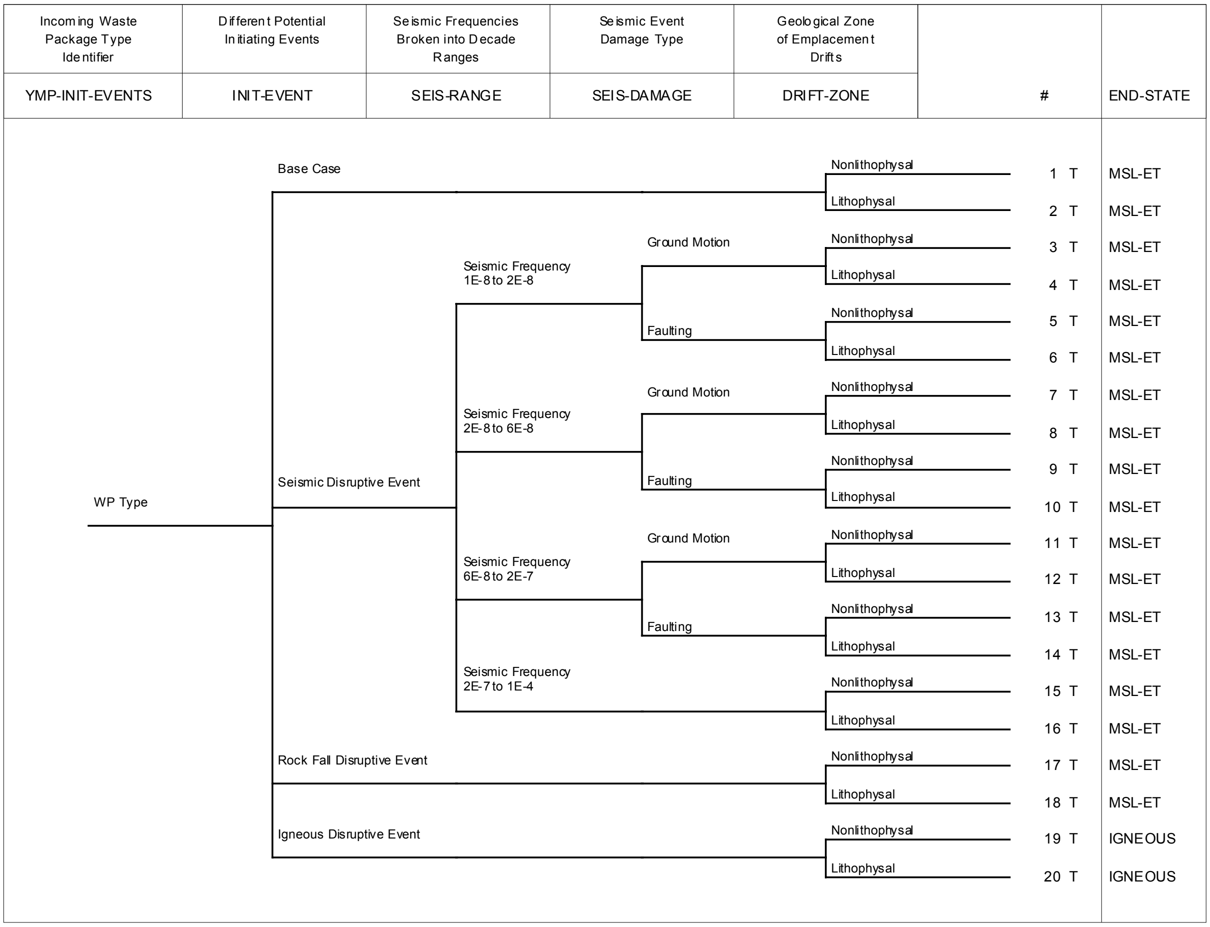
The 22 commercial and DOE SNF waste package types listed in Figure 6.2-1 are utilized as the initiating event in 22 separate event trees. The sole purpose of these event trees is to transfer to the event tree that initiates the evaluation of the four criticality FEPs cases. An example of the "Waste Package Type" event tree representing the 21-PWR Absorber Plate waste package is presented in Figure 6.2-2. The automatic transfer of this event tree is indicated by the "T" after the event tree sequence number in the "#" column. The "YMP-INIT-EVENTS" end state name in the "END-STATE" column indicates the name of the event tree to which the transfer occurs.



Source: BSC 2004 [DIRS 168552], Attachment I.

Figure 6.2-2. Example of Waste Package Type Event Tree

The "YMP-INIT-EVENTS" event tree is presented in Figure 6.2-3. This event tree directs the evaluation of the four criticality FEPs cases — (1) Base Case, (2) Seismic Disruptive Event, (3) Rock Fall Disruptive Event, and (4) Igneous Disruptive Event. These cases are respectively represented by the four branches of the first top event — INIT-EVENT. The probabilities of occurrence assigned to the top event branches representing these four criticality FEPs cases are as follows:



Source: BSC 2004 [DIRS 168552], Attachment I.

Figure 6.2-3. Event Tree for Processing Criticality FEPs Cases

BASE-CASE = 0.000E–000 (complement of 1.00)
SEISMIC-EVENT = 1.000E–000
ROCKFALL-EVENT = 0.000E–000
IGNEOUS-EVENT = 1.700E–004

The probability of BASE-CASE branch of this top event has been assigned a probability of 0.0 because the value of an upper branch, or failure branch, is interpreted by SAPHIRE as the complement of its assigned value (i.e., one minus the assigned value). Since the base case criticality FEPs are always to be evaluated, a zero value is assigned to this branch (i.e., 0=1–1). The evaluation of the base case criticality FEPs is presented in Section 6.3.

The seismic disruptive event branch, or second branch, of top event INIT-EVENT, is also assigned a probability of 1.0 (i.e., always evaluated). This was done so as not to modify the seismic sub-event probabilities of top events SEIS-RANGE and SEIS-DAMAGE. As indicated by the top event SEIS-RANGE, the seismic disruptive event has been divided into four sub-events, each representing a seismic frequency range. Top event SEIS-DAMAGE further subdivides the top three seismic frequency ranges based on whether the seismic induced damage results from ground motion or faulting.

Seismic consequences have been evaluated for annual exceedance frequencies ranging from 10^{-4} to 10^{-8} per year (BSC 2004 [DIRS 169183], Section 6.4.2). The determination of the subdivision of the seismic case analysis represented by top event SEIS-RANGE is based on the seismic faulting event's impact on the waste package. For seismic event annual exceedance frequencies greater than 2×10^{-7} per year (i.e., less severe earthquakes), no waste package damage occurs due to faulting (BSC 2004 [DIRS 169183], Section 6.7.5). For seismic event annual exceedance frequencies less than 2×10^{-7} per year (i.e., more severe earthquakes) waste package failure is initiated. Six waste packages are predicted to fail for seismic faulting events at the 6×10^{-8} to 2×10^{-7} per year annual exceedance frequency range. A maximum of 56 waste package failures are predicted to occur for seismic faulting events at the 1×10^{-8} to 2×10^{-8} per year annual exceedance frequency range (BSC 2004 [DIRS 169183], Section 6.7.5). Seismic event annual exceedance frequencies from 1×10^{-8} to 2×10^{-8} per year are represented by the upper branch of top event SEIS-RANGE. The second branch represents the annual exceedance frequency range of 2×10^{-8} to 6×10^{-8} per year, the third branch represents 6×10^{-8} to 2×10^{-7} per year, and the lower branch represent 2×10^{-7} to 1×10^{-4} per year annual exceedance frequencies. These basic events assigned to these branches are SEIS-1E-8TO2E-8, SEIS-2E-8TO6E-8, SEIS-6E-8TO2E-7, and SEIS-2E-7TO1E-4, respectively. The probabilities of these basic events are determined using Equation 6.2-1 and the information provided in Table 6.2-3:

$$\text{Probability} = [(1-e^{-\Delta\lambda\Delta t})] \qquad \text{(Eq. 6.2-1)}$$

where: $\Delta\lambda$ is the difference in the seismic annual exceedance frequencies of interest ($\lambda_2 - \lambda_1$)
Δt is the difference in the time periods of interest ($t_1 - t_2$)

Table 6.2-3. Calculation of Seismic Basic Event Probabilities

Seismic Basic Event	**λ_1** (events/year)	**λ_2** (events/year)	**t_1** (years)	**t_2** (years)	**Probability**
SEIS-1E-8TO2E-8	1.0E-8	2.0E-8	10,000	0	1.000E-4
SEIS-2E-8TO6E-8	2.0E-8	6.0E-8	10,000	0	4.000E-4
SEIS-6E-8TO2E-7	6.0E-8	2.0E-7	10,000	0	1.400E-3
SEIS-2E-7TO1E-4	2.0E-7	1.0E-4	10,000	0	6.314E-1

The top three branches of top event SEIS-RANGE are further subdivided to account for the waste package failure dependency on seismic induced ground motions and faulting. The lower branch of top event SEIS-RANGE is not subdivided because seismic faulting is not predicted to result in any waste package failures for this annual exceedance frequency range. The event SEIS-GROUND defines the upper branch of the SEIS-DAMAGE top event and is used to evaluate the potential of waste package failure due to seismic induced ground motions. The event SEIS-FAULT represents the lower branch of the SEIS-DAMAGE top event and is used to evaluate the potential of waste package failure due to seismic induced faulting. To activate evaluation of both branches of this top event, event /SEIS-GROUND is assigned a value of 0.0 (complement of 1.0) for all seismic ranges. The event SEIS-FAULT is assigned a value of 1.0 for seismic ranges represented by the first and second branches of SEIS-RANGE for all commercial SNF waste package types (21–PWR Absorber Plate, 21–PWR Control Rod, 12-PWR Absorber Plate, 44–BWR Absorber Plate, and 24–BWR Absorber Plate waste package types). For the DOE SNF waste package types (5–DHLW/DOE Short, 5–DHLW/DOE Long, and 2–MCO/2–DHLW waste package types), SEIS-FAULT is assigned a value of 1.0 for seismic ranges represented by the upper and first, second, and third branches of SEIS-RANGE.

The evaluation of the seismic disruptive event is presented in Section 6.4.

The rock fall disruptive event is represented by the third branch of top event INIT-EVENT. The basic event for this criticality FEPs case is ROCKFALL-EVENT. This event has been assigned a value of 0.0 because, as is discussed in Section 6.5, rock fall does not result in any new potentially critical scenarios beyond those already defined for the base case. Rock fall is the result of natural drift degradation phenomena and is expected to occur throughout the postclosure period without any predictable frequency. The rock fall disruptive event is differentiated from rock fall that may occur during a seismic disruptive event. Damage resulting from seismic induced rock fall is accounted for in the Section 6.4.

The igneous disruptive event case is represented by the fourth branch of the INIT-EVENT top event. Its basic event is IGNEOUS-EVENT. The igneous disruptive event has a probability of occurrence of 1.7×10^{-4} over the 10,000-year regulatory period. Determination of this probability is performed using the following equation:

$$\text{Probability} = [(1-e^{-\lambda t})] \qquad \text{(Eq. 6.2-2)}$$

where

λ = intersection frequency (mean) of volcanic event with repository 1.7×10^{-8}/yr (BSC 2004 [DIRS 169989], Table 7-1)

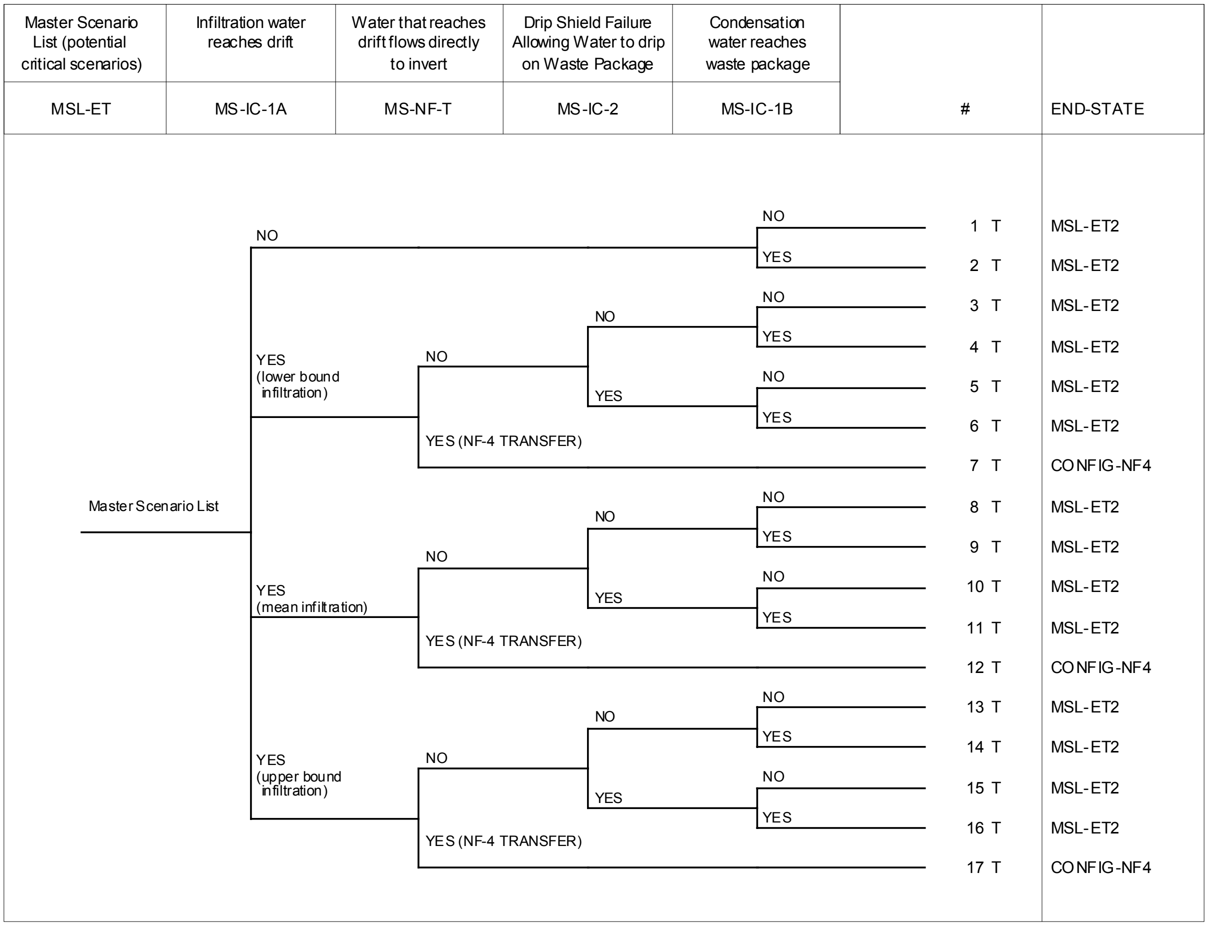
t = 10,000 years

The evaluation of the igneous disruptive event is presented in Section 6.6.

The DRIFT top event of the "YMP-INIT-EVENTS" event tree is used to split the criticality FEP evaluations between the two geological zones of the drifts – lithophysal and nonlithophysal. Based on the drift area information presented in Table 4.1-2, of the 4,983,152 m^2 of total emplacement drift area, 745,486 m^2 is in the nonlithophysal geological zone. This results in a top event split fraction of 0.15 for nonlithophysal (745,486/4,983,152) and 0.85 for lithophysal. These values are applied to the event tree evaluation by assigning the value of 0.85 to DRIFT-ZONE. The upper branch of DRIFT-ZONE (i.e., /DRIFT-ZONE) is assigned the complement value (i.e., 1 - 0.85 = 0.15). As is discussed in Section 6.3 (base case criticality FEPs), Section 6.4 (seismic disruptive event criticality FEPs), Section 6.5 (rock fall disruptive event criticality FEPs), and Section 6.6 (igneous disruptive event criticality FEPs), it is important to distinguish between the two geological units to account for their different impacts on seepage, drip shield damage, and waste package damage.

The sequences of the "YMP-INIT-EVENTS" event tree of Figure 6.2-3 automatically transfer to another event tree. An event tree transfer is indicated by the "T" after the sequence numbers in the "#" column. The "MSL-ET" end state name in the "END-STATE" column for the first ten sequences indicates the name of the event tree to which the transfer occurs. The "MSL-ET" event tree (shown in Figure 6.2-4) performs the probability evaluation for availability of seepage, drip shield and waste package failure, availability of condensation, seepage accumulation in the waste package (i.e., formation of a bathtub or flow-through configuration), and neutron absorber material misload.

A transfer to the "IGNEOUS" event tree is indicated for the end states of the remaining two sequences. The "IGNEOUS" event tree directs the probability evaluation of potentially critical configurations during an igneous event.

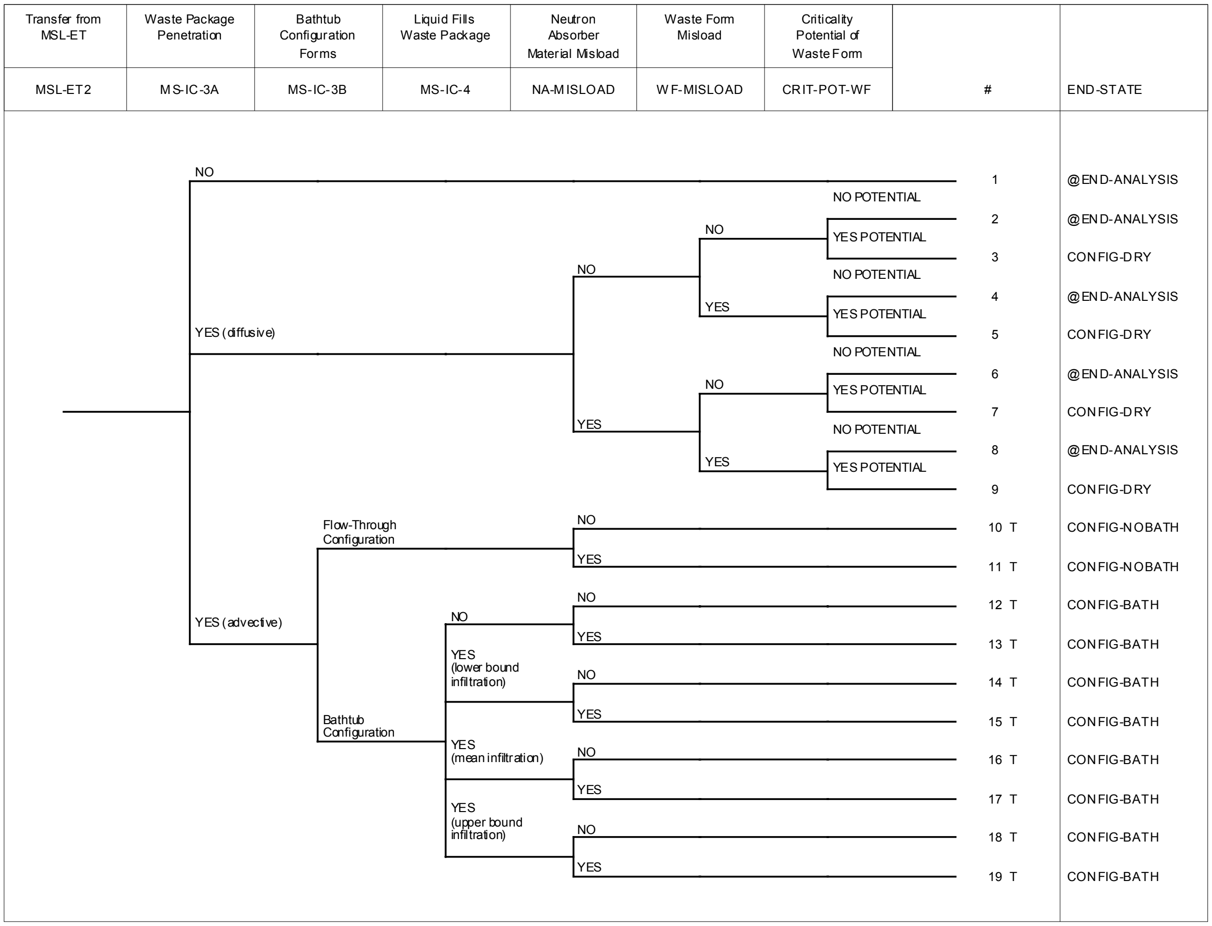


Source: BSC 2004 [DIRS 168552], Attachment I.

Figure 6.2-4. Master Scenario List Event Tree – MSL-ET

As presented in the "MSL-ET" event tree and its continuation event tree "MSL-ET2" of Figures 6.2-4 and 6.2-5, nine top events are used to define the events and processes necessary for the formation of a waste package bathtub or flow-through configuration. The purpose of the first top event, MS-IC-1A, is to evaluate the probability of infiltration water or seepage reaching the drift. This top event is separated into four branches. The first branch represents the no seepage case. The second through fourth branches represent lower bound, mean, and upper bound seepage rates, respectively. The quantification of the branch probabilities is provided in Sections 6.3 through 6.6.

If seepage is predicted to occur (i.e., any one of the three bottom branches of the MS-IC-1A top event), then top event MS-NF-T is queried. The purpose of this top event is to account for the availability of water in the drift invert, or near-field. Water in the invert provides a transport mechanism of fissile material to the far-field in the event of waste package breach and its release of the waste form. Water in the invert may also provide a reducing environment that causes the deposition and accumulation of fissile material in the near-field. The upper branch, of this top event accounts for the availability of water to enter a failed waste package. The lower branch, accounts for seepage water in the invert. The lower branch transfers directly to the near-field event tree “CONFIG-NF4” for further evaluation. Both branches of this top event are evaluated in order to assess the criticality potential of these scenarios. Therefore, /MS-NF-T is assigned a value of 0.00 (i.e., the complement of 1.00) and MS-NF-T is assigned a value of 1.00.



Source: BSC 2004 [DIRS 168552], Attachment I.

Figure 6.2-5. Continuation of Master Scenario List Event Tree – MSL-ET2

Top event MS-IC-2 evaluates the probability that, given seepage in the drift, the drip shield is failed in such a manner to allow water to pass through to the waste package. Regardless of whether the drip shield is failed (i.e., branching goes down) or not (i.e., branching goes up), top event MS-IC-1B is queried. If the drip shield is failed, the query of top event MS-IC-1B is performed to determine if, in addition to seepage, condensation water flux is available to enter a waste package. If the drip shield is not failed, the query of the condensation top event is performed to determine if any water flux is available to enter a waste package.

Other than the sequences of the lower branch of top event MS-NF-T, which transfer to the "CONFIG-NF4" event tree, all remaining sequences of the "MSL-ET" event tree transfer to its continuation event tree, "MSL-ET2".

There are six top events in the "MSL-ET2 event tree to complete the master scenario list initiation. The first top event to be queried is MS-IC-3A. Top event MS-IC-3A evaluates the probability of a waste package failure. The branching of this top event allows for breaches that permit both advective and diffusive flow paths into the waste package as well as no waste package failures. The middle branch of this top event represents a diffusive failure of the waste package. The bottom branch of this top event represents a waste package failure that allows advective flow of water to enter and support the generation of a potentially critical configuration. If the waste package is not failed (i.e., branching goes up), then the analysis is terminated. Termination of sequence evaluation is indicated by the @END-ANALYSIS end state name (the @ symbol prefixing an end state name indicates to SAPHIRE to stop processing).

Top event MS-IC-3B evaluates the probability that, given an advective flow path into the waste package (bottom branch of top event MS-IC-3A), either a flow-through or a bathtub configuration is formed. A flow-through configuration results from a failure of both the top and bottom of the waste package, allowing the water to flow in through the top of the waste package and out through the bottom. This configuration is represented by the upper branch of this top event. A bathtub configuration is formed when only a top failure of the waste package occurs. The bathtub waste package configuration is represented by the bottom branch of this top event. If a flow-through waste package configuration is formed, the next top event queried is NA-MISLOAD. If a bathtub waste package configuration is formed, then top event MS-IC-4 is queried.

Top event MS-IC-4 evaluates the probability that, given its availability to enter a failed waste package, water accumulates in and fills the waste package creating a potentially critical configuration. The probability value for water accumulation and waste package filling is dependent on the seepage scenario of top event MS-IC-1A of event tree "MSL-ET". Therefore, separate branches are provided in top event MS-IC-4 that reflect the branching of MS-IC-1A for the lower-bound, mean, and upper-bound seepage scenarios. The second through fourth branches from the top of this top event respectively represents these seepage scenarios. The upper branch of this top event represents the probability that water does not accumulate in sufficient quantity to fill the waste package.

The accumulation and retention of water in the waste package is referred to as a bathtub configuration and is represented on the event tree as a downward branch for top event MS-IC-3B. It is also possible for water to enter the waste package, but does not accumulate due to a breach in the waste package bottom. This condition is referred to as a flow-through configuration and is represented on the event tree as an upward branch for top event MS-IC-3B. Potentially critical configurations could result from either condition through the degradation of the waste package internals and the separation or removal of neutron absorber and/or fissile materials.

Another possible configuration is one in which a breach in the top and bottom of the waste package exists, but that the bottom hole is much smaller than the top hole so more water could enter the waste package through the top than could exit through the bottom. This configuration is not explicitly considered in this analysis because such a bottom breach would have to be a diffusive type that would make this waste package configuration a subset of the bathtub configuration. Otherwise, it would be a flow-through configuration.

The next top event evaluated for the “MSL-ET2” event tree is NA-MISLOAD. This top event is queried for either waste package diffusive or advective (both bathtub and flow-through configurations) flow path failure branches of all the branches of the MS-IC-3A and MS-IC-3B top events. The NA-MISLOAD top event evaluates the probability that neutron absorber material is not loaded as designed into the waste package or waste form. Evaluation of neutron absorber material misload is an important consideration for the determination of a configuration’s criticality potential. Dependent on the top event MS-IC-4 branching, both misload and no misload branches transfer to the appropriate “CONFIG-BATH” and “CONFIG-NOBATH” event trees for further criticality potential evaluation.

If the NA-MISLOAD top event is queried following a diffusive failure of the waste package (middle branch of top event MS-IC-3A), then the processing of these sequences proceeds to the evaluation of top events WF-MISLOAD and CRIT-POT-WF. The WF-MISLOAD misload top event queries the potential for misloading the waste package’s waste form and top event CRIT-POT-WF evaluates the criticality potential of the resulting configuration. The upper branch of the CRIT-POT-WF top event indicates that this configuration does not have any criticality potential and processing of this sequence is terminated. The lower branch of this top event indicates that the configuration has a criticality potential and the probability associated with that potential is assigned to end state CONFIG-DRY.

As stated previously, the above section provides an overview of only the initial event trees from the configuration generator. Forty-eight event trees comprise the configuration generator, of which 26 have been discussed (22 of these represent the waste form/waste package type configuration, of which only one representative event tree has been discussed). Detailed discussion for the remaining 22 event trees of the configuration generator are presented in *Configuration Generator Model* (BSC 2004 [DIRS 168552]).

Evaluation of the configuration generator by the SAPHIRE software code allows for the truncation of sequences based on their in-process probability value. If the probability of a sequence falls below the truncation or cutoff value, continued processing of this sequence is halted and a value of zero assigned. This cutoff threshold is equivalent to the probability screening criterion discussed in the *Disposal Criticality Analysis Methodology Topical Report* (BSC 2003 [DIRS 165505], Section 3.2.1) and is used to screen from further consideration configuration classes that contribute insignificantly to the total probability of a criticality occurring in the repository during the period of regulatory concern. A value of 10^{-15} is utilized as the probability screening criterion for SAPHIRE sequence evaluation. This value has been utilized based on the limitation of personal computers for the number of significant digits that can be tracked with double precision.

6.3 ANALYSIS OF BASE CASE CRITICALITY FEPS

This screening analysis of the base case postclosure criticality FEPs evaluates the probability that water is able to enter a waste package to degrade the waste package internals and waste form and create a potentially critical configuration during the regulatory period (10,000 years after repository closure). The probability of potentially critical configurations is considered for both internal and external waste package scenarios.

For a criticality event to occur, the proper combination of materials (neutron moderators, neutron absorbers, fissile materials, or isotopes) and geometric configuration must exist. A critical system for the geological repository is defined as one having an effective neutron multiplication factor (k_{eff}) larger than the critical limit. The critical limit is the value of k_{eff} at which a system (configuration of fissile material) is considered critical as characterized by statistical tolerance limits (BSC 2004 [DIRS 168553], Section 6.3.1).

All postclosure criticality FEPs, internal and external, require water infiltration to degrade the waste package internals and waste form. Neutron absorber material loss and a flooded waste package condition for neutron moderation is the most likely scenario that could result in a potentially critical configuration in any of the in situ criticality FEPs. Seepage flow-through and humid air conditions internal to the waste package may also degrade waste package internal components and waste forms. However, based on its corrosion rate (Assumption 5.1.9), sufficient neutron absorber material loss (Assumption 5.1.9) and adequate neutron moderation are unlikely under these conditions and the generation of an internal criticality configuration is improbable. External criticality FEPs (near-field and far-field) also require the separation of neutron absorber materials from the waste form and, additionally, the transport of fissile material from the waste package and its re-accumulation in the drift invert or beyond.

Water, silica, and carbon are the only potential moderating materials for internal and external configurations. Water, the most effective neutron-moderating material, can enter the waste package as percolation flow or be present in the pores of the rock. Silica is present in appreciable quantities in the high-level radioactive waste glass canisters and in the rock. Silica can also be introduced into the waste package through precipitation from the percolation flow. Carbon is present in only limited amounts in less than 20 percent of the DOE SNF waste package types (DOE 2004 [DIRS 170071]) and, therefore, has a limited impact on the potential for criticality. The loading of the DOE-standardized SNF canisters, the design of the basket structure inside the canisters, and the addition of neutron absorber materials take into account the presence and effect of degraded glass in DOE SNF codisposal waste packages. Silica from the degradation of high-level radioactive waste glass, therefore, has no impact on the potential for criticality in DOE SNF waste packages. Silica is a much less effective moderator than water and its introduction into commercial SNF waste packages from seepage infiltration will displace water and effectively reduce the reactivity of the system, thus reducing the potential for criticality. Additionally, silica can act as a neutron reflector. However, inside the waste package its reflector effects, which increase reactivity, are secondary to its water displacement effects, which decrease reactivity (YMP 2003 [DIRS 165505], Section 3.7.2). Current evaluations from *Total Dust Settling on Naval Long Waste Packages in 100 Years* (BSC 2004 [DIRS 171462], Table 4) indicate only a limited quantity of tuff (up to 20 kg) is available to enter a failed waste package.

In addition, criticality without water infiltration is unlikely for the repository since the critical mass for unmoderated or silica moderated systems exceeds the fissionable content of a waste package (YMP 2003 [DIRS 165505], Section 3.7.1.1). This also results from satisfying a preclosure operations requirement that the MGR provide means to ensure criticality control during SNF/HLW handling operations, including waste package loading (Curry 2004 [DIRS 170557], Requirement 1.1.6-4).

Some of the DOE SNF waste forms have highly enriched fuel or a waste form that could potentially support unmoderated (fast) criticality if (1) the fissile material is concentrated beyond its design concentration in the waste form, and (2) the neutron absorber materials are removed. Concentration of the fissile material beyond its design concentration could result from either the degradation of the waste form resulting from water infiltration or a disruptive event. However, removal of the neutron absorber materials from a DOE SNF waste package would require a breach of the waste package and a removal mechanism. The most likely neutron absorber material removal mechanism is through water infiltration resulting in degradation of the waste package internal components, dissolving of the neutron absorber material in the water, and flushing of the material from the waste package.

6.3.1 Internal (In Situ) Criticality

Water entering a failed waste package may occur from two primary pathways: (1) water dripping from the drift crown, and (2) water dripping from the underside of the drip shield due to evaporation and condensation. The first pathway can occur if the drip shield fails to divert dripping water from the drift crown into a failed waste package. The second pathway can occur if water vapor condenses on the underside of the drip shield and falls onto and enters a failed waste package. The probability that these conditions exist for the base case criticality FEPs is discussed in Section 6.3.3. The list of base case internal (in situ) criticality FEPs to be evaluated is presented in Table 6.3−1.

The intact, fully flooded configuration of FEPs 2.1.14.15.0A, 2.1.14.18.0A, 2.1.14.21.0A, and 2.1.14.24.0A is discussed in Section 6.2. Criticality is precluded by design for this configuration.

Table 6.3-1. Base Case Configurations: Internal (In Situ) Criticality FEPs

FEP Number	FEP Name	FEP Description
2.1.14.15.0A	In-package criticality (intact configuration)	The waste package internal structures and the waste form remain intact. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ. In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.1.14.16.0A	In-package criticality (degraded configurations)	The waste package internal structures and the waste form may degrade. If a critical configuration (sufficient fissile material and neutron moderator, lack of neutron absorbers) develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.

Source: Table 6.1-1

6.3.2 External (Near-Field and Far-Field) Criticality

The probability of external criticality is less than the probability of water entering a waste package. If the probability of water entering a waste package (in either a bathtub or flow-through configuration) during the regulatory period is calculated to be below the regulatory probability criterion for inclusion of events (at least one chance in 10,000 of occurring over 10,000 years (10 CFR 63.114(d) DIRS [156605]), then the probability of an external criticality would be even lower. This is because, in addition to the events evaluated to calculate the probability of water entering a waste package, the probability of the following events must be considered:

- Degrading the waste form during the regulatory period
- Separating the fissile materials from the degraded waste form
- Removing the fissile materials from the waste package
- Accumulating sufficient fissile materials into a potentially critical configuration in the near-field or far-field environments
- Having sufficient neutron moderator available.

The minimum critical mass required to be accumulated in the invert has been calculated for a range of ^{235}U enrichments in *Critical Mass Search Calculation in the Invert* (BSC 2004 [DIRS 170060]). The critical mass results from this calculation are summarized in Table 6.3-2. *Critical Mass Search Calculation in the Invert* (BSC 2004 [DIRS 170060]) calculates that less than 11 kg of uranium will accumulate in the invert under a waste package. Based on the values presented in Table 6.3-2, 11 kg of uranium in the invert will not have criticality potential.

Table 6.3-2. Minimum ^{235}U Critical Mass

Invert Void Fraction (percent)	Waste Form ^{235}U Enrichment (weight percent)					
	5	15	25	50	75	100
27	N/A	20.85 kg	19.39 kg	17.63 kg	16.63 kg	16.23 kg
39	29.00 kg	29.19 kg	27.28 kg	25.50 kg	23.00 kg	21.83 kg

Source: BSC 2004 [DIRS 170060]

NOTE: N/A – not applicable; insufficient fissile material to result in a critical mass

The base case external criticality FEPs are presented in Table 6.3-3. The external FEPs define criticality configurations that begin with source terms resulting from the transport of fissile materials from the waste package in a form (either as solutes, colloids, or slurry of fine particulate) that can be transported into the drift invert (near-field) and beyond (far-field).

Table 6.3-3. Base Case Configurations: External (Near-Field and Far-Field) Criticality FEPs

FEP Number	FEP Name	FEP Description
2.1.14.17.0A	Near-field criticality	Near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.2.14.09.0A	Far-field criticality	Far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.

Source: Table 6.1-1

6.3.3 SAPHIRE Event Probabilities for Base Case Analyses

Assignments of the event probabilities for the base case SAPHIRE criticality FEPs evaluation are presented in the following sections. The events presented in these sections are used to quantify the master scenario list and a near-field configuration event tree for Appendix B, Figures B-4, B-5, and B-18.

6.3.3.1 Quantification of Event Trees “MSL-ET” and “MSL-ET2

Six events and processes are required to define the formation of a waste package bathtub or flow-through configuration. These events are listed as top events of the “MSL-ET” event tree (Appendix B, Figure B-4) and its continuation event tree “MSL-ET2” (Appendix B, Figure B-5).

These events are:

(1) The probability that seepage flux is available to enter a waste package (top event MS-IC-1A)

(2) The probability of drip shield failure (top event MS-IC-2)

(3) The probability that condensation flux is available to enter a waste package (top event MS-IC-1B)

(4) The probability of waste package failure (top event MS-IC-3A)

(5) The probability that the waste package failure will allow for the formation of a bathtub configuration (top event MS-IC-3B)

For bathtub configurations only:

(6) The probability of sufficient seepage to fill and overflow the waste package during the regulatory period (top event MS-IC-4).

In addition, event trees "MSL-ET" and "MSL-ET2" contain four other top events necessary to define the internal and external configuration classes. The first of these is top event MS-NF-T that defines whether seepage that reaches the drift flows directly to the invert and is available to influence the formation of near-field configuration classes. The second top event, NA-MISLOAD, helps define the internal waste package conditions by querying whether the waste package's or waste form's neutron absorber material was misloaded. The third top event, WF-MISLOAD, defines the probability that a waste form has been misloaded into a waste package. Finally, the fourth top event determines the criticality potential for failed waste packages under dry diffusion conditions.

The following subsections provide justification for the probabilities assigned to the events used in the quantification of event trees "MSL-ET" and "MSL-ET2" for the base case criticality FEPs analysis. Of the 10 top events of these two event trees, only eight are necessary for the quantification of the base case criticality FEPs. Table 6.3-4 summarizes the event probability assignments discussed below.

Table 6.3-4. Event Probability Assignment for the “MSL-ET” and “MSL-ET2” Event Trees for Base Case Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Availability of Seepage			Section 6.3.3.1.1
For the lithophysal zone:			
/MS-IC-1A-NOM-NWL (no seepage scenario) [a]	7.605E-1	2.395E-1	
MS-IC-1A-NOM-LL (lower-bound seepage scenario)	1.104E-2	1.104E-2	
MS-IC-1A-NOM-ML (mean seepage scenario)	1.007E-1	1.007E-1	
MS-IC-1A-NOM-UL (upper-bound seepage scenario)	1.278E-1	1.278E-1	
For the nonlithophysal zone:			
/MS-IC-1A-NOM-NWNL (no seepage scenario)	5.170E-1	4.830E-1	
MS-IC-1A-NOM-LNL (lower-bound seepage scenario)	3.518E-2	3.518E-2	
MS-IC-1A-NOM-MNL (mean seepage scenario)	2.127E-1	2.127E-1	
MS-IC-1A-NOM-UNL (upper-bound seepage scenario)	2.351E-1	2.351E-1	
(MS-IC-1A top event)			
Flow of Seepage to the Near-Field Environment			Section 6.3.3.1.2
/MS-NF-T (water available to enter failed WP)	True [a]	0.00	
MS-NF-T (water available directly to drift)	True	1.00	
(MS-NF-T top event)			
Probability that drip shield fails within 10,000 years.			Section 6.3.3.1.3
/MS-IC-2 (no drip shield failure)	True [a]	0.00	
MS-IC-2 (drip shield failure)	False	0.00	
(MS-IC-2 top event)			
Availability of Condensation			Section 6.3.3.1.4
/MS-IC-1B (no condensation flux)	True [a]	0.00	
MS-IC-1B (condensation flux)	False	0.00	
(MS-IC-1B top event)			
Probability of waste package failure within 10,000 years.			Section 6.3.3.1.5
/**MS-IC-3A** (no failure)	8.99972E-1	**1.00028E-1**	
MS-IC-3A[1] (diffusive flow path)	1.00028E-1	**1.00028E-1**	
MS-IC-3A[2] (advective flow path)	False	**0.00**	
(MS-IC-3A top event)			

Table 6.3-4. Event Probability Assignment for the “MSL-ET” and “MSL-ET2” Event Trees for Base Case Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Probability of Neutron Absorber Material Misload in the Waste Package or Waste Form (MS-IC-3B top event)			Section 6.3.3.1.8
For the 21-PWR Control Rod waste package type			
/NA-MISLOAD	~1	3.758E-9	
NA-MISLOAD	3.758E-9	3.758E-9	
For the 21-PWR Absorber Plate waste package type			
/NA-MISLOAD	~1	4.576E-8	
NA-MISLOAD	4.576E-8	4.576E-8	
For the 12-PWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For the 44-BWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For the 24-BWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For DOE SNF Group 1 waste package types with neutron absorber materials in the canister basket [b]			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For DOE SNF Group 2 waste package types with neutron absorber materials in filler [c]			
/NA-MISLOAD	~1	3.906E-8	
NA-MISLOAD	3.906E-8	3.906E-8	
For DOE SNF Group 3 waste package types with neutron absorber materials in canister basket and filler [d]			
/NA-MISLOAD	~1	3.912E-8	
NA-MISLOAD	3.912E-8	3.912E-8	
For DOE SNF waste package types without neutron absorber materials [e]			
/NA-MISLOAD (no misload)	True [a]	0.00	
NA-MISLOAD (misload)	False	0.00	

Table 6.3-4. Event Probability Assignment for the “MSL-ET” and “MSL-ET2” Event Trees for Base Case Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Probability of Waste Form Misload (WF-MISLOAD top event)			Section 6.3.3.1.9
For the 21-PWR Absorber Plate waste package			
/WF-MISLOAD	~1	1.18E-5	
WF-MISLOAD	1.18E-5	1.18E-5	
For the 21-PWR Control Rod waste package			
/WF-MISLOAD	True[a]	0.00	
WF-MISLOAD	False	0.00	
For the 12-PWR Absorber Plate waste package			
/WF-MISLOAD (no misload)	True[a]	0.00	
WF-MISLOAD (misload)	False	0.00	
For the 44-BWR Absorber Plate waste package	True[a]	0.00	
/WF-MISLOAD (no misload)	False	0.00	
WF-MISLOAD (misload)			
For the 24-BWR Absorber Plate waste package			
/WF-MISLOAD (no misload)	True[a]	0.00	
WF-MISLOAD (misload)	False	0.00	
For DOE waste package types with misload potential[f]			
/WF-MISLOAD	~1	1.475E-8	
WF-MISLOAD	1.475E-8	1.475E-8	
For DOE waste package types without misload potential[g]			
/WF-MISLOAD (no misload)	True[a]	0.00	
WF-MISLOAD (misload)	False	0.00	
Criticality potential of waste package dry diffusion configuration			Section 6.3.3.1.10
/CRIT-POT-WF (no criticality potential)	True[a]	0.00	
CRIT-POT-WF (criticality potential)	False	0.00	
(CRIT-POT-WF top event)			

NOTES:
[a] For event names prefixed by a slash “/,” the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1-value) of the assigned value. True states that a branch is evaluated, False states that it is not evaluated. Example: Using neutron absorber material for waste forms with no criticality potential is not considered a misload since the criticality potential is not increased.
[b] Aluminum Based, MOX, and U-Zr Hx DOE SNF waste forms with neutron absorber materials in the canister basket assembly
[c] U/Th Oxide DOE SNF waste form with neutron absorber material in the canister filler materials
[d] U-Zr/U-Mo Alloy DOE SNF waste form with neutron absorber material in the canister basket and filler materials
[e] HEU Oxide, LEU Oxide, U-Metal, and U/Th Carbide DOE SNF waste forms without neutron absorber materials
[f] MOX DOE SNF waste form with misload potential
[g] Aluminum Based, HEU Oxide, LEU Oxide, U-Metal, U/Th Carbide, U/Th Oxide, and U-Zr Hx, and U-Zr/U-Mo Alloy DOE SNF waste forms without misload potential

6.3.3.1.1 Top Event MS–IC–1A

The amount of seepage reaching the drift is an important factor in waste package degradation and criticality potential. Two parameters characterize the seepage into the emplacement drifts – the seepage fraction (location within the drifts that see seepage) and the seepage rate (the volume of water entering the drift on an annual basis). The purpose of top event MS-IC-1A is to represent the possibility that seepage is available in a drift to enter a breached waste package. The upper branch of this top event indicates that seepage does not occur and the bottom three branches indicates that seepage does occur: branch 1 – lower-bound seepage scenario, branch 2 – mean seepage scenario and branch 3 – upper-bound seepage scenario. The probability of attaining seepage for the lower-bound, mean, and upper-bound seepage scenarios is based on *Analysis of Infiltration Uncertainty* (BSC 2003 [DIRS 165991], Table 7-1) and seepage fraction calculated in Appendix C, Sections C.1 and C.2.

The seepage fraction (i.e., the fraction of waste packages that see seepage) and seepage rate distributions for the lower-bound, mean, and upper-bound climate scenario is based on the glacial transition climate that is expected to last from roughly 2000 to 10,000 years after repository closure (BSC 2004 [DIRS 170002], Section 6.6.1). (Climate projections for the first 2000 years have been identified as modern interglacial and monsoonal with lower projected seepage rates.) The Latin Hypercube Sampling process performed in Appendix C, Sections C.1 and C.2 was performed for 20,000 realizations to obtain the seepage fraction used to quantify the seepage scenario branch probabilities. The results of the sampling process are documented in Appendix C, Sections C.1 and C.2 for the lithophysal and nonlithophysal geological zones, respectively.

Because of differences in the drift after a seismic event for the lithophysal and nonlithophysal geologic zone, it was necessary to perform separate Latin Hypercube samplings for each zone. The results reported in Appendix C, Sections C.1 and C.2 are the drift fractional probability of seepage given the specified seepage scenario (i.e., lower-bound, mean, or upper-bound). The probability of the individual seepage scenarios is specified in *Analysis of Infiltration Uncertainty* (BSC 2003 [DIRS 165991], Table 7-1). The seepage scenario probability is calculated by taking the seepage fraction for each scenario (i.e., lower-bound, mean, and upper-bound) and multiplying it to the probability of being in that seepage scenario. This calculation has been performed in the EXCEL spreadsheet "Probability of Seepage" (Appendix G). The appropriate seepage probability is then substituted into the SAPHIRE analysis based on the sequence branching of top event DRIFT-ZONE of the "YMP-INIT-EVENT" event tree. The results of this calculation are assigned as follows:

Lithophysal Zone Base Case Seepage Probabilities

/MS-IC-1A-NOM-NWL = 2.395E-1 (no seepage probability — SAPHIRE takes the complement of this value)
MS-IC-1A-NOM-LL = 1.104E-2 (lower-bound seepage scenario probability)
MS-IC-1A-NOM-ML = 1.007E-1 (mean seepage scenario probability)
MS-IC-1A-NOM-UL = 1.278E-1 (upper-bound seepage scenario probability)

Nonlithophysal Zone Base Case Seepage Probabilities

/MS-IC-1A-NOM-NWNL = 4.830E-1 (no seepage probability — SAPHIRE takes the complement of this value)
MS-IC-1A-NOM-LNL = 3.518E-2 (lower-bound seepage scenario probability)
MS-IC-1A-NOM-MNL = 2.127E-1 (mean seepage scenario probability)
MS-IC-1A-NOM-UNL = 2.351E-1 (upper-bound seepage scenario probability)

6.3.3.1.2 Top Event MS–NF-T

The branching of top event MS-NF-T represents the availability of seepage to flow directly into the invert. The upper branch indicates that seepage does not flow into the invert and the lower branch indicates that it is available. If seepage is available to flow directly into the invert, the sequence transfers to the "CONFIG-NF4" event tree for the evaluation of near-field configuration class NF-4. Seepage flow directly to the invert can follow either of two pathways, i.e., dripping from the drift crown onto the drip shield or down the drift wall. Because both pathways are likely to occur simultaneously, both branches of this top event are processed to ensure the evaluation of all configuration classes. In order to process both branches of this top event, /MS–NF–T is assigned a value of 0.00 (i.e., the complement of 1.00, True) and MS–NF–T is assigned a value of 1.00 (True).

6.3.3.1.3 Top Event MS–IC–2

The probability of water passing through the drip shield to a failed waste package is an important factor in waste package degradation and criticality. This event is associated with top event MS–IC–2 of the "MSL–ET" event tree (Figure B-4). The upper branch represents no drip shield failure and the lower branch represents that the drip shield has failed.

Water pathways through the drip shield can be created by corrosion (Assumption 5.1.1) and emplacement errors. Drip shield failures can be categorized as being caused by either time-dependent or time-independent mechanisms. Corrosion failure mechanisms are time-dependent and may be active or inactive during the performance evaluation period.

Time-independent drip shield failure mechanisms are defined as those failure mechanisms that can occur randomly from the time of initial emplacement. Drip shield emplacement errors, rock fall, or seismic events are types of time-independent failure mechanisms that can potentially result in immediate creation of an advective pathway through the drip shield. In certain cases, such as fabrication errors, the failure mechanism is an initiator that exacerbates corrosion (a time-dependent mechanism).

The drip shield failure mechanisms are discussed in the remainder of this section. The intent of these discussions is to justify the probability values of top event MS–IC–2 for the evaluation of the base case criticality FEPs. Drip shield failure is defined as those drip shield damage mechanisms that can result in an advective flow path through the drip shield and onto the waste package surface. Drip shield failure could be the result of a crack in the drip shield surface or from the catastrophic failure of the complete drip shield. As is discussed, not all drip shield damage results in the failure of the drip shield's primary function.

Based on the discussions provided below, for the base case criticality FEPs conditions there are no known failure mechanisms of the drip shield. Therefore, only the upper branch of top event MS-IC-2 is activated and /MS-IC-2 is assigned a value of 0.0 (True) and MS-IC-2 is assigned a value of 0.0 (False).

General Corrosion Failure of the Drip Shield

This is a time-dependent drip shield failure mechanism. As stated in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2004 [DIRS 169996], Section 6.5.2 and Figure 23), the earliest failure of the drip shield due to general corrosion does not occur until after 10,000 years (approximately 47,500 years).

It is assumed that TSPA-LA will show there are no general corrosion failures of the drip shield before 10,000 years (Assumption 5.1.12) and, therefore, the probability of drip shield failure due to general corrosion during the regulatory period is zero. The probability of occurrence of this drip shield failure mechanism is negligible.

Localized Corrosion Failure of the Drip Shield

This is a time-dependent drip shield failure mechanism. As stated in *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2004 [DIRS 169845], Section 6.6.3.1), “Localized corrosion of Ti Grade 7 would not initiate in a repository-relevant environment…” Therefore, the probability of occurrence for this drip shield failure mechanism is negligible.

Stress Corrosion Cracking Failure of the Drip Shield

This is a time-dependent drip shield failure mechanism. As discussed in this section, drip shield fabrication errors can result in the formation of stress corrosion cracks. *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2004 [DIRS 169985], Section 6.3.7) states that stress corrosion cracks are expected to fill with corrosion products or be plugged with precipitates such as carbonate. Stress corrosion cracks are expected to be sealed within a few hundred years if water flows through the cracks at the expected very low film flow rate. If the cracks are bridged by water, the sealing process may take several thousand years, but no flow occurs. Because of the high density of the crack plugging materials and the lack of a pressure gradient to drive water through the crack, the probability of flow through the plugged crack approaches zero.

Given the very low flow rates through a stress corrosion crack in the drip shield for, at most, a few hundred years, it is concluded that stress corrosion cracking does not prevent the drip shield from fulfilling its primary role to keep water from contacting the waste packages. The probability of occurrence for this drip shield failure mechanism is negligible.

Hydrogen Detonation Failure of the Drip Shield

This is a time-dependent drip shield failure mechanism. It has been conjectured that explosive gas mixtures, such as hydrogen, could accumulate within the waste package or under the drip shield *Engineered Barrier System Features, Events, and Processes* (BSC 2004 [DIRS 169898], Section 6.2.76). This mechanism has been excluded from the TSPA-LA and likewise will not contribute to the criticality potential of internal configuration classes. Therefore, the probability of occurrence for this drip shield failure mechanism is negligible.

Emplacement Error Failure of the Drip Shield

This is a time-independent drip shield failure mechanism. The probability of a drip shield emplacement error is calculated in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*, (BSC 2004 [DIRS 170024], Section 6.3.7) as having a median value of 6.0×10^{-6} per drip shield with an error factor of 4.7. The 5 percentile, the 95 percentile, and the mean values are calculated to be 1.3×10^{-6}, 2.8×10^{-5}, and 9.3×10^{-6}, respectively.

However, *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2004 [DIRS 170024], Section 6.4.7) goes on to state that it is not credible that a drip shield emplacement error will result in a nondetected gap exceeding the length of the drip shield connecting plates. Because any gap between two adjacent drip shields improperly interlocked is expected to be small, water from the drift is not expected to fall directly onto an underlying waste package. The drip shield interlock geometry will most likely cause water to first hit the lower drip shield's connecting plate and thus divert the seepage from the waste package surface. Therefore, although a drip shield emplacement error is considered possible, the drip shield failure area due to such an emplacement error is zero. Because the primary function of the drip shield (to prevent advective flow onto the waste package) is not compromised, the probability of occurrence for this drip shield failure mechanism is negligible.

Fabrication Error Failure of the Drip Shield

This is a time-independent drip shield failure mechanism. Four drip shield fabrication errors are identified in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*, (BSC 2004 [DIRS 170024], Table 20) as having the potential to increase the susceptibility of the drip shield to stress corrosion cracking or localized corrosion. These fabrication errors are weld flaws, base metal flaws, improper heat treatment, and damage by mishandling.

However, *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2004 [DIRS 169845], Section 6.6.3.1) states that "Localized corrosion of Ti Grade 7 would not initiate in a repository-relevant environment…." In addition, *Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material* (BSC 2004 [DIRS 169985], Section 6.3.7) states that stress corrosion cracks are expected to fill with corrosion products or be plugged with precipitates such as carbonate. Stress corrosion cracks are expected to be sealed within a few hundred years if water flows through the cracks at the expected very low film flow rate. If the cracks are bridged by water, the sealing process may take several thousand years, but no flow occurs. Because of the high density of the crack plugging materials and the lack of a pressure gradient to drive water through the crack, the probability of flow through the plugged crack approaches zero.

Since neither localized corrosion or stress corrosion cracking will result in an advective flow area through the drip shield, the drip shield failure area associated with drip shield fabrication errors as initiators is zero. Therefore, because the primary function of the drip shield is not compromised, the probability of occurrence for this drip shield failure mechanism is negligible.

Thermal Expansion Failure of the Drip Shield

This is a time-independent drip shield failure mechanism. As stated in *EBS Radionuclide Transport Abstraction* (BSC 2004 [DIRS 169868], Section 6.3.2.3), "Thermal and mechanical response of the drip shield may produce gaps between adjacent sections of drip shield. These breaching mechanism have been screened out …". Therefore, the probability of occurrence for this drip shield failure mechanism is negligible.

Seismic Failure of the Drip Shield

This is a time-independent drip shield failure mechanism. Seismic failures of the drip shield are not considered during the base case criticality FEPs analysis. This failure mechanism is only considered during the evaluation of the seismic disruptive event criticality FEPs analysis (Section 6.4).

Rock Fall Failure of the Drip Shield

This is a time-independent drip shield failure mechanism. Rock fall failures of the drip shield are not considered during the base case criticality FEPs analysis. This failure mechanism is only considered during the evaluation of the rock fall disruptive event criticality FEPs (Section 6.5).

It should be noted that rock fall damage to the drip shield due to a seismic event is accounted for in the BE-DS-SEISMIC1 basic event during the seismic initiating event evaluation presented in Section 6.4.

Igneous Failure of the Drip Shield

This is a time-dependent drip shield failure mechanism. Igneous failures of the drip shield are not considered during the base case criticality FEPs analysis. This failure mechanism is only considered during the evaluation of the igneous disruptive event criticality FEPs (Section 6.6).

6.3.3.1.4 Top Event MS–IC–1B

The availability of condensation water to enter a failed waste package is an important factor in waste package degradation and criticality and is associated with top event MS-IC-1B of the "MSL-ET" event tree (Appendix B, Figure B-5). The upper branch of this top event represents the availability of, at most, only insignificant quantities of condensation to enter a failed waste package. The lower branch represents that significant condensation is available to enter a failed waste package.

Based on the information contained in *In-Drift Natural Convection and Condensation* (BSC 2004 [DIRS 164327], Section 8.3), condensation can occur on the underside of the drip shield. However, it is assumed that any condensation flux from the underside of the drip shield has little potential for dripping onto the exposed waste package (Assumption 5.2.4). Therefore, condensation flux is not predicted to impact the criticality potential of a waste package and events /MS-IC-1B and MS-IC-1B will each be assigned a value of 0.00.

6.3.3.1.5 Top Event MS–IC–3A

The ability for water to enter a waste package is an important factor in waste package degradation and criticality and is associated with top event MS–IC–3A of the "MSL–ET2" event tree (Appendix B, Figure B-5). Water pathways into the waste package can be created by corrosion and/or failures caused by the waste package response to events such as seismic activity and fabrication errors. Waste package failures can be categorized as being caused by either time-dependent or time-independent mechanisms. Corrosion failure mechanisms are time-dependent and may be active or inactive during the performance evaluation period.

Time-independent waste package failure mechanisms are defined as those failure mechanisms that can occur randomly from the time of initial emplacement. A seismic event is a type of time-independent failure mechanism that can potentially result in immediate creation of an advective pathway into the waste package. In certain cases, such as fabrication errors, the failure mechanism is an initiator that exacerbates corrosion (a time-dependent mechanism).

The waste package failure mechanisms are discussed in the remainder of this section. The intent of these discussions is to justify the probability values of top event MS-IC-3A used for the evaluation of the base case criticality FEPs. Waste package failure is defined as any breach of a waste package, regardless of the mechanism, that can result in either a diffusive or advective flow path through the waste package outer barrier. The upper branch of this top event represents the probability of no waste package failures. The second and third branches respectively represent the probability of a diffusive or advective waste package failure. Waste package failure could be the result of a crack in the waste package surface or from the catastrophic failure of the complete waste package. As is discussed, not all waste package damage mechanisms result in an advective failure of the waste package.

Based on the discussions provided below, for the base case criticality FEPs conditions, the probability of occurrence of a diffusive waste package failure is calculated to be 0.100028 (sum of localized corrosion [0.1 from "Localized Corrosion Failure of the Waste Package" header] and fabrication [2.8×10^{-5} from "Fabrication Induced Failure of the Waste Package" header] failure mechanisms from fabrication induced failure of the waste package). The probability of occurrence of an advective waste package failure is negligible. The probability of no waste package failures is calculated to be 0.899972 (i.e., one minus the probability of diffusive and advective waste package failures). Therefore, /MS-IC-3A is assigned a value of 0.100028 (complement of 0.899972), MS-IC-3A[1] is also assigned a value of 0.100028, and MS-IC-3A[2] is assigned a value of 0.00.

General Corrosion Failure of the Waste Package

This is a time-dependent waste package failure mechanism. As stated in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2004 [DIRS 169996], Section 6.5.2 and Figure 22), the earliest patch failure of the waste package due to general corrosion does not occur until after 10,000 years (approximately 120,000 years). It is assumed that this information will be confirmed by TSPA-LA (Assumption 5.1.12).

It is assumed that TSPA-LA will show that there are no general corrosion failures of the waste package before 10,000 years (Assumption 5.1.12) and, therefore, the probability of waste package failure due to general corrosion during the regulatory period is zero. Therefore, the probability of occurrence of this waste package failure mechanism is negligible.

Localized Corrosion Failure of the Waste Package

This is a time-dependent waste package failure mechanism. It is assumed that localized corrosion could conceivably occur in 10 percent of the waste packages (Assumption 5.1.1). When certain environmental conditions exist in the presence of certain dust assemblages, deliquescence induced localized corrosion could conceivably result in an advective flow path into the waste package. The area impacted by this corrosion mechanism is at the top of the waste package, where the majority of dust particles with soluble salts are predicted to accumulate. However, because the drip shield is not failed to allow drift seepage to flow into the waste package (Section 6.3.3.1.1) and condensation under the drip shield (Section 6.3.3.1.4) would have only a small potential to drip onto a breached waste package, the release mechanism is controlled by diffusion. Therefore, the probability of this waste package failure mechanism is conservatively set to 0.10.

Stress Corrosion Cracking Failure of the Waste Package

This is a time-dependent waste package failure mechanism. Stress corrosion cracking of the waste package will result in a diffusive failure of the waste package (BSC 2004 [DIRS 169996], Section 6.3.5). As stated in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (BSC 2004 [DIRS 169996], Section 6.5.2 and Figure 24), the earliest crack failure of the waste package due to stress corrosion cracking does not occur until after 10,000 years (approximately 120,000 years). It is assumed that this information will be confirmed by TSPA-LA (Assumption 5.1.12).

It is assumed that TSPA-LA will show that there are no stress corrosion cracking failures of the waste package before 10,000 years (Assumption 5.1.12) and, therefore, the probability of waste package failure due to stress corrosion cracking during the regulatory period is zero. Thus, the probability of occurrence of this waste package failure mechanism is negligible.

Hydrogen Detonation Failure of the Waste Package

This is a time-dependent waste package failure mechanism. It has been conjectured that explosive gas mixtures, such as hydrogen, could accumulate within the waste package or under the drip shield *Engineered Barrier System Features, Events, and Processes* (BSC 2004 [DIRS 169898], Section 6.2.76). This mechanism has been excluded from the TSPA-LA and likewise will not contribute to the criticality potential of internal configuration classes. Therefore, the probability of occurrence for this waste package failure mechanism is negligible.

Fabrication Induced Failure of the Waste Package

This is a time-independent waste package failure mechanism. Four waste package fabrication errors are identified in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*, (BSC 2004 [DIRS 170024], Table 20) as having the potential to increase the susceptibility of the waste package to stress corrosion cracking. These fabrication errors are weld flaws, improper heat treatment, improper laser peening, and damage by mishandling. Stress corrosion cracking of the waste package will result in a diffusive failure of the waste package (BSC 2004 [DIRS 169996], Section 6.3.5). Other fabrication errors, e.g., assembly errors, have been screened out since improper components will either not fit into the waste package or the waste form cannot be loaded.

After ultrasonic testing inspection, the mean probability of the occurrence of one or more weld flaws in the upper and middle closure lids is 0.18 and 0.20, respectively (BSC 2004 [DIRS 170024], Table 13). For the waste package seam weld, the mean probability increases to 0.46 (BSC 2004 [DIRS 170024], Table 13). The residual stresses/stress intensity factors resulting from weld flaws may induce stress corrosion cracking. However, as noted above in this section, the earliest crack failure of the waste package due to stress corrosion cracking is not predicted to occur until after 10,000 years (approximately 120,000 years) (BSC 2004 [DIRS 169996], Section 6.5.2, Figure 24). It is assumed that this information will be confirmed by TSPA-LA (Assumption 5.1.12).

The probability of improper heat treatment has been combined with the probabilities of improper laser peening and damage by mishandling. From the information presented in Table 4.1-1, this event has been calculated to have a median value of 7.2×10^{-6} per waste package with an error factor of 15 and a mean value of 2.8×10^{-5} per waste package (BSC 2004 [DIRS 170024], Table 22). The probability of having at least one waste package early failure in the repository due to fabrication errors has been calculated to be 0.17 (BSC 2004 [DIRS 169996], Section 6.4.12). Recommendations from *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (BSC 2004 [DIRS 170024], Section 6.4.8) state that the entire waste package surface should be considered affected by an improper heat treatment.

Based on the information above, the probability of occurrence for waste package early failure is 2.8×10^{-5}.

Seismic Failure of the Waste Package

This is a time-independent waste package failure mechanism. Seismic failures of the waste package are not considered during the base case criticality FEPs analysis. This failure mechanism is only considered during the evaluation of the seismic disruptive event criticality FEPs (Section 6.4).

Rock Fall Failure of the Waste Package

Rock fall failures of the waste package during the base case criticality FEPs analysis are not considered credible since no drip shield failures occur from rock fall.

Igneous Failure of the Waste Package

This is a time-dependent waste package failure mechanism. Igneous failures of the waste package are not considered during the base case criticality FEPs analysis. This failure mechanism is only considered during the evaluation of the igneous disruptive event criticality FEPs (Section 6.6).

6.3.3.1.6 Top Event MS–IC–3B

This top event is not accessed during the base case criticality FEPs analysis.

6.3.3.1.7 Top Event MS-IC-4

This top event is not accessed during the base case criticality FEPs analysis.

6.3.3.1.8 Top Event NA–MISLOAD

The presence of neutron absorber materials in a waste package is important to criticality control during the regulatory period for the majority of the waste forms proposed for disposal in the repository. Misload of the neutron absorber materials is associated with top event NA–MISLOAD of the "MSL–ET2" event tree (Figure B-5). The upper branch of this top event indicates that there is no neutron absorber material misload and the lower branch indicates that there is a misload.

Neutron absorber material misload can occur as the result of several mechanisms during the waste package fabrication and loading processes. These processes include the use of wrong materials, failure to load the neutron absorber materials into the waste package or waste form, and selection of the wrong waste package type. The probabilities necessary to quantify the NA–MISLOAD top event for each of the waste package/waste form types are summarized in Table 6.3-5. The justification for their value assignment is discussed in the remainder of this section.

Assessment of the neutron absorber material misload event only accounts for the potential to load none or less than the designed mass of neutron absorber material. No penalty is assigned for loading additional neutron absorber materials into a waste package or waste form.

Because the manufacturing, fabrication, and waste form loading processes have not yet been established for the waste package and its related components, the following probabilities are based on generic human reliability analysis values for the performance of basic operations. As the manufacturing processes, fabrication process, and surface facility operational procedures are developed, more detailed evaluation of the probability of neutron absorber material misload can be performed. It is assumed that the use of generic human reliability analysis values generate more limiting (i.e., higher probability of failure) results (Assumption 5.1.4).

Based on the information provided below, the probabilities listed in Table 6.3-5 are assigned to the various waste package/waste form types for both /NA-MISLOAD and NA-MISLOAD.

Table 6.3-5. Neutron Absorber Material Misload Probabilities

Waste Package / Waste Form Type	Event Probability
21-PWR Control Rod Waste Package	4.576E-8
21-PWR Absorber Plate Waste Package	7.875E-9
12-PWR Absorber Plate Waste Package	6.217E-11
44-BWR Absorber Plate Waste Package	6.217E-11
24-BWR Absorber Plate Waste Package	6.217E-11
DOE SNF canister baskets with neutron absorber materials [a]	6.217E-11
DOE SNF canisters with neutron absorber filler materials [b]	3.906E-8
DOE SNF canisters with neutron absorber filler materials and baskets with neutron absorber materials [c]	3.912E-8
DOE SNF canisters without neutron absorber materials [d]	0.0 [e]

Source: Tables 6.3-6, 6.3-7, and 6.3-8

NOTES: [a] Aluminum Based, MOX, and U-Zr Hx DOE SNF waste forms
[b] U/Th Oxide DOE SNF waste form
[c] U-Zr/U-Mo DOE SNF waste form
[d] HEU Oxide, LEU Oxide, U-Metal, and U/Th Carbide DOE SNF waste forms.
[e] No misload potential results in zero probability of misload.

Material Selection Errors

During the manufacturing of the neutron absorber material to be included in the fabrication of the waste form container (either a waste package or a DOE standardized SNF canister) it is possible that the manufacturer could inadvertently select a material that does not have any neutron absorbing properties. Although no specific analysis of neutron absorber material selection error has been performed, improper material selection evaluations have been performed for weld and base metal materials in *Analysis of Mechanisms of Early Waste Package/Drip Shield Failure* (BSC 2003 [DIRS 170024], Section 6.2.3). The results of this evaluation yield a median probability of 3.5×10^{-5} and an error factor of 2.3. From this information, a mean probability of 3.979×10^{-5} is calculated using Equation 6.3-1. Therefore, the probability of occurrence for this event is assigned a value of 3.979×10^{-5}.

$$\mu = 50^{th} \cdot \exp\left(\frac{1}{2}\cdot\sigma^2\right) \qquad \text{(Eq. 6.3-1)}$$

where

μ = mean human error probability
50^{th} = median human error probability
$\sigma = \left(\frac{\ln(EF)}{1.645}\right)$ (Modarres 1993 [DIRS 104667], p. 266)
EF = error factor

During the assembly of the commercial SNF waste package, it is possible that the assembler could inadvertently select a waste package basket assembly that does not have neutron absorber materials. This selection error is only possible for the 21–PWR Absorber Plate and the 21–PWR Control Rod waste package types. Basket selection errors for other commercial SNF waste packages are not possible because of the dimensional differences of the basket assemblies. The 21–PWR Absorber Plate and 21–PWR Control Rod waste package basket assemblies are identical in dimensions, but differ in material. The 21–PWR Absorber Plate waste package basket assembly is manufactured from a nickel-gadolinium alloy and the 21–PWR Control Rod waste package basket assembly is manufactured from stainless steel.

It is assumed (Assumption 5.1.5) that because the 21–PWR Absorber Plate waste package and the 21–PWR Control Rod waste package are dimensionally identical, they may be fabricated by the same manufacturer(s). It is further assumed that the commercial SNF waste packages are delivered at the repository with the basket assembly already contained within the waste package. When the manufacturer assembles the basket assemblies, it is possible that the 21–PWR Control Rod waste package basket assembly could be selected and inserted into a 21–PWR Absorber Plate waste package or that the waste package could be mislabeled prior to shipping.

The selection of the wrong basket material can be approximated by the probability of an operator selecting a wrong control from a panel of similar looking controls. This event has a median probability of 3.0×10^{-3} and an error factor of 3 (Swain and Guttman 1983 [DIRS 139383], Item 2 of Table 20-12). From this information, a mean probability of 3.75×10^{-3} is calculated using Equation 6.3-1. Therefore, the probability of occurrence for this event is assigned a value of 3.750×10^{-3} per waste package.

The mislabeling of the waste package prior to shipping can be approximated by the probability of an error of commission in reading and recording quantitative information. This event has a median probability of 1.0×10^{-3} and an error factor of 3 (Swain and Guttman 1983 [DIRS 139383], Item 9 of Table 20-10). From this information, a mean probability of 1.25×10^{-3} is calculated using Equation 6.3-1. Therefore, the probability of occurrence for this event is assigned a value of 1.250×10^{-3} per waste package.

It is possible to recover from the above selection and labeling errors. The possibility of using improper materials has been virtually eliminated with the evolution of new instrumentation, such as portable X-ray spectroscopy equipment, to perform quick field measurements of material composition. It is assumed that such a quality control inspection will be performed on the waste packages and canisters upon receipt of the waste package at the repository or the DOE standardized SNF canister at the DOE SNF loading facility (Assumption 5.1.8). It is also assumed that a separate independent verification inspection will be performed just prior to the loading of the waste form (Assumption 5.1.15). However, there is still the possibility that there is a failure to perform these operations correctly. The human error probability (HEP) can be approximated by the (lognormal) probability of improperly checking a digital display, which has a median of 1.0×10^{-3} and an error factor of 3 (Swain and Guttman 1983 [DIRS 139383], Item 2 of Table 20-10). From this information, a mean probability of 1.25×10^{-3} is calculated using Equation 6.3-1. Therefore, the probability of non-recovery is assigned a value of 1.250×10^{-3} per waste package for each of these tests.

The probability of this event can be calculated for each waste package / waste form type using Equation 6.3-2:

$$Pr_{mse} = (Pr_{wm} + Pr_{se} + Pr_{ml})(Pr_{nrec\text{-}receipt})(Pr_{nrec\text{-}load}) \qquad \text{(Eq. 6.3-2)}$$

where

Pr_{mse} = probability of material selection error
Pr_{wm} = probability of wrong materials
Pr_{se} = probability of basket material selection error
Pr_{ml} = probability of mislabeling the waste package
$Pr_{nrec\text{-}receipt}$ = probability of non-recovery at receipt
$Pr_{nrec\text{-}load}$ = probability of non-recovery at loading

The values assigned to each of these probabilities and the calculated result for each waste form / waste package type is calculated as follows in Table 6.3-6:

Table 6.3-6. Waste Package Neutron Absorber Material Selection Error Probabilities

Waste Package / Waste Form Type	Event Probability					
	Pr_{wm}	Pr_{se}	Pr_{ml}	$Pr_{nrec\text{-}receipt}$	$Pr_{nrec\text{-}load}$	Pr_{mse}
21-PWR Control Rod Waste Package	3.979E-5	0.0 [c]	1.250E-3	1.250E-3	1.250E-3	2.015E-9
21-PWR Absorber Plate Waste Package	3.979E-5	3.750E-3	1.250E-3	1.250E-3	1.250E-3	7.875E-9
12-PWR Absorber Plate Waste Package	3.979E-5	0.0 [c]	0.0 [c]	1.250E-3	1.250E-3	6.217E-11
44-BWR Absorber Plate Waste Package	3.979E-5	0.0 [c]	0.0 [c]	1.250E-3	1.250E-3	6.217E-11
24-BWR Absorber Plate Waste Package	3.979E-5	0.0 [c]	0.0 [c]	1.250E-3	1.250E-3	6.217E-11
DOE standardized SNF canister baskets with neutron absorber materials [a]	3.979E-5	0.0 [c]	0.0 [c]	1.250E-3	1.250E-3	6.217E-11
DOE standardized SNF canister baskets without neutron absorber materials [b]	0.0 [c]	0.0 [c]	0.0 [c]	0.0 [c]	0.0 [c]	0.0

NOTES [a] DOE standardized SNF canister baskets for Aluminum Based, U-Zr/U-Mo Alloy, and U-Zr Hx DOE SNF waste forms
[b] DOE standardized SNF canisters for, HEU Oxide, LEU Oxide, U-Metal, U/Th Carbide, and U/Th Oxide DOE SNF waste forms
[c] Probability is zero since error is not applicable to this waste package type or has no consequences.

Waste Form Neutron Absorber Material Loading Error

For select commercial PWR SNF, the neutron absorber material is integral to the waste form. Control rods of neutron absorbing B_4C (Assumption 5.1.3) are inserted and locked into the guide tubes of PWR fuel assemblies designated for the 21-PWR Control Rod waste package type. The neutron absorber material for DOE SNF waste forms is poured into the DOE standardized SNF canister in the form of shot at the time of waste form loading. The DOE SNF waste forms that require neutron absorber materials are U/Th Oxide and U-Zr/U-Mo Alloy. The probability of neutron absorber misload errors is set to 0.00 for waste forms not requiring absorber material to be loaded with the waste form.

During the loading of commercial PWR SNF assemblies, the burnup and initial enrichment of each assembly is compared to the 21–PWR Absorber Plate loading curve (BSC 2004 [DIRS 171414]). Based on this comparison, the assembly is either acceptable to load into a 21–

PWR Absorber Plate waste package or is designated for inclusion in the 21–PWR Control Rod waste package type. If the assembly is slated for the 21–PWR Control Rod waste package type, a control rod assembly is inserted into the fuel assembly's guide tubes. Failure to insert the control rod assembly could result in the loading of the assembly into the 21-PWR Control Rod waste package without adequate reactivity control. It should be noted that loading a waste form into the wrong waste package type (such as putting an assembly intended for a 21–PWR Control Rod waste package into a 21–PWR Absorber Plate waste package) is covered by the WF–MISLOAD top event.

Failure to insert the neutron absorber materials can occur due to one of two mechanisms – (1) failure to properly identify the waste form or, after properly identifying the waste form, (2) failure to insert the neutron absorber material. Both failure mechanisms are equivalent to incorrectly using a procedure with check-off provisions. For long list procedures (more than 10 items), the median probability is listed as 1.0×10^{-2} with an error factor of 3 (Swain and Guttman 1983 [DIRS 139383], Item 4 of Table 20-7). From this information, a mean probability of 1.25×10^{-2} is calculated using Equation 6.3-1. Therefore, the probability of occurrence is each assigned a value of 1.250×10^{-2} per loading.

Recovery of a neutron absorber material misload for a waste form is likely. This is because the absence of the neutron absorber material is visibly recognizable during the loading processes. Although the missing neutron absorber materials are readily visible, there is always the possibility that its omission is missed as the waste form is loaded and the container sealed. The probability of non-recovery can be approximated by the probability of improperly checking a digital display, which has a median probability of 1.0×10^{-3} and an error factor of 3 (Swain and Guttman 1983 [DIRS 139383], Item 2 of Table 20-10). From this information, a mean probability of 1.25×10^{-3} is calculated using Equation 6.3-1. Therefore, this probability of non-recovery is assigned a value of 1.250×10^{-3} per loading.

An additional recovery action for DOE standardized SNF canisters is the weighing of the canisters prior to shipping. If the weight of the canister is less than the expected weight within tolerances, then the neutron absorber material may not have been added at loading and the error recovered. Although the weight of the canister is readily verified, there is always the possibility that the weight is misread or the action not performed. The probability of non-recovery can be approximated to be the same as the visual inspection. Therefore, this probability of non-recovery is assigned a value of 1.250×10^{-3} per DOE standardized SNF canister.

The analysis of commercial SNF misload probabilities performed in *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316]) indicates that if a 21-PWR Control Rod waste package is mistakenly selected when a 21-PWR Absorber Plate waste package is required, there is a 4.374×10^{-8} probability that no control rods or other neutron absorber materials will be inserted into any of the PWR assemblies loaded into the waste package (BSC 2003 [DIRS 166316], Table 11, Sequences 18C, 20C, 29C, and 31C). This probability includes recovery actions.

The probability of this event can be calculated for each waste package/waste form type using Equation 6.3-3:

$$Pr_{wfle} = (Pr_{wfid} + Pr_{wfl})(Pr_{nrec\text{-}visual})(Pr_{nrec\text{-}weigh}) \qquad \text{(Eq. 6.3-3)}$$

where

Pr_{wfle} = probability of waste form loading error
Pr_{wfid} = probability of waste form identification error
Pr_{wfl} = probability of failure to load neutron absorber material into the waste form
$Pr_{nrec\text{-}visual}$ = probability of non-recovery due to visual inspection
$Pr_{nrec\text{-}weigh}$ = probability of non-recovery due to weighing (DOE SNF only)

The values assigned to each of these probabilities and the calculated result for each waste form/waste package type or DOE standardized SNF canister is listed as follows in Table 6.3-7:

Table 6.3-7. Waste Form Neutron Absorber Material Loading Error Probabilities

Waste Package / Waste Form Type	**Event Probability**				
	Pr_{wfid}	Pr_{wfl}	$Pr_{nrec\text{-}visual}$	$Pr_{nrec\text{-}weigh}$	Pr_{wfle}
21-PWR Control Rod Waste Package	N/A [a]	N/A [a]	N/A [a]	N/A [a]	4.374×10^{-8}
21-PWR Absorber Plate Waste Package	0.0 [d]	0.0 [d]	0.0 [d]	0.0 [d]	0.0
12-PWR Absorber Plate Waste Package	0.0 [d]	0.0 [d]	0.0 [d]	0.0 [d]	0.0
44-BWR Absorber Plate Waste Package	0.0 [d]	0.0 [d]	0.0 [d]	0.0 [d]	0.0
24-BWR Absorber Plate Waste Package	0.0 [d]	0.0 [d]	0.0 [d]	0.0 [d]	0.0
DOE SNF waste forms with filler materials [b]	1.250E-2	1.250E-2	1.250E-3	1.250E-3	3.906E-8
DOE SNF waste forms without filler materials [c]	0.0 [d]	0.0 [d]	0.0 [d]	0.0 [d]	0.0

NOTES: [a] N/A means that the total probability was not derived from Equation 6.3-3.
[b] U/Th Oxide and U-Zr/U-Mo Alloy DOE SNF waste forms
[c] Aluminum Based, HEU Oxide, LEU Oxide, MOX, U-Metal, U/Th Carbide, and U-Zr Hx DOE SNF waste forms
[d] Probability is zero since error is not applicable to this waste package type or has no consequences.

Waste Package Selection Error

A waste package selection error during waste package loading operations can occur if either (1) the operator inadvertently requests and receives the wrong waste package type or (2) the operator requests the correct waste package type, but the wrong waste package type is selected and delivered. This error is based on the assumption that, at any given time, an inventory of all waste package types is available at the repository. Recovery of a waste package selection error is guaranteed in almost all cases because of the different waste package sizes and internal configurations. The only selection error where recovery may not be possible, or where there are negative consequences, is when a 21–PWR Control Rod waste package is utilized in place of a 21–PWR Absorber Plate waste package. All other waste package selection error probabilities are given a 0.0 value since there are no negative consequences. This selection error is credible because both waste package types are identical in size and configuration. The only difference is that the basket assembly of the 21–PWR Control Rod waste package does not contain any neutron absorber material. The evaluation of this event in *Commercial Spent Nuclear Fuel*

Waste Package Misload Analysis (BSC 2003 [DIRS 166316], Section 6.2.1), indicates that probability of occurrence for this event, including recovery, is 1.394×10^{-6} (BSC 2003 [DIRS 166316], Table 11, Sequences 13C and 24C). Therefore, the probability of occurrence for this event is 1.394×10^{-6} per 21–PWR Absorber Plate waste package. This probability value includes the recovery action for an independent checker to detect discrepancies between the operator's actions and the procedure. However, if a field measurement to determine the basket composition is performed just prior to waste package loading, an additional reduction in probability of misload can be achieved. As documented in the "Material Selection Errors" discussion above, the mean probability of non-recovery for this action is 1.250×10^{-3}. Accounting for this additional recovery action results in a probability of 1.743×10^{-9}.

Based on the discussion above, the probability of waste package selection error assigned to each waste form/waste package type is presented in Table 6.3-8.

Table 6.3-8. Waste Package Selection Error Probabilities

Waste Package / Waste Form Type	Event Probability
21-PWR Control Rod Waste Package	0.0 [a]
21-PWR Absorber Plate Waste Package	1.743E-9
12-PWR Absorber Plate Waste Package	0.0 [a]
44-BWR Absorber Plate Waste Package	0.0 [a]
24-BWR Absorber Plate Waste Package	0.0 [a]
All DOE SNF waste packages	0.0 [a]

Note: [a] Probability is zero since error is not applicable to this waste package type or has no consequences.

6.3.3.1.9 Top Event WF–MISLOAD

The WF–MISLOAD top event represent the probability that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

An analysis of commercial SNF misload probabilities was performed in *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316]). Results from this analysis reports the probability of misloading an SNF assembly into a 21–PWR Absorber Plate Waste Package as 1.18×10^{-5} (BSC 2003 [DIRS 166316], Table 41). For the 44–BWR Absorber Plate (BSC 2003 [DIRS 166316], Table 41) waste package type, the probability is reported as 1.73×10^{-5}. According to *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316], Section 7), the probability of assembly misload for the 21–PWR Control Rod, 12–PWR Absorber Plate and 24–BWR Absorber Plate waste package types is negligible.

The only DOE SNF waste form that has any misload potential is MOX. It is assumed that the misload probability for the MOX waste form will not exceed the highest misload probability calculated for commercial SNF waste package types (i.e., 1.18×10^{-5} for the 21–PWR Absorber Plate waste package) (Assumption 5.1.13). The MOX misload potential is the loading of six assemblies into the DOE standardized SNF canisters with a loading restriction of five assemblies. Such a misload is possible because there are six cell locations available within the DOE standardized SNF canister for this waste form.

An additional reduction of the MOX misload probability can be achieved by accounting for a visual inspection of the loaded canister to verify that one location within the canister is empty. Although the loaded and empty canister cell locations should be readily identifiable, there is always the possibility that the presence of an extra assembly is overlooked and the container sealed. The probability of non-recovery for this scenario can be approximated by the probability of improperly checking a digital display, which has a median probability of 1.0×10^{-3} and an error factor of 3 (Swain and Guttman 1983 [DIRS 139383], Item 2 of Table 20-10). From this information, a mean probability of 1.25×10^{-3} is calculated using Equation 6.3-1. Therefore, this probability of nonrecovery is assigned a value of 1.250×10^{-3} per MOX DOE standardized SNF canister. Combining this secondary recovery action with the 1.18×10^{-5} misload probability results in a calculated probability of misload for the MOX DOE SNF waste form of 1.475×10^{-8} (probability of misload times the probability of nonrecovery).

Based on the information provided above, the probabilities listed in Table 6.3-9 are assigned to the various waste package/waste form types for both /WF–MISLOAD and WF–MISLOAD.

Table 6.3-9. Waste Form Misload Probabilities

Waste Package / Waste Form Type	Event Probability
21-PWR Control Rod Waste Package	0.0
21-PWR Absorber Plate Waste Package	1.18E-5
12-PWR Absorber Plate Waste Package	0.0
44-BWR Absorber Plate Waste Package	0.0
24-BWR Absorber Plate Waste Package	0.0
DOE SNF waste forms with misload potential [a]	1.475E-8
DOE SNF waste forms without misload potential [b]	0.0

NOTES: [a] MOX DOE SNF waste form
[b] Aluminum Based, HEU Oxide, LEU Oxide, U-Metal, U/Th Carbide, U/Th Oxide, U-Zr Hx, and U-Zr/U-Mo Alloy DOE SNF waste forms

6.3.3.1.10 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of a waste package with a diffusive failure. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

Ten percent of the waste package inventory is assumed to fail from localized corrosion that is initiated after repository closure due to seepage and/or dust associated chemistries (Assumption 5.1.1). No water accumulation in the waste package occurs because of the lack of seepage or condensation flow into the failed waste packages due to no drip shield failures in the base case. In addition, for the base case the waste forms are predicted to remain intact. For each of the waste forms evaluated in the base case criticality FEPs analysis, criticality evaluations have shown that without water for neutron moderation, criticality cannot occur (refer to DOE SNF references in Table 6.2-1 and commercial SNF references BSC 2004 [DIRS 171414] and BSC 2004 [DIRS 169963]). This is true even if a waste form or neutron absorber material misload occurs. Therefore, for all base case criticality FEPs conditions, only the upper branch of this top event is activated and /CRIT-POT-WF is assigned a value of 0.00 (True) and CRIT-POT-WF is assigned a value of 0.00 (False).

6.3.3.2 Quantification of Event Tree "CONFIG-NF4"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree "CONFIG-NF4" (Figure B-18 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-4. This event tree consists of four top events, of which only one is required for the evaluation of base case criticality FEPs. Table 6.3-10 summarizes the event probability assignments discussed below.

Near-field configurations that involve fissile material from one waste package affecting the criticality potential of adjacent waste packages have been screened out based upon the neutronic isolation of the waste packages. The neutronic isolation is a result of the exclusion of effective reflectors around the waste packages, i.e., no external pooling expected, and the low probability of near-field criticality (Table 6.3-12).

Table 6.3-10. Event Probability Assignment for the "CONFIG-NF4" Event Tree for the Base Case Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Water ponds on drift floor due to sealing and/or damming			
/MS-NF-2 (seepage does not pond on drift floor)	True [a]	0.00	Section 6.3.3.2.1
MS-NF-2 (seepage does pond on drift floor)	False	0.00	
(MS-NF-2 top event)			
Dry transport of fissile material from the waste package transfers to the surface of the invert			
/MS-NF-DD (no accumulation of fissile material on invert)	True [a]	0.00	Section 6.3.3.2.2
MS-NF-DD (accumulation of fissile material on invert)	False	0.00	
(MS-NF-DD top event)			

NOTE: [a] For events prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.3.3.2.1 Top Event MS-NF-2

The branching of top event MS-NF-2 determines whether seepage water ponds on the drift floor due to sealing or damming. The upper branch of this top event indicates that ponding does not occur and the bottom branch indicates that it does. As stated in *Engineered Barrier System Features, Events, and Processes* (BSC 2004 [DIRS 169898], Section 6.2.40), ponding in the invert has been excluded. Therefore, /MS-NF-2 is assigned a value of 0.00 (True) and MS-NF-2 is assigned a value of 0.00 (False).

6.3.3.2.2 Top Event MS-NF-DD

The branching of top event MS-NF-DD determines whether fissile material can accumulate on the invert surface due to dry transport mechanisms from a failed waste package that does not experience advective flow. The upper branch of this top event indicates that fissile material does not accumulate on the invert surface, and the bottom branch indicates that it does. *EBS Radionuclide Transport Abstraction* (BSC 2004 [DIRS 169868], Executive Summary and Section 8.1) states that diffusive transport is the sole means of transport in a no-seep envirnment (no drip shield separation) for fissile material that to leave a failed waste package. The quantity of this material is shown below to be insufficient for achieving a critical mass. Therefore, /MS-NF-DD is assigned a value of 0.00 (True) and MS-NF-DD is assigned a value of 0.00 (False).

The following calculation shows that the amount of uranium released by diffusive transport from a waste packaged breached by stress corrosion cracks over a 10,000-year period is insufficient to achieve a critical mass.

In a no-seep environment where there is no flow of liquid water, uranium can diffuse from the breached waste package through porous corrosion products that fill the stress corrosion products. Dissolution of uranium and subsequent diffusion occur in a thin film of water that is adsorbed onto and partially saturates the corrosion products. The diffusive flux of dissolved uranium from a waste package, q (kg U/s), is given by Fick's first law of diffusion (Bird et. al. 1960 [DIRS 103524], p. 503):

$$q = -DA\frac{\partial C}{\partial x} \approx -DA\frac{\Delta C}{\Delta x}, \qquad \text{(Eq. 6.3-4)}$$

where A is the cross sectional diffusive area of the stress corrosion cracks (m^2), D is the diffusion coefficient for uranium (m^2/s), ΔC is the concentration gradient of uranium (kg U/m^3), and Δx is the diffusive path length (m).

The mass of uranium released by diffusion through stress corrosion cracks, m (kg U), over a period of time, Δt (yr), is given by:

$$m = q\Delta t = DA\Delta t\frac{\Delta C}{\Delta x}. \qquad \text{(Eq. 6.3-5)}$$

The earliest crack failure of the waste package due to stress corrosion cracking is not predicted to occur until after 10,000 years (approximately 120,000 years) (BSC 2004 [DIRS 169996], Figure 24). Thus, considering stress-corrosion cracking prior to 500,000 years is a conservative approach. The cross-sectional area of a single stress corrosion crack is estimated to be 7.7×10^{-6} m^2 (BSC 2004 [DIRS 169868], Section 6.3.3.1.2.1). At the 95th percentile confidence interval, the average number of crack penetrations per failed CSNF waste package ranges from zero to about 30 for times between 200,000 and 500,000 years (BSC 2004 [DIRS 169996],

Figure 26). Using 30 stress corrosion cracks per waste package, the total cross-sectional diffusive area of stress corrosion crack openings in a failed waste package is $A = 2.31 \times 10^{-4}$ m^2.

The diffusion coefficient for uranium in porous corrosion products is given by an empirical function of porosity and saturation, Archie's law (BSC 2004 [DIRS 169868], Section 6.5.1.2.1.4.2):

$$D = \phi^{1.3} S_{we,CP}^{2} D_0 \qquad \text{(Eq. 6.3-6)}$$

where D_0 is the self-diffusion coefficient of water (2.299×10^{-5} cm^2/s), used as a bounding value for diffusivity in bulk liquid water for all radionuclides (BSC 2004 [DIRS 169868], Section 6.3.4.1).

It is assumed that the porous corrosion products that fill the stress corrosion cracks have a porosity of $\phi = 0.4$ (fraction) (BSC 2004 [DIRS 169868], Section 6.5.1.2.1.3.2).

The corrosion products are partially saturated with water. The effective water saturation of corrosion products, $S_{we,CP}$ (fraction), depends on the relative humidity, RH (fraction), of the air in the immediate vicinity of the stress corrosion cracks and on the specific surface area of corrosion products, $\bar{s}_{CP}$ (m^2/kg) (BSC 2004 [DIRS 169868], Section 6.5.1.2.1.4.2):

$$S_{we,CP} = 1.312 \times 10^{-6} \bar{s}_{CP} \left(-\ln RH \right)^{-1/2.45} . \qquad \text{(Eq. 6.3-7)}$$

The specific surface area of corrosion products is uncertain, ranging from 1000.0 to 22,000 m^2/kg (BSC 2004 [DIRS 169868], Section 6.5.1.2.1.3.1). Diffusive releases will be maximized when the specific surface area of corrosion products is $\bar{s}_{CP} = 22{,}000$ m^2/kg.

Diffusive releases will also be maximized when the concentration gradient of uranium, ΔC, is maximized. According to Table 8-2 of *In-Package Chemistry Abstraction* (BSC 2004 [DIRS 167621]), the pH inside a failed CSNF waste package will lie in the range 4.5 to 7.0 during the period from 600 to 20,000 years if the temperature is between 25 °C and 100 °C. For this range of pH, the solubility limit of uranium inside a CSNF waste package breached under nominal conditions or by seismic activity is 2.33 ($\log_{10}$ U (mg/L)) (BSC 2004 [DIRS 169425], Section 8.1). This is a concentration inside the package of 214 mg/L. The maximum concentration gradient will occur when the concentration outside the package is zero, giving $\Delta C = 214$ mg/L or .214 kg/m^3.

The diffusive path length from a source of dissolved uranium inside a waste package to the exterior of the waste package is uncertain, ranging from 0.02 to 0.859 m (parameter Diff_Path_Length_CP_CSNF, BSC 2004 [DIRS 169868], Table 8.2-5). Diffusive releases will be maximized when the diffusive path length is at its minimum, $\Delta x = 0.02$ m. This is the thickness of the waste package outer corrosion barrier, so it is also the diffusive path length through stress corrosion cracks alone; any additional path length inside the waste package from a uranium source to a stress corrosion crack in the outer corrosion barrier is neglected.

Using the parameter values above that maximize the diffusive release, the mass of uranium released by diffusion through stress corrosion cracks over a period of time, Δt (yr), is then given as a function of RH as:

$$
\begin{aligned}
m = q\Delta t = DA\Delta t\frac{\Delta C}{\Delta x} \\
&= 1.72\times10^{-12}\,\phi^{1.3}\,\overline{s}_{CP}^{\,2}\left(-\ln RH\right)^{-2/2.45} D_0 A\Delta t\frac{\Delta C}{\Delta x} \qquad \text{(Eq. 6.3-8)} \\
&= 4.54\times10^{-8}\left(-\ln RH\right)^{-2/2.45}\Delta t.
\end{aligned}
$$

Over a time period of Δt = 10,000 years, the mass of uranium released by diffusion through stress corrosion cracks for a range of relative humidities is shown in Table 6.3-11.

Table 6.3-11. Diffusive Release of Uranium over 10,000 Years

RH	Diffusive Releases of Uranium Over 10^4 Years (kg U)
0.9	2.9×10^{-3}
0.99	1.9×10^{-2}
0.999	1.3×10^{-1}
0.9999	8.4×10^{-1}

These results show that the mass of uranium released from a waste package through stress corrosion cracks over a 10,000-year period is insufficient to achieve a critical mass (Table 6.3-2).

6.3.4 Base Case Criticality FEPs Analysis Results

The probability of criticality per waste package for the base case criticality FEPs are shown in Table 6.3-12. These probability results have been generated to address the criticality FEPs of Tables 6.3-1 and 6.3-3 and are summarized from the SAPHIRE analysis results presented in Appendix B, Section B.23. Because there is no mechanism to breach the drip shield for these base case criticality FEPs during the regulatory period, there is no probability for advective flow to enter a failed waste package and generate a potentially critical configuration. Therefore, the probability of criticality for the base case criticality FEPs analysis is negligible.

Table 6.3-12. Per Waste Package Criticality Probabilities from SAPHIRE Analysis of Base Case Criticality FEPs

Waste Package Type	**Number of Waste Packages**[a]	**Per Waste Package Probability of Criticality**[b]			
		Intact In-Package	**Degraded In-Package**	**Near-Field**	**Far-Field**
21-PWR Absorber Plate	4299	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21-PWR Control Rod	95	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12-PWR Absorber Plate	163	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24-BWR Absorber Plate	84	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44-BWR Absorber Plate	2831	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ MOX	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ MOX	61	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U-Zr Hx	165	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U-Metal	16	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U-Metal	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF MCO w/ U-Metal	220	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ HEU Oxide	655	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ HEU Oxide	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U/Th Oxide	20	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U/Th Oxide	73	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U/Th Carbide	605	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ Aluminum Based	1226	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ Aluminum Based	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U-Zr/U-Mo Alloy	14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U-Zr/U-Mo Alloy	19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ LEU Oxide	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ LEU Oxide	344	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Source: [a] Values from Table 4.1-3
[b] SAPHIRE V. 7.18 (BSC 2002 [DIRS 160873]) analysis results (Appendix B, Section B.24) and Microsoft EXCEL spreadsheet "endstate.xls". (Probability values below the screening criterion are set to 0.0.)

6.4 ANALYSIS OF SEISMIC DISRUPTIVE EVENT CRITICALITY FEPS

Vibratory ground motion and rock fall induced by a seismic event have been conjectured as initiating events that could cause drip shield failure through separation and/or corrosion leading to subsequent waste package failure. Such failures may allow the influx of seepage (either advective or diffusive) into the waste package, which, in turn, has the potential to cause a criticality. Although these failure mechanisms have been determined not to affect the criticality potential of the repository through analyses showing no drip shield separation due to seismic events (BSC 2004 [DIRS 170295], Section 6.5.4) and no corrosion related mechanisms for drip shield failure resulting in advective flow paths (Section 6.3.4), discussion of these processes are included in this section for purposes of completeness. The probabilities associated with the events are set to 0.0 since there is no mechanism for them to occur and thus no contribution to the criticality potential for the repository.

A seismic event can, however, induce fault displacement that can potentially lead to drip shield and waste package failure for those structures intersecting the fault, which can then potentially allow advective or diffusive flow into the waste package and lead to conditions conducive to criticality. Additionally, new fractures that intersect the drift segments and the collapsing of the drift due to a seismic event will have an affect on the seepage as to both location and rate. However, these changes in seepage have no impact on the repository's potential for criticality without drip shield failure resulting from fault displacement. Thus, fault displacement (Section 6.4.4.1) is the only seismic disruptive event affecting the criticality potential of the repository.

Table 6.4-1 presents the seismic disruptive event criticality FEPs 2.1.14.18.0A, 2.1.14.19.0A, 2.1.14.20.0A, and 2.2.14.10.0A, which may initiate a sequence of events that can lead to a potential critical event. The direct and indirect effects of seismic activities on in-package criticality, near-field criticality, and far-field criticality are analyzed in this section.

Table 6.4-1. Seismic Disruptive Event Criticality FEPs

FEP Number	FEP Title	FEP Description
2.1.14.18.0A	In-package criticality resulting from a seismic event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a seismic disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.
2.1.14.19.0A	In-package criticality resulting from a seismic event (degraded configurations)	Either during or as a result of, a seismic disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.20.0A	Near-field criticality resulting from a seismic event	Either during or as a result of, a seismic disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.10.0A	Far-field criticality resulting from a seismic event	Either during or as a result of, a seismic disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Source: Table 6.1-1

Uncertainty is included in the seismic evaluation of potential in-package criticality, because of its importance to any analysis. Uncertainty is included throughout the evaluation by the development of probability distributions sampled via a Latin Hypercube Sampling method. The principle of Latin Hypercube Sampling is provided by Modarres (1993 [DIRS 104667], p. 244). The developed probability distributions represent the epistemic uncertainty for the parameters of interest. An example is the damaged area (i.e., separation) of drip shield, which is dependent upon the seismic event PGV. The analysis develops a probability distribution representing the epistemic uncertainty about the damaged area of the drip shield (i.e., separation) and then samples this distribution to obtain the damaged area (i.e., separation) based on the seismic event.

The developed Latin Hypercube Sampling method evaluates the epistemic uncertainty of all input parameters either developed within the evaluation or based on other reports. An example of an external parameter with its epistemic uncertainty accounted for in the Latin Hypercube Sampling method would be the seepage rate.

Seismic Peak Ground Velocity

The horizontal peak ground velocity (PGV) is related to the mean annual seismic exceedance frequency. This relationship was developed in *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Section 6.4). The relationship between the PGV values and the mean annual seismic exceedance frequency was developed by scaling the PGV values at the monitored geologic repository (MGR) surface down to the drift. Based on this relationship scaled to the drift, the PGV values and their related mean annual seismic exceedance frequencies are listed in Table 6.4-2 (DTN: MO0409SPACALSS.005 [DIRS 171833], Table 1).

Table 6.4-2. Mean Annual Exceedance Frequency and Corresponding Peak Ground Velocity

Mean Annual Exceedance Frequency (1/yr)	Peak Ground Velocity (m/s)
6.26×10^{-4}	0.159
2.78×10^{-4}	0.239
9.30×10^{-5}	0.398
1.84×10^{-5}	0.796
3.07×10^{-6}	1.59
2.28×10^{-7}	3.98
8.15×10^{-8}	5.57
2.60×10^{-8}	7.96
6.56×10^{-9}	11.9

Source: DTN: MO0409SPACALSS.005 [DIRS 171833], Table 1

Drip Shield Failure from Seismic Event

Damage to the drip shield via drip shield separation, which has the potential to allow advective flow to reach the waste package, can occur due to vibratory ground motion. The percent damaged area (i.e., separation) of the drip shield from a seismic event follows a uniform distribution. The lower-bound of the uniform distribution for the percent damaged area is based on linear interpolation below a PGV value of 5.35 m/s and linear extrapolation for PGV values above 5.35 m/s. The lower-bound tabular values are shown in Table 6.4-3 (DTN: MO0409SPACALSS.005 [DIRS 171833], Table 1).

Table 6.4-3. Lower-Bound Percent Damaged Area of Drip Shield Due to Seismic Event

PGV Value (m/s)	Damaged Area to Drip Shield (percent)
0.00	0.0
2.44	0.0
5.35	10.0

Source: DTN: MO0409SPACALSS.005 [DIRS 171833], Table 1

The upper-bound of the uniform distribution is also correlated to the PGV value. Table 6.4-4 provides the upper-bound percent damaged area of the drip shield based on PGV value. The upper-bound value can be interpolated for PGV values not directly listed. The tabulated values (DTN: MO0409SPACALSS.005 [DIRS 171833], Table 1) are listed in Table 6.4-4.

Table 6.4-4. Upper-Bound Percent Damaged Area of Drip Shield Due to Seismic Event

PGV Value (m/s)	Damaged Area to Drip Shield (percent)
0.00	0.00
2.44	0.00
5.35	50.0
20.0	50.0

Source: DTN: MO0409SPACALSS.005 [DIRS 171833], Table 1

Waste Package Failure

Waste package failure is defined as any breach of a waste package, regardless of the mechanism, that can result in either a diffusive or advective flow path through the waste package outer barrier. A waste package failure that creates a diffusive flow path can occur due to vibratory ground motion. The percent damaged area of the waste package from a seismic event follows a uniform distribution. The calculated percent damaged area of a waste package follows a uniform distribution (DTN: MO0409SPACALSS.005 [DIRS 171833], Table 1) ranging from a minimum of 0.0 to an upper-bound that is correlated to the PGV value by

$$\text{Upper Bound} = \begin{array}{ll} 0.436 \times \text{PGV} - 0.305 & \text{PGV} > 0.7 \\ 0.0 & \text{PGV} \leq 0.7. \end{array} \qquad \text{(Eq. 6.4-1)}$$

6.4.1 Seismic Ground Motion Effects on In-Package Criticality Evaluations

A seismic event has the potential to lead to a critical event by causing damage to the drip shield and waste package, which can create an advective or diffusive flow to penetrate the damaged waste package. Water penetrating a damaged waste package can lead to a potential criticality via moderation or degradation of the waste form into a more critical composition. This section uses the information from *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183]) and

Abstraction of Drift Seepage (BSC 2004 [DIRS 169131]) in the probability evaluation of sufficient seepage filling a damaged waste package, which then has the potential of becoming critical.

6.4.1.1 Seismic Effects in the Lithophysal Zone

A seismic event can affect the drip shield, waste package, and cladding from vibratory ground motion. Rock fall induced by the seismic event can cause stress cracks on the drip shield, but will not cause any damage to the waste package. A seismic event can also affect the seepage of water into the drift due to new fractures or the collapsing of the drift. Seepage is an important factor that can lead to a waste package criticality. Seepage can lead to localized corrosion on the outer barrier of the waste package and possible penetration of the barrier, which allows the seepage water to enter and fill the waste package. Seepage is an important aspect to criticality because of its moderation potential. In order for seepage to penetrate the waste package and potentially lead to a criticality, multiple barriers must be breached. A seismic event can initiate breach of these barriers, which is the drip shield separation that can lead to waste package outer barrier breach via localized corrosion. Breaching (i.e., separation) of a drip shield followed by waste package damage from localized corrosion are analyzed below. In addition, the development and use of seepage rate distributions filling a damaged waste package is analyzed.

The analysis is divided into two separate repository geological zones, lithophysal and nonlithophysal. Each zone requires separate evaluations because of the effect a seismic event has on the seepage rates due to drift fracturing or collapse. The lithophysal zone represents approximately 85 percent of the total repository drift area (refer to Section 6.2).

The methodology for evaluating damage to the drip shield and waste package is the same for both repository drift zones. Therefore, drip shield and waste package damage assessment process is independent of location within the repository.

6.4.1.1.1 Drip Shield and Waste Package Damage

Drifts in the lithophysal zone are expected to collapse during a seismic event and the void area between the drip shield and the drift area to become filled. The collapse of the drift in this zone does not damage the drip shield because the rock type is low in compressive strength and is permeated with void spaces (BSC 2004 [DIRS 169183], Section 6.6.2). This weak rock is expected to collapse into small fragments under the load imposed by the vibratory ground motion. Any failure to the drip shield in this zone is expected to occur only from the vibratory ground motions that cause the drip shields to separate, allowing an advective flowpath for seepage into the waste package.

To account for drip shield damage, *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Section 6.6.3) developed an abstraction, which is followed to calculate the drip shield percent damaged area (i.e., separation). To account for the drip shield damage, a Mathcad spreadsheet was developed (Appendix D) to use the seismic inputs listed above in subsections (Drip Shield Failure from Seismic Event) and (Waste Package Failure). This Mathcad spreadsheet also accounts for the uncertainty in the drip shield percent damaged area (i.e., separation) by performing a Latin Hypercube Sampling process.

The process to calculate the drip shield percent damaged area (i.e., separation) is outlined in *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Section 6.9.2) and DTN: MO0409SPACALSS.005 [DIRS 171833]. The process discusses sampling the mean annual exceedance frequency of a seismic event to obtain a PGV value. The mean annual seismic exceedance frequency follows a log-uniform distribution between 10^{-8} to 10^{-6} per year. Although *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Section 6.9.2) addresses seismic annual exceedance frequencies between 10^{-8} to 10^{-4} per year, only annual exceedance frequencies less than 10^{-6} per year (corresponding to a PGV value of 2.44 m/s) will result in drip shield damage (i.e., separation) (BSC 2004 [DIRS 169183], Section 6.9.2).

The sampled mean annual seismic exceedance frequency is used to obtain the corresponding PGV value from log-linear interpolation of the lookup table (refer to Table 6.4-2). The interpolated PGV value is used to determine the upper and lower-bounds of the uniform distribution representing the drip shield percent damaged area (i.e., separation). However, the information provided in *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Section 6.4.4) limits, or caps, the maximum PGV values at 5.0 m/s, thereby limiting the predicted damage area for the drip shield. However, drip shield damage area (i.e., separation) is maximized at 50 percent for seismic annual exceedance frequencies of 10^{-7} per year. At these frequencies and lower the drip shields are predicted to relocate and completely overlap one another (BSC 2004 [DIRS 169183], Section 6.5.6).

The upper-bound percent damaged area is interpolated from Table 6.4-4 based on the sampled PGV value. This interpolated upper-bound value is input into the uniform distribution that represents the drip shield percent damaged area (i.e., separation). The lower-bound of the uniform distribution is also determined by interpolation. The lower-bound percent damaged area uses the lookup table shown in Table 6.4-3. The lower-bound percent damaged area is based on the same sampled PGV value. Once the lower and upper-bounds of the uniform distribution are obtained, this distribution is then sampled to calculate the drip shield percent damaged area (i.e., separation) for that particular seismic event. This percent damaged area value is stored within the Mathcad spreadsheet.

The process then repeats with a newly sampled mean seismic exceedance frequency. This newly sampled mean seismic exceedance frequency leads to a new drip shield percent damaged area (i.e., separation) based on that seismic event. This process is performed for 30,000 realizations. The mean fraction of drip shield damaged area (i.e., percent damage divided by 100) from the sampled vibratory ground motions is calculated to be 4.568×10^{-2} and the 5 and 95 percentile are 0.0 and 1.811×10^{-1}, respectively (refer to Appendix D, pp. D-3 and D-4).

The waste package may also be damaged due to vibratory ground motion in the lithophysal zone. The damage to the waste package is not calculated in this analysis because all seismic induced waste package damage is stress corrosion cracks. These cracks will only allow diffusive flow to enter the waste package, which is an insufficient amount of water for moderation. Therefore, seismic induced waste package damage will not be calculated and carried further in the analysis.

Advective flow paths into the waste package may be created following a seismic event if the corresponding drip shield damage (i.e., separation) allows the infiltration of seepage to reach the waste package. Even if the waste package does not see seepage, localized corrosion can still occur and is assumed to attack up to 10 percent of the total population of waste packages (Assumption 5.1.1) creating an advective flow path into these waste packages. Otherwise, waste package damage will only create a diffusive flow path.

6.4.1.1.2 Seepage Rate Probability Distribution for Lithophysal

The process used to determine the seepage rate distributions, which is used to calculate the seepage probability, follows the process steps discussed in *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1). The determination of the seepage rate distributions is discussed below and presented in Appendix C, Section C.3.

In order to determine seepage rate distributions, a Latin Hypercube Sampling process was developed to handle the spatial variability and uncertainty of the seepage parameters. The routine sampled each seepage parameter for 20,000 realizations to ensure sufficient coverage of the parameter range. There are three key parameters, which are sampled in order to determine the seepage rate distributions.

The first parameter, capillary strength ($1/\alpha$), is determined to have a spatial variability that is uniformly distributed with a range between 402 Pa to 780 Pa, and a mean of 591 Pa. The uncertainty about the capillary strength, $\Delta(1/\alpha)$, follows a triangular distribution with a lower-bound of -105 Pa, upper-bound of +105 Pa, and a mean of 0.0 (BSC 2004 [DIRS 169131], Section 6.7.1.1). These distributions are identical for all geological zones. The Latin Hypercube Sampling process samples a capillary strength value from the spatial variability and adds it to the sampled capillary strength value from the uncertainty distribution. This calculated capillary strength is used in the interpolation process along with the other sampled key parameters to determine the seepage rate. This sampling process is performed for 20,000 realizations.

The next key parameter for the lithophysal zone, permeability (k), is determined to have a spatial variability distribution that is lognormal with a mean of -11.5 (in log 10) and a standard deviation of 0.47 (in log 10). The mean and standard deviation of permeability was determined from statistical analysis on the log-transformed data. The permeability uncertainty (Δk) follows a triangular distribution with a lower-bound of -0.92, upper-bound +0.92, and a mean of 0.0 (BSC 2004 [DIRS 169131], Section 6.7.1.1). These distributions are for the lithophysal zone only. The Latin Hypercube Sampling process samples a permeability value from the spatial variability and adds it to the sampled permeability value from the uncertainty distribution. This calculated permeability is used in the interpolation process along with the other sampled key parameters to determine the seepage rate. This sampling process is performed for 20,000 realizations.

Percolation flux is sampled from the percolation flux information that represents the repository area (BSC 2004 [DIRS 169131], Figure 6.6-10). The sampling process uses the glacial transition climate percolation flux information, which occurs 2000 years after repository closure and lasts through the regulatory period of 10,000 years (BSC 2004 [DIRS 170002], Section 6.6.1). The percolation flux uncertainty is expressed by three different scenarios (lower-bound, mean, and upper-bound). Since there are three different scenarios that are used to represent the uncertainty, three different final seepage rate distributions are obtained (one for each scenario).

The percolation flux is adjusted to account for intermediate-scale heterogeneity by using flow focusing factors (Equation 6.4-2) (DTN: LB0104AMRU0185.012 [DIRS 163906]). The flow focusing factors are obtained by sampling the cumulative distribution function (Equation 6.4-2). The sampled flow focusing factor is then multiplied to the sampled percolation flux. Equation 6.4-2 is the cumulative distribution function for the flow focusing factors where the variable x represents the flow-focusing factor.

$$ff = -0.3137x^4 + 5.4998x^3 - 35.66x^2 + 102.3x - 11.434 \qquad \text{(Eq. 6.4-2)}$$

The seepage rate for each of the uncertainty scenarios (i.e., lower-bound, mean, and upper-bound) is determined via the developed sampling routine (refer to Appendix C, Section C.3). The sampling routine samples a value from the three key parameters (i.e., capillary strength, permeability, and adjusted percolation flux), that are used to interpolate the mean seepage rate and seepage rate standard deviation. The mean seepage rate and seepage rate standard deviation are from the lookup table for the degraded drift (DTN: LB0307SEEPDRCL.002 [DIRS 164337]). Prior to using the standard deviation, it is adjusted to account for uncertainty by creating a uniform distribution with a lower-bound of $-\sqrt{3}$ times the sampled standard deviation and an upper-bound of $+\sqrt{3}$ times the sampled standard deviation. The uniform distribution to account for uncertainty is sampled and added to the interpolated mean seepage rate. This process is performed for 20,000 realizations (refer to Appendix C, Section C.3).

The resulting seepage rate values are adjusted prior to being used to determine the seepage flux probability by (1) setting seepage rates less than 0.1 kg/yr per waste package to zero (since these small values are the result of interpolation (BSC 2004 [DIRS 169131], Section 6.7.1.1), and (2) capping calculated seepage rates at 100 percent.

Seepage rates are then filtered in order to develop a distribution that represents the seepage rate values by discarding all seepage rates with a zero value. The remaining nonzero seepage rates are then used to develop a Weibull distribution for each of the scenarios (i.e., lower-bound, mean, and upper-bound) to represent the seepage rate at the drift (refer to Appendix C, Section C.3). These Weibull distributions are used to calculate the probability of having sufficient seepage to fill and overflow a damaged waste package (refer to Appendix D). In addition, to calculate the fraction of waste package locations with seepage, the number of nonzero seepage rates is divided by the total number of realizations (i.e., seepage fraction). The Weibull parameters, scale and shape (α and β, respectively), and seepage fraction for each scenario are listed in Table 6.4-5.

Table 6.4-5. Weibull Parameters and Seepage Fraction (Lithophysal Zone)

Weibull Parameters	Value	Seepage Fraction
Lower-Bound Seepage Scenario (Drift Collapse)		
α (scale)	9.303E+00 (liters/year)	1.926E−01
β (shape)	4.95E−01	
Mean Seepage Scenario (Drift Collapse)		
α (scale)	1.455E+02 (liters/year)	5.149E−01
β (shape)	4.561E−01	
Upper-Bound Seepage Scenario (Drift Collapse)		
α (scale)	3.81E+02 (liters/year)	6.408E-01
β (shape)	4.858E−01	

Source: Appendix C, p. C-45

6.4.1.2 Seismic Effects in the Nonlithophysal Zone

The nonlithophysal zone is analyzed separately because of the difference in seepage rates due to the drift fracturing instead of collapsing as it does in the lithophysal zone. Damage to the drip shield and waste package remains the same for the nonlithophysal zone as discussed in Section 6.4.1.1. However, drip shields can be impacted by rock blocks being ejected from the drift due to a seismic event. This damage is discussed below.

6.4.1.2.1 Drip Shield and Waste Package Damage

Seismic induced rock fall has been determined in *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Sections 6.6.2) and determined that stress corrosion cracks were created on the drip shield. However, these stress corrosion cracks are small and tight, which makes advective flow passing through these cracks negligible (BSC 2004 [DIRS 169183], Sections 6.5.4). Seismic induced rock fall does not to result in waste package failure as discussed in *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Sections 6.6.3). The rock blocks can not reach the waste packages since the drip shields remain relatively intact.

Vibratory ground motion damage to the drip shield and waste package is the same in the nonlithophysal zone as in the lithophysal zone. The effects of this damage mechanism are presented in Section 6.4.1.1.1. Therefore, no additional discussion of this damage mechanism is necessary.

6.4.1.2.2 Seepage Rate Probability Distribution for Nonlithophysal

The process used to determine the seepage rate distribution for the nonlithophysal zone, which is used to calculate the seepage probability, follows the process steps discussed in *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1) and Section 6.4.1.1.2. The only differences are the permeability, k, and the look-up table for seepage rate, and the seepage rate standard deviation.

Capillary strength ($1/\alpha$) is the same for the nonlithophysal zone as it is for the lithophysal zone.

The nonlithophysal zone permeability (*k*) is determined to have a spatial variability distribution that is lognormal with a mean of -12.2 (in log 10) and a standard deviation of 0.34 (in log 10). The mean and standard deviation of permeability were determined from statistical analysis on the log-transformed data. The permeability uncertainty (Δk) follows a triangular distribution with a lower-bound of −0.68, upper-bound +0.68, and a mean of 0.0 (BSC 2004 [DIRS 169131], Section 6.7.1.1). These distributions are for the nonlithophysal zone only.

The percolation flux representing the repository area (BSC 2004 [DIRS 169131], Figure 6.6-10) is the same for the nonlithophysal as for the lithophysal. The percolation flux uncertainty is expressed by three different scenarios for the spatial flux distributions (lower-bound, mean, and upper-bound). Since three different scenarios are used to represent the uncertainty, three seepage rate distributions (one for each scenario) are obtained for the nonlithophysal zone.

The percolation flux is adjusted for intermediate-scale heterogeneity by using flow-focusing factors (Equation 6.4-2), which are sampled and multiplied by the sampled percolation flux. However, for the nonlithophysal zone, the interpolated seepage rate is increased by 20 percent to account for rock bolts and drift degradation (BSC 2004 [DIRS 169131], Section 6.7.1.2).

The seepage rate at the drift for each of the uncertainty scenarios (i.e., lower-bound, mean, and upper-bound) is determined using the same sampling process discussed in Section 6.4.1.1.2. The sampled value from the three key parameters (i.e., capillary strength, permeability, adjusted percolation flux) is used to interpolate the mean seepage rate and seepage rate standard deviation using the lookup table for the non-degraded drift (DTN: LB0304SMDCREV2.002 [DIRS 163687]). The standard deviation is adjusted to account for uncertainty by creating a uniform distribution with a lower-bound of $-\sqrt{3}$ times the sampled standard deviation and an upper-bound of $+\sqrt{3}$ times the sampled standard deviation. The uniform distribution to account for uncertainty is sampled and then added to the interpolated mean seepage rate. This process is performed for 20,000 realizations (refer to Appendix C, Section C.4).

The resulting seepage rate values are adjusted prior to being used to determine the seepage rate probability by (1) setting seepage rates less than 0.1 kg/yr per package to zero (since these small values are the result of interpolation (BSC 2004 [DIRS 169131], Section 6.7.1.1)), and (2) capping calculated seepage rates at 100 percent.

Seepage rates are then filtered in order to develop a distribution that represents the seepage rate values by discarding all seepage rates with a zero value. The remaining nonzero seepage rates are then used to develop a Weibull distribution for each of the scenarios (i.e., lower-bound, mean, and upper-bound) to represent the seepage rate at the drift (refer to Appendix C, Section C.2). These Weibull distributions are used to calculate the probability of having sufficient seepage to fill and overflow a damaged waste package (refer to Appendix D). In addition, to calculate the fraction of waste package locations that see seepage, the number of nonzero seepage rates is divided by the total number of realizations (i.e., seepage fraction). The Weibull parameters, scale and shape (α and β, respectively), and seepage fraction for each scenario are listed in Table 6.4-6.

Table 6.4-6. Weibull Parameters and Seepage Fraction (Nonlithophysal Zone)

Weibull Parameters	Values	Seepage Fraction
Lower-Bound Seepage Scenario (Drift Collapse)		
α (scale)	5.099E+00 (liters/year)	1.542E−01
β (shape)	5.135E−01	
Mean Seepage Scenario (Drift Collapse)		
α (scale)	8.414E+01 (liters/year)	5.234E−01
β (shape)	4.619E−01	
Upper-Bound Seepage Scenario (Drift Collapse)		
α (scale)	2.232E+02 (liters/year)	6.716E−01
β (shape)	4.932E−01	

Source: Appendix C, p. C-60

6.4.2 SAPHIRE Event Probability Assignment for Seismic Scenarios

Based on the calculations in the above sections, the following basic events are modified from the base case criticality FEPs SAPHIRE analysis of the seismic disruptive event evaluations. Assignment of the event probabilities for the seismic SAPHIRE criticality FEPs evaluation is presented in the following sections. The events presented in these sections are used to quantify:

- The master scenario list event trees “MSL-ET” and “MSL-ET2” (Figures B-4 and B-5 of Appendix B, respectively)
- The waste package internal configuration event trees “CONFIG-BATH” and “CONFIG-IP4-A” (Figures B-6 and B-11 of Appendix B, respectively)
- The near-field configuration event trees “CONFIG-NF-F”, “CONFIG-NF1”, “CONFIG-NF2”, “CONFIG-NF3”, and “CONFIG-NF4” (Figures B-14, B-15, B-16, B-17, and B-18 of Appendix B, respectively)
- The far-field configuration event trees “CONFIG-FF-J”, “CONFIG-FF-K”, and “CONFIG-FF3” (Figures B-21, B-22, and B-23 of Appendix B, respectively).

Justification for the probability values assigned to these events is, in part, based on the information presented in the previous discussions.

6.4.2.1 Quantification of Event Trees “MSL-ET” and “MSL-ET2

The quantification of nine events and processes are required to define the formation of a waste package bathtub or flow-through configuration. These events are listed as top events of the “MSL-ET” event tree (Figure B-4, Appendix B) and its continuation event tree “MSL-ET2” (Figure B-5, Appendix B). The following subsections provide justification for the probabilities assigned to the events used in the quantification of event trees “MSL-ET” and “MSL-ET2” for the seismic criticality FEPs evaluations. Table 6.4-7 summarizes the event probability assignments discussed below.

Table 6.4-7. Event Probability Assignment for the "MSL-ET" and "MSL-ET2" Event Trees for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Availability of Seepage			Section 6.4.2.1.1
For the lithophysal zone:			
/MS-IC-1A-SEIS-NWL (no seepage scenario)	5.184E-1	4.816E-1	
MS-IC-1A-SEIS-LL (lower-bound seepage scenario)	4.622E-2	4.622E-2	
MS-IC-1A-SEIS-ML (mean seepage scenario)	2.111E-1	2.111E-1	
MS-IC-1A-SEIS-UL (upper-bound seepage scenario)	2.243E-1	2.243E-1	
For the nonlithophysal zone:			
/MS-IC-1A-SEIS-NWNL (no seepage scenario)	5.133E-1	4.867E-1	
MS-IC-1A-SEIS-LNL (lower-bound seepage scenario)	3.701E-2	3.701E-2	
MS-IC-1A-SEIS-MNL (mean seepage scenario)	2.146E-1	2.146E-1	
MS-IC-1A-SEIS-UNL (upper-bound seepage scenario)	2.351E-1	2.351E-1	
(MS-IC-1A top event)			
Availability of Seepage in the Near-Field Environment			Section 6.4.2.1.2
/MS-NF-T (water available to enter failed WP)	True [a]	0.00	
MS-NF-T ((water available directly to drift))	True	1.00	
(MS-NF-T top event)			
Probability that drip shield failure within 10,000 years.			Section 6.4.2.1.3
For seismic ground motion scenarios			
/MS-IC-2	True [a]	0.0	
MS-IC-2	False	0.0	
For seismic faulting scenarios			
/MS-IC-2	False [a]	1.00	
MS-IC-2	True	1.00	
(MS-IC-2 top event)			
Availability of Condensation underneath the drip shield			Section 6.4.2.1.4
/MS-IC-1B	True [a]	0.00	
MS-IC-1B	False	0.00	
(MS-IC-1B top event)			

Table 6.4-7. Event Probability Assignment for the "MSL-ET" and "MSL-ET2" Event Trees for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Probability of waste package fails within 10,000 years.			Section 6.4.2.1.5
For no seepage or no drip shield failure scenarios:			
/**MS-IC-3A** (no failure)	False [a]	1.00	
MS-IC-3A[1] (diffusive flow path)	True	1.00	
MS-IC-3A[2] (advective flow path)	False	0.0	
For seepage and drip shield failure scenarios before 2000 years			
/**MS-IC-3A** (no failure)	False [a]	1.00	
MS-IC-3A[1] (diffusive flow path)	False	0.00	
MS-IC-3A[2] (advective flow path)	True	1.00	
(MS-IC-3A top event)			
Probability of formation of waste package bathtub configuration			Section 6.4.2.1.6
/MS-IC-3B	False [a]	1.00	
MS-IC-3B	True	1.00	
(MS-IC-3B top event)			

Table 6.4-7. Event Probability Assignment for the "MSL-ET" and "MSL-ET2" Event Trees for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Probability of filling and overflowing the waste package given a bathtub configuration [b]			Section 6.4.2.1.7
Lower-bound seepage scenario for a 21-PWR Absorber Plate waste package type in the lithophysal zone:			
/MS-IC-4 (not filled scenario)	8.229E-1	1.771E-1	
MS-IC-4[1] (lower-bound seepage scenario)	1.771E-1	1.771E-1	
MS-IC-4[2] (mean seepage scenario)	False	0.00	
MS-IC-4[3] (upper-bound seepage scenario)	False	0.00	
Lower-bound seepage scenario for a 21-PWR Absorber Plate waste package type in the nonlithophysal zone:			
/MS-IC-4 (not filled scenario)	8.419E-1	1.581E-1	
MS-IC-4[1] (lower-bound seepage scenario)	1.581E-1	1.581E-1	
MS-IC-4[2] (mean seepage scenario)	False	0.00	
MS-IC-4[3] (upper-bound seepage scenario)	False	0.00	
Mean seepage scenario for a 21-PWR Absorber Plate waste package type in the lithophysal zone:			
/MS-IC-4 (not filled scenario)	7.686E-1	2.314E-1	
MS-IC-4[1] (lower-bound seepage scenario)	False	0.00	
MS-IC-4[2] (mean seepage scenario)	2.314E-1	2.314E-1	
MS-IC-4[3] (upper-bound seepage scenario)	False	0.00	
Mean seepage scenario for a 21-PWR Absorber Plate waste package type in the nonlithophysal zone:			
/MS-IC-4 (not filled scenario)	7.758E-1	2.242E-1	
MS-IC-4[1] (lower-bound seepage scenario)	False	0.00	
MS-IC-4[2] (mean seepage scenario)	2.242E-1	2.242E-1	
MS-IC-4[3] (upper-bound seepage scenario)	False	0.00	
Upper-bound seepage scenario for a 21-PWR Absorber Plate waste package type in the lithophysal zone:			
/MS-IC-4 (not filled scenario)	2.447E-1	2.447E-1	
MS-IC-4[1] (lower-bound seepage scenario)	False	0.00	
MS-IC-4[2] (mean seepage scenario)	False	0.00	
MS-IC-4[3] (upper-bound seepage scenario)	2.447E-1	2.447E-1	
Upper-bound seepage scenario for a 21-PWR Absorber Plate waste package type in the nonlithophysal zone:			
/MS-IC-4 (not filled scenario)	2.404E-1	2.404E-1	
MS-IC-4[1] (lower-bound seepage scenario)	False	0.00	
MS-IC-4[2] (mean seepage scenario)	False	0.00	
MS-IC-4[3] (upper-bound seepage scenario)	2.404E-1	2.404E-1	
(MS-IC-1A top event)			

Table 6.4-7. Event Probability Assignment for the “MSL-ET” and “MSL-ET2” Event Trees for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Probability of neutron absorber material misload in the waste package or waste form			Section 6.4.2.1.8
For the 21-PWR Control Rod waste package type			
/NA-MISLOAD	~1	3.758E-9	
NA-MISLOAD	3.758E-9	3.758E-9	
For the 21-PWR Absorber Plate waste package type			
/NA-MISLOAD	~1	4.576E-8	
NA-MISLOAD	4.576E-8	4.576E-8	
For the 12-PWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For the 44-BWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For the 24-BWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For DOE SNF Group 1 waste package types with neutron absorber materials in the canister basket [c]			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For DOE SNF Group 2 waste package types with neutron absorber materials in filler [d]			
/NA-MISLOAD	~1	3.906E-8	
NA-MISLOAD	3.906E-8	3.906E-8	
For DOE SNF Group 3 waste package types with neutron absorber materials in canister basket and filler [e]			
/NA-MISLOAD	~1	3.912E-8	
NA-MISLOAD	3.912E-8	3.912E-8	
For DOE SNF waste package types without neutron absorber materials [f]			
/NA-MISLOAD	True [a]	0.00	
NA-MISLOAD	False	0.00	
(MS-IC-3B top event)			

Table 6.4-7. Event Probability Assignment for the “MSL-ET” and “MSL-ET2” Event Trees for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Probability of waste package misload:			Section 6.4.2.1.9
For the 21-PWR Absorber Plate waste package			
/WF-MISLOAD	~1	1.18E-5	
WF-MISLOAD	1.18E-5	1.18E-5	
For the 21-PWR Control Rod waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 12-PWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 44-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 24-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For DOE waste package types with misload potential [g]			
/WF-MISLOAD	~1	1.475E-5	
WF-MISLOAD	1.475E-5	1.475E-5	
For DOE waste package types without misload potential[h]			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
(WF-MISLOAD top event)			

Table 6.4-7. Event Probability Assignment for the "MSL-ET" and "MSL-ET2" Event Trees for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package for all waste package types)	Justification
Criticality potential of waste package dry diffusion configuration **/CRIT-POT-WF** **CRIT-POT-WF** (CRIT-POT-WF top event)	True [a] False	0.00 0.00	Section 6.4.2.1.10

NOTES: [a] For event names prefixed by a slash "/," the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1-value) of the assigned value.

[b] Only an example of this top event's probability assignment for one waste package type under seismic induced localized corrosion conditions is provided here. A complete list of this event's probabilities for all waste package types, corrosion scenarios, and seepage scenarios are found in Tables 6.4-5 and 6.4-6.

[c] Aluminum Based, MOX, and U-Zr Hx DOE SNF waste forms with neutron absorber materials in the canister basket assembly

[d] U/Th Oxide DOE SNF waste form with neutron absorber material in the canister filler materials

[e] U-Zr/U-Mo Alloy DOE SNF waste form with neutron absorber material in the canister basket and filler materials

[f] HEU Oxide, LEU Oxide, U-Metal, and U/Th Carbide DOE SNF waste forms without neutron absorber materials

[g] MOX DOE SNF waste form with misload potential

[h] Aluminum Based, HEU Oxide, LEU Oxide, U-Metal, U/Th Carbide, U/Th Oxide, and U-Zr Hx, and U-Zr/U-Mo Alloy DOE SNF waste forms without misload potential

6.4.2.1.1 Top Event MS-IC-1A

The amount of seepage reaching the drift is an important factor in waste package degradation and criticality potential. Two parameters characterize the seepage into the emplacement drifts – the seepage fraction (location within the drifts that see seepage) and the seepage rate (the volume of water entering the drift on an annual basis). The purpose of top event MS-IC-1A is to represent the possibility that seepage is available in a drift to enter a breached waste package. The upper branch of this top event indicates that seepage does not occur and the bottom three branches indicates that seepage does occur: branch 1 – lower-bound seepage scenario, branch 2 - mean seepage scenario and branch 3 – upper-bound seepage scenario. The probability of attaining seepage for the lower-bound, mean, and upper-bound seepage scenarios is based on *Analysis of Infiltration Uncertainty* (BSC 2003 [DIRS 165991], Table 7-1) and seepage fraction calculated in Sections 6.4.1.1.2 and 6.4.1.2.2.

The seepage fraction (i.e., the fraction of waste packages that see seepage) and seepage rate distributions for the lower-bound, mean, and upper-bound climate scenario is based on the glacial transition climate. The glacial transition is expected to last from roughly 2000 to 10,000 years after repository closure (BSC 2004 [DIRS 170002], Section 6.6.1). The Latin Hypercube Sampling process discussed in Sections 6.4.1.1.2 and 6.4.1.2.2 was performed for 20,000 realizations to obtain the seepage fraction used to quantify the seepage scenario branch probabilities. The results of the sampling process are documented in Appendix C, Sections C.3 and C.4 for the lithophysal and nonlithophysal geological zones, respectively.

Because of differences in the drift after a seismic event for the lithophysal and nonlithophysal geologic zone, it was necessary to perform separate Latin Hypercube samplings for each zone. The results reported in Tables 6.4-2 and 6.4-3 are the drift fractional probability of seepage given the specified seepage scenario (i.e., lower-bound, mean, or upper-bound). The probability of the individual seepage scenarios is specified in Table 7-1 of *Analysis of Infiltration Uncertainty* (BSC 2003 [DIRS 165991]). The seepage scenario probability is calculated by taking the seepage fraction for each scenario (i.e., lower-bound, mean, and upper-bound) and multiplying it to the probability of being in that seepage scenario. This calculation has been performed in the EXCEL spreadsheet "Probability of Seepage" (Appendix G). The appropriate seepage probability is then substituted into the SAPHIRE analysis based on the sequence branching of top event DRIFT-ZONE of the "YMP-INIT-EVENT" event tree. The results of this calculation are assigned as follows:

Lithophysal Zone Seismic Disruptive Event Seepage Probabilities

/MS-IC-1A-SEIS-NWL = 4.816E-1 (no seepage probability — SAPHIRE takes the complement of this value)
MS-IC-1A-SEIS-LL = 4.622E-2 (lower-bound seepage scenario probability)
MS-IC-1A-SEIS-ML = 2.111E-1 (mean seepage scenario probability)
MS-IC-1A-SEIS-UL = 2.243E-1 (upper-bound seepage scenario probability)

Nonlithophysal Zone Seismic Disruptive Event Seepage Probabilities

/MS-IC-1A-SEIS-NWNL = 4.867E-1 (no seepage probability — SAPHIRE takes the complement of this value)
MS-IC-1A-SEIS-LNL = 3.701E-2 (lower-bound seepage scenario probability)
MS-IC-1A-SEIS-MNL = 2.146E-1 (mean seepage scenario probability)
MS-IC-1A-SEIS-UNL = 2.351E-1 (upper-bound seepage scenario probability)

6.4.2.1.2 Top Event MS-NF-T

The branching of top event MS-NF-T represents the availability of seepage to flow directly into the invert. The upper branch indicates that seepage does not flow into the invert and the lower branch indicates that it is available. If seepage is available to flow directly into the invert, the sequence transfers to the "CONFIG-NF4" event tree for the evaluation of near-field configuration class NF-4. Because both pathways are likely to occur simultaneously, both branches of this top event are processed to ensure the evaluation of all configuration classes. In order to process both branches of this top event, /MS-NF-T is assigned a value of 0.00 (i.e., the complement of 1.00) and MS-NF-T is assigned a value of 1.00.

6.4.2.1.3 Top Event MS-IC-2

The probability of water passing through the drip shield in order to reach the waste package is an important factor in waste package degradation and criticality. Water pathways through the drip shield can be created by stress corrosion cracks and/or gaps caused by the drip shield response to seismic events. This event is associated with top event MS-IC-2 of the "MSL-ET" event tree (Figure B-4, Appendix B). The upper branch represents no drip shield failure and the lower branch represents that the drip shield has failed.

The intent of this discussion is to justify the probability value of top event MS–IC–2 for the evaluation of the seismic criticality FEPs. Drip shield failure is defined as drip shield damage, which results in an advective flow path through the drip shield and onto the waste package outer barrier.

Based on the discussions provided below, for the seismic criticality FEPs conditions, the drip shield becomes damaged and allows advective flow to reach the waste package outer barrier. Therefore, /MS-IC-2 and MS-IC-2 are each assigned a value of 1.00.

Seismic Failure of the Drip Shield

This time independent drip shield failure mechanism can cause an advective flow through the drip shield. However, seismic failures of the drip shield are not predicted to occur due to seismic ground motion (BSC 2004 [DIRS 169183], Section 6.5.4.3). For seismic faulting events, drip shields on the fault are damaged to the point where they are completely ineffective (i.e., 100 percent failure) (BSC 2004 [DIRS 169183], Section 6.7.5).

Therefore, for seismic ground motion scenarios, the probability of occurrence for drip shield failure is negligible. For seismic faulting scenarios, drip shield failure probability is 1.0.

6.4.2.1.4 Top Event MS-IC-1B

The availability of condensation water to enter a failed waste package is an important factor in waste package degradation and criticality and is associated with top event MS-IC-1B of the "MSL-ET" event tree (Appendix B, Figure B-5). The upper branch of this top event represents the availability of, at most, only insignificant quantities of condensation to enter a failed waste package. The lower branch represents that significant condensation is available to enter a failed waste package.

Based on the information contained in *In-Drift Natural Convection and Condensation* (BSC 2004 [DIRS 164327], Section 8.3), condensation can occur on the underside of the drip shield. However, it is assumed that any condensation flux from the underside of the drip shield has little potential for dripping onto the exposed waste package (Assumption 5.2.4). Therefore, condensation flux is not predicted to impact the criticality potential of a waste package and events /MS-IC-1B and MS-IC-1B will each be assigned a value of 0.00.

6.4.2.1.5 Top Event MS-IC-3A

The ability for water to enter a waste package is an important factor in waste package degradation and criticality and is associated with top event MS-IC-3A of the "MSL-ET2" event tree (Appendix B, Figure B-5). Water pathways into the waste package can be created by corrosion and/or failures caused by the waste package response to seismic events. The intent of this discussion is to justify the probability value of top event MS-IC-3A used for the evaluation of the seismic criticality FEPs. Waste package failure is defined as waste package damage, which results in either a diffusive or advective flow path into the waste package. The upper branch of this top event represents the probability of no waste package failures. The second and third branches respectively represent the probability of a diffusive or advective waste package failure.

The ground motion of seismic events with annual exceedance frequencies less than 10^{-4} (PGV of 0.384 m/s) per year will result in damage to all of the waste packages. However, without an advective flow path into the waste package failure locations (i.e., no seepage or drip shield failure), the damage to the waste package is considered diffusive. For these conditions, /MS-IC-3A is assigned a value of 1.00 (complement of 0.00), MS-IC-3A[1] is assigned a value of 1.00, and MS-IC-3A[2] is assigned a value of 0.00.

Dependent on the waste package type, waste packages located on faults during a seismic event with annual exceedance frequencies less than 2×10^{-7} per year (BSC [DIRS 169183], Section 6.7.5) will result in damage to all of the waste packages. Because the drip shields are also failed at these fault locations, an advective flow path into the failed waste packages will be formed if seepage is present. For these conditions, /MS-IC-3A is assigned a value of 1.00 (complement of 0.00), MS-IC-3A[1] is assigned a value of 0.00, and MS-IC-3A[2] is assigned a value of 1.00.

6.4.2.1.6 Top Event MS-IC-3B

The branching of top event MS-IC-3B represents the probability that waste package failure will result in the formation of a bathtub or flow-through configuration. The upper branch indicates the formation of a flow-through waste package configuration and the lower branch indicates that a bathtub configuration is formed. As discussed in Section 6.4.2.1.5, two post-seismic conditions could result in the formation of an advective flow path into the waste package. For all seismic events, it is assumed (Assumption 5.2.7) that all waste package failure conditions resulting in advective flow will result in the formation of a bathtub condition. Since a bathtub condition is believed to result in a higher likelihood of a critical configuration, this assumption is considered limiting. Although waste package damage initiated by seismic events is expected to occur over the entire surface of the waste package, it is assumed that the damage on the bottom surface remains in a diffuse mode or becomes plugged with corrosion products for the remainder of the regulatory period (Assumption 5.2.7). Therefore, /MS-IC-3B and MS-IC-3B are each assigned a value of 1.00.

6.4.2.1.7 Top Event MS-IC-4

The availability of sufficient water to fill and overflow a waste package in a bathtub configuration is associated with top event MS-IC-4 of the "MSL-ET2" event tree (Appendix B, Figure B-5). The upper branch of this top event represents that there is insufficient seepage to fill and overflow a failed waste package during the regulatory period. The second, third, and fourth branches represent the probability of sufficient seepage to fill and overflow a failed waste package for the lower-bound, mean, and upper-bound seepage scenarios, respectively. The probability of occurrence for this top event is calculated using information on the various seepage scenarios from *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131]) and the failure mechanisms for the drip shield and waste package given a seismic event. It is assumed that localized corrosion induced waste package failures will always result in the formation of a bathtub configuration (Assumption 5.2.7).

The probability of attaining sufficient seepage for these seepage scenarios is calculated in Appendix D using a Latin Hypercube Sampling process with 50,000 realizations. The evaluation for the determination of the probabilities is further dependent on:

- the seismic event's time of occurrence, which provides the time remaining to fill the waste package (i.e., 10,000 years minus time of occurrence).
- the waste package free volume to be filled (liters – waste package type dependent).
- whether the waste package is located in the lithophysal or nonlithophysal geologic zone.

Table 6.4-8 summarizes the results for this sampling process for the seismic faulting induced waste package failures.

Table 6.4-8. Probability of Overfilling Waste Package After a Seismic Faulting Event

Waste Package Type	Geologic Zone	Probability of Waste Package Overfilling		
		Lower-Bound Seepage Scenario	**Mean Seepage Scenario**	**Upper-Bound Seepage Scenario**
21-PWR Absorber Plate	Lithophysal	1.771E-1	2.314E-1	2.447E-1
	Nonlithophysal	1.581E-1	2.242E-1	2.404E-1
21-PWR Control Rod	Lithophysal	1.771E-1	2.314E-1	2.447E-1
	Nonlithophysal	1.581E-1	2.242E-1	2.404E-1
12-PWR Absorber Plate	Lithophysal	1.129E-1	1.415E-1	1.486E-1
	Nonlithophysal	1.027E-1	1.378E-1	1.464E-1
44-BWR Absorber Plate	Lithophysal	1.760E-1	2.310E-1	2.445E-1
	Nonlithophysal	1.568E-1	2.237E-1	2.401E-1
24-BWR Absorber Plate	Lithophysal	1.162E-1	1.428E-1	1.494E-1
	Nonlithophysal	1.066E-1	1.394E-1	1.474E-1
DOE SNF Short	Lithophysal	6.816E-1	8.830E-1	9.325E-1
	Nonlithophysal	6.108E-1	8.565E-1	9.167E-1
DOE SNF Long	Lithophysal	6.364E-1	8.644E-1	9.205E-1
	Nonlithophysal	5.579E-1	8.339E-1	9.019E-1
DOE SNF MCO	Lithophysal	3.225E-1	4.181E-1	4.416E-1
	Nonlithophysal	2.890E-1	4.055E-1	4.341E-1

Source: Appendix D, pp. D-6 and D-9

6.4.2.1.8 Top Event NA-MISLOAD

The presence of neutron absorber materials in a waste package is important to criticality control during the regulatory period for the majority of the waste forms proposed for disposal in the repository. Misload of the neutron absorber materials is associated with top event NA-MISLOAD of the "MSL-ET2" event tree (Appendix B, Figure B-5). The lower branch of this top event indicates the occurrence of a misload of neutron absorber materials in the waste package or waste form and the upper branch indicates that no misload occurred.

Neutron absorber material misload can occur as the result of several mechanisms during the waste package fabrication and loading processes. These processes include the use of wrong materials, failure to load the neutron absorber materials into the waste package or waste form, and selection of the wrong waste package type. The probabilities necessary to quantify the NA–MISLOAD top event for each of the waste package/waste form types are the same as those presented in Section 6.3.3.1.8.

Assessment of the neutron absorber material misload event only accounts for the potential to not load any neutron absorber material or to load less than the designed mass. No penalty is assigned for loading additional neutron absorber materials into a waste package or waste form.

6.4.2.1.9 Top Event WF-MISLOAD

The WF-MISLOAD top event represent the probability that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

An analysis of commercial SNF misload probabilities was performed in *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316]). The probabilities necessary to quantify the WF–MISLOAD top event for each of the waste package/waste form types are the same as those presented in Section 6.3.3.1.9.

6.4.2.1.10 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of a waste package with a diffusive failure. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

As a result of seismic events with annual exceedance frequencies less than 10^{-4} per year (PGV of 0.384 m/s), all waste packages are damaged. This damage is initially diffusive, resulting from stress corrosion cracking. However, 10 percent of the waste package inventory are assumed to have waste package failures resulting from localized corrosion initiated soon after repository closure (Assumption 5.1.1). For those waste packages that are located in no-seepage areas of the repository or for which the drip shield is not failed, the waste packages remain in a dry, diffusive failure mode. In addition, for the seismic disruptive event, the waste form has been breached by the seismic event (BSC 2004 [DIRS 169183], Section 6.5.7.3) and converted (degraded) into a more reactive configuration.

For each of the waste forms evaluated, criticality evaluations have shown that without water for neutron moderation, criticality cannot occur (refer to DOE SNF references in Table 6.2-1 and commercial SNF references BSC 2004 [DIRS 171414] and BSC 2004 [DIRS 169963]). This is true even if a waste form or neutron absorber material misload occurs. Therefore, for waste packages with a diffusive failure, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

6.4.2.2 Quantification of Event Tree "CONFIG–BATH"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the event tree "CONFIG–BATH" (Figure B-6 of Appendix B). This event tree initiates the evaluation of the internal waste package configuration classes IP-1, IP-2, and IP-3. This event tree consists of 11 top events, all of which are required for the evaluation of this waste package internal configuration class for the seismic disruptive event. Table 6.4-9 summarizes the event probability assignments discussed below.

Table 6.4-9. Event Probability Assignment for the "CONFIG–BATH" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Initiate evaluation of waste package internal configuration class IP-1			
/CONFIG-SCEN	False[a]	1.00	Section 6.4.2.2.1
CONFIG-SCEN[1] (configuration class IP-1)	True	1.00	
CONFIG-SCEN[2] (transfer to CONFIG-IP2-D event tree)	True	1.00	
CONFIG-SCEN[3] (transfer to CONFIG-IP3 event tree)	True	1.00	
(CONFIG-SCEN top event)			
Waste package internal structures degrade slower than waste form (configuration class IP-1)			
/MS-IC-6	False[a]	1.00	Section 6.4.2.2.2
MS-IC-6[1] (configuration class IP-1A)	True	1.00	
MS-IC-6[2] (configuration class IP-1B)	True	1.00	
MS-IC-6[3] (transfer to CONFIG-IP2-D event tree)	True	1.00	
MS-IC-6[4] (transfer to CONFIG-IP4-A event tree)	True	1.00	
(MS-IC-6 top event)			
Waste package internal structures degrade at same rate as waste form			
/MS-IC-7	True[a]	0.00	Section 6.4.2.2.3
MS-IC-7	False	0.00	
(MS-IC-7 top event)			
Waste package internal structures degrade faster than waste form			
/MS-IC-8	True[a]	0.00	Section 6.4.2.2.4
MS-IC-8	False	0.00	
(MS-IC-8 top event)			

Table 6.4-9. Event Probability Assignment for the “CONFIG–BATH” Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Waste form degrades in place (configuration class IP-1A) **/MS-IC-9** **MS-IC-9** (MS-IC-9 top event)	False [a] True	1.00 1.00	Section 6.4.2.2.5
Waste package internal structures degrade (transfer to CONFIG-IP2-D event tree) **/MS-IC-10** **MS-IC-10** (MS-IC-10 top event)	True [a] False	0.00 0.00	Section 6.4.2.2.6
Degraded waste form is mobilized, separating fissile material from neutron absorber material (configuration class IP-1B) For all waste form evaluation sequences with waste package overfill (either MS-IC-4[1] or MS-IC-4[2] activated). **/MS-IC-11** **MS-IC-11[1]** (configuration class IP-1B) **MS-IC-11[2]** (transfer to CONFIG NF-F)	False [a] True True	1.00 1.00 1.00	Section 6.4.2.2.7
For all waste form evaluation sequences with no waste package overfill (/MS-IC-4 activated). **/MS-IC-11** **MS-IC-11[1]** (configuration class IP-1B) **MS-IC-11[2]** (transfer to CONFIG NF-F) (MS-IC-11 top event)	False [a] True False	1.00 1.00 0.00	
Waste package bottom fails, draining liquid (transfer to CONFIG-IP4-A) **/MS-IC-12** **MS-IC-12** (MS-IC-12 top event)	False [a] True	1.00 1.00	Section 6.4.2.2.8

Table 6.4-9. Event Probability Assignment for the “CONFIG–BATH” Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Probability of waste package misload:			Section 6.4.2.2.9
For the 21-PWR Absorber Plate waste package			
/WF-MISLOAD	~1	1.18E-5	
WF-MISLOAD	1.18E-5	1.18E-5	
For the 21-PWR Control Rod waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 12-PWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 44-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 24-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For DOE waste package types with misload potential [b]			
/WF-MISLOAD	~1	1.475E-5	
WF-MISLOAD	1.475E-5	1.475E-5	
For DOE waste package types without misload potential [c]			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
(WF-MISLOAD top event)			

Table 6.4-9. Event Probability Assignment for the "CONFIG–BATH" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Criticality potential of waste package advective flow configuration			
For all non- misload scenarios (neutron absorber material or waste form)			
/CRIT-POT-WF	True [a]	0.00	
CRIT-POT-WF	False	0.00	
For neutron absorber material or DOE SNF misload scenarios			Section 6.4.2.2.10
/CRIT-POT-WF	False [a]	1.00	
CRIT-POT-WF	True	1.00	
For commercial SNF misload scenarios			
/CRIT-POT-WF	~1	2.480E-5 [d]	
CRIT-POT-WF	2.480E-5	2.480E-5	
(CRIT-POT-WF top event)			

NOTES: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

[b] MOX DOE SNF waste form with misload potential

[c] Aluminum Based, HEU Oxide, LEU Oxide, U-Metal, U/Th Carbide, U/Th Oxide, and U-Zr Hx, and U-Zr/U-Mo Alloy DOE SNF waste forms without misload potential

[d] Conservative value, i.e., probability of criticality from a misload in a 21-PWR Absorber Plate waste package is calculated as 7.80E-6 in *Probability of Assembly Compensation for a Misloaded Waste Package* (BSC 2004 [DIRS 171622], Section 6).

6.4.2.2.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN is used to configure the in-package, bathtub configuration classes IP-1, IP-2, and IP-3 for evaluation. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The three in-package, bathtub configuration classes are represented by the second through fourth branches from the top of this top event. These three branches direct the evaluation of configuration subclass IP-1, IP-2, and IP-3, respectively. The processing of the bottom three branches of this top event are initiated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], and CONFIG-SCEN[3] a value of 1.00.

6.4.2.2.2 Top Event MS-IC-6

The branching of top event MS-IC-6 initiates the evaluation of in-package configuration class IP-1 defined as the scenario in which the waste package internal structures degrade at a slower rate than the waste form. This top event has five branches that are accessed by the second branch of top event CONFIG-SCEN. The upper branch indicates that waste package internal structures do not degrade slower than the waste form and the lower four branches indicate that they do.

For the seismic evaluations, the waste package internals degrade slower than the waste form. The reason this occurs is due to the magnitude of seismic events evaluated. All seismic events with a mean annual exceedance frequency less than 10^{-4} per year starts to cause waste package/waste form damage. Once the waste form has been damaged, it is available for degradation. Therefore, all seismic events will have the waste form degrading faster than the waste package internal structures.

The branching under this top event is used to create the formation of the configuration subclasses of IP-1 and any transformations that can occur. The second and third branches of this top event create the formation of configuration subclasses IP-1A and IP-1B. These configuration subclasses are created due to the fact the waste form has been damaged from the seismic event and is therefore, available for degradation at a rate faster than the waste package internals.

The fourth branch evaluates whether configuration class IP-1 transforms into configuration class IP-2. This transformation can take place if the degradation of the waste package internals catch up to the degradation of the waste form. The fifth branch evaluates whether configuration class IP-1 transforms into configuration class IP-4. This transformation requires the bottom of the waste package to breach and create a flow through system. For this evaluation, all four of these branches are evaluated. Therefore, /MS-IC-6, MS-IC-6[1], MS-IC-6[2], and MS-IC-6[3] are each assigned a value of 1.00.

6.4.2.2.3 Top Event MS-IC-7

The branching of top event MS-IC-7 represents the in-package scenario of the waste package internal structures degrading at the same rate as the waste form and the subsequent transfer of the SAPHIRE evaluation to event tree “CONFIG-IP2-D”. This top event is queried by the third branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade at the same rate as the waste form and the lower branch indicates that they do.

All waste forms are breached subsequent to a seismic event (BSC 2004 [DIRS 169183], Section 6.5.7.3). Once breached, the degradation of the waste forms is expected to occur at much more rapid rate than the oxidation of the waste package internal structures. Although some waste package internal components will degrade quickly (such as the carbon steel assembly tubes of the commercial SNF waste package types), other components such as the Ni-Gd alloy basket assemblies are predicted to degrade slowly and will remain intact throughout the regulatory period (refer to Sections 4.1.12 and 5.1.9). Therefore, it is unlikely that the waste package internal structure could degrade at the same rate as the waste form. Based on this information, /MS–IC–7 and MS–IC–7 are each assigned a value of 0.00.

6.4.2.2.4 Top Event MS-IC-8

The branching of top event MS-IC-8 represents the in-package scenario of the waste package internal structures degrading faster than the waste form and the subsequent transfer of the SAPHIRE evaluation to event tree “CONFIG-IP3”. This top event is queried by the fourth branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade faster than the waste form and the lower branch indicates that they do degrade faster.

All waste forms are breached subsequent to a seismic event (BSC 2004 [DIRS 169183], Section 6.5.7.3). Once breached, the degradation of the waste forms is expected to occur at much more rapid rate than the oxidation of the waste package internal structures. Although some waste package internal components will degrade quickly (such as the carbon steel assembly tubes of the commercial SNF waste package types), other components such as the Ni-Gd alloy basket assemblies are predicted to degrade slowly and will remain intact throughout the regulatory period (refer to Sections 4.1.12 and 5.1.9). Therefore, it is unlikely that the waste package internal structure could degrade faster than the waste form and /MS-IC-8 and MS-IC-8 are each assigned a value of 0.00.

6.4.2.2.5 Top Event MS-IC-9

The branching of top event MS-IC-9 represents the waste form degrading in-place for the evaluation of configuration subclass IP-1A. This top event is queried by the second branch of top event MS-IC-6. The upper branch indicates that the waste form does not degrade in-place and the lower branch indicates that it does. In order to evaluate configuration subclass IP-1A, only the bottom branch of this top event is activated. Therefore, /MS-IC-9 and MS-IC-9 are each assigned a value of 1.00.

6.4.2.2.6 Top Event MS-IC-10

The branching of top event MS-IC-10 evaluates whether waste package internal structures degrade at some point during the regulatory period thereby transforming configuration class IP-1 into IP-2. This top event is queried by the third branch of top event MS–IC–6. The upper branch indicates that the waste package internal components do not degrade and the lower branch indicates that they do.

Although some waste package internal components will degrade quickly (such as the carbon steel assembly tubes of the commercial SNF waste package types), other components such as the Ni-Gd alloy basket assemblies are predicted to degrade slowly and will remain intact throughout the regulatory period (refer to Sections 4.1.12 and 5.1.9). Therefore, only the upper branch of this top event is activated and /MS-IC-10 and MS-IC-10 are each assigned a value of 0.00.

6.4.2.2.7 Top Event MS-IC-11

The branching of top event MS-IC-11 represents the mobilization of the degraded waste form and its separation from any intact neutron absorber material. The upper branch indicates that the degraded waste form is not separated from any intact neutron absorber materials and the lower two branches indicate that it does. The second branch of this top event evaluates configuration subclass IP-1B. The third, or bottom, branch of this top event represents the flushing of the mobilized waste form into the near-field environment via this sequence's immediate transfer to the "CONFIG-NF-F" event tree.

The second branch of this top event is activated for all waste form/waste package types regardless of whether the waste form initially contained neutron absorber material or not. Therefore, /MS-IC-11 and MS-IC-11[1] are each assigned a value of 1.00.

The third branch of this top event is only activated if the waste package is in an overfill condition as indicated by the second through fourth branches of the MS-IC-4 top event of event tree "MSL-ET2". For these branches of the MS-IC-4 top event, MS-IC-11[2] is assigned a value of 1.00.

For sequences activated through the first branch of the MS-IC-4 top event, MS-IC-11[2] is assigned a value of 0.00 since, for this branch of the MS-IC-4 top event, no waste package overflow is available to transport the fissile material of the degraded waste form into the near-field environment.

6.4.2.2.8 Top Event MS-IC-12

The branching of top event MS-IC-12 evaluates whether waste package bottom fails at some point during the regulatory period thereby transforming configuration class IP-1 into IP-4. This top event is queried by the fourth branch of top event MS-IC-6. The upper branch indicates that the waste package bottom does not fail and the lower branch indicates that they do.

Although no information currently exists to determine probability of a waste package bottom failure occurring during the regulatory period, it is more limiting to assume that it does occur (Assumption 5.2.7). Therefore, only the lower branch of this top event is activated and /MS-IC-12 and MS-IC-12 are each assigned a value of 1.00.

6.4.2.2.9 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probability that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

An analysis of commercial SNF misload probabilities was performed in *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316]). The probabilities necessary to quantify the WF–MISLOAD top event for each of the waste package/waste form types are the same as those presented in Section 6.3.3.1.9.

6.4.2.2.10 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of in-package configuration subclasses IP-1A and IP-1B. For a seismic disruptive event, the waste form has been breached by the seismic event (BSC 2004 [DIRS 169183], Section 6.5.7.3) and converted (degraded) into a more reactive configuration. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

For the waste packages that are not misloaded, criticality analyses for in-package configuration subclasses IP-1A and IP-1B have shown that the calculated k_{eff} of these configurations is below the critical limit (refer to DOE SNF references in Table 6.2-1 and commercial SNF references (BSC 2004 [DIRS 171414] and BSC 2004 [DIRS 169963]). Therefore, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

For all waste package types that have neutron absorber material misloads, the resulting scenario is assumed to have criticality potential (Assumption 5.1.16). Therefore, only the lower branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 1.00.

For commercial SNF misloads, the resulting scenario is assumed to have criticality potential (Assumption 5.1.7). Based on the commercial SNF misload scenarios, an evaluation was conducted to calculate the probability of misloading a fuel assembly with sufficient reactivity to create a potential critical configuration. The evaluation of commercial SNF misload scenarios resulted in a mean probability of 2.480×10^{-5} {Table 6.4-9, conservative preliminary value (BSC 2004 [DIRS 171622], Section 6)}. This evaluation was based on the fact that the resulting misloaded fuel assembly would create a potential critical configuration (BSC 2004 [DIRS 171622]). Therefore, for commercial SNF misload scenarios, /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 2.480×10^{-5}.

For the misload of DOE SNF, the resulting scenario is evaluated as having criticality potential (Assumption 5.1.7). Therefore, only the lower branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 1.00.

6.4.2.3 Quantification of Event Tree "CONFIG-IP4-A"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the in-package configuration event tree "CONFIG-IP4-A" (Figure B-11 of Appendix B). This event tree initiates the evaluation of the internal waste package configuration subclasses IP-4A and IP-4B. This event tree consists of six top events, all of which are required for the evaluation of this waste package internal configuration class for the seismic disruptive event. Table 6.4-10 summarizes the event probability assignments discussed below.

Table 6.4-10. Event Probability Assignment for the "CONFIG-IP4-A" Event Tree for the Seismic Disrupt Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Initiate evaluation of waste package internal configuration class IP-4			Section 6.4.2.3.1
/CONFIG-SCEN	False [a]	1.00	
CONFIG-SCEN[1] (configuration subclass IP-4A)	True	1.00	
CONFIG-SCEN[2] (configuration subclass IP-4B)	True	1.00	
CONFIG-SCEN[3] (transfer to CONFIG-IP5-B event tree)	True	1.00	
(CONFIG-SCEN top event)			
Waste form degradation products hydrate in initial location (configuration subclass IP-4A)			Section 6.4.2.3.2
/MS-IC-32	False [a]	1.00	
MS-IC-32	True	1.00	
(MS-IC-32 top event)			
Waste package internal structures degrade at same rate as waste form			Section 6.4.2.3.3
/MS-IC-33	False [a]	1.00	
MS-IC-33	True	1.00	
(MS-IC-33 top event)			
Degraded waste form is mobilized and hydrating, separating from neutron absorber materials			Section 6.4.2.3.4
/MS-IC-34	False [a]	1.00	
MS-IC-34[1]	False	0.00	
MS-IC-34[2]	True	1.00	
(MS-IC-34 top event)			

Table 6.4-10. Event Probability Assignment for the “CONFIG-IP4-A” Event Tree for the Seismic Disrupt Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Probability of waste package misload:			Section 6.4.2.3.5
For the 21-PWR Control Rod waste package			
/WF-MISLOAD	~1	1.18E-5	
WF-MISLOAD	1.18E-5	1.18E-5	
For the 21-PWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 12-PWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 44-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 24-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For DOE waste package types with misload potential [b]			
/WF-MISLOAD	~1	1.475E-8	
WF-MISLOAD	1.475E-8	1.475E-8	
For DOE waste package types without misload potential [c]			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
(WF-MISLOAD top event)			

Table 6.4-10. Event Probability Assignment for the "CONFIG-IP4-A" Event Tree for the Seismic Disrupt Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Criticality potential of in-package configuration class IP-4			Section 6.4.2.3.6
For all no waste form misload scenarios			
/CRIT-POT-WF	True [a]	0.00	
CRIT-POT-WF	False	0.00	
For neutron absorber material and DOE SNF misload scenarios			
/CRIT-POT-WF	False [a]	1.00	
CRIT-POT-WF	True	1.00	
For commercial SNF misload scenarios			
/CRIT-POT-WF	~1	2.480E-5 [d]	
CRIT-POT-WF	2.480E-5	2.480E-5	
(CRIT-POT-WF top event)			

NOTES: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

[b] MOX DOE SNF waste form with misload potential

[c] Aluminum Based, HEU Oxide, LEU Oxide, U-Metal, U/Th Carbide, U/Th Oxide, and U-Zr Hx, and U-Zr/U-Mo Alloy DOE SNF waste forms without misload potential

[d] Conservative value, i.e., probability of criticality from a misload in a 21-PWR Absorber Plate waste package is calculated as 7.80E-6 in *Probability of Assembly Compensation for a Misloaded Waste Package* (BSC 2004 [DIRS 171622], Section 6).

6.4.2.3.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN is used to configure the in-package, flow-through configuration subclasses IP-4A and IP-4B. The upper branch is not utilized in these analyses and is included only for modeling convenience. The three in-package, flow-through configuration subclasses are represented by the second and third branches from the top of this top event. These two branches direct the evaluation of configuration subclass IP-4A and IP-4B, respectively. The bottom, or fourth, branch initiates a transfer to the processing of configuration class IP-5. The processing of the bottom three branches of this top event are activated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], and CONFIG-SCEN[3] a value of 1.00.

6.4.2.3.2 Top Event MS-IC-32

The branching of top event MS-IC-32 initiates the evaluation of in-package configuration subclass IP-4A defined as the scenario in which the waste form degradation products hydrate in their initial location. This top event is queried by the second branch of top event CONFIG-SCEN. The upper branch indicates that waste form degradation products do not hydrate in their initial location and the lower branch indicates that they do. To initiate the evaluation of configuration subclass IP-4A, only the bottom branch of this top event is activated and /MS–IC–32 and MS–IC–32 are each assigned a value of 1.00.

6.4.2.3.3 Top Event MS-IC-33

The branching of top event MS-IC-33 represents the degradation of the waste package internal structures. This top event is queried by the third branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade and the lower branch indicates that they do. Activation of the lower branch of this top event initiates a transfer to the "CONFIG-IP5-B" event tree.

Certain waste package internal components will degrade at a faster rate than others, such as the carbon steel fuel tubes of the commercial waste package types. Because it is likely that some of the waste package internal structure would degrade during the regulatory period given a waste package breach, /MS-IC-33 and MS-IC-33 are each assigned a value of 1.00.

6.4.2.3.4 Top Event MS-IC-34

The branching of top event MS-IC-34 represents the mobilization and hydration of the degraded waste form and its separation from the neutron absorber materials of the waste package. This top event is queried by the third branch of top event CONFIG-SCEN. The upper branch of this top event indicates that the waste form is not mobilized and separated from the neutron absorber materials and the bottom two branches indicate that it is. The second branch represents the waste form mobilization and separation internal to the waste package to initiate the evaluation of configuration subclass IP-4B. The bottom, or third, branch represent the transport of the mobilized waste form to the near-field environment as indicated by the transfer to the "CONFIG-NF-F" event tree.

Because the Ni-Gd neutron absorber materials have a low degradation rate (Assumption 5.1.9), the mobilization of the waste form in a waste package flow through condition will result in the flushing of the waste form from the waste package into the near-field. Retention and accumulation of the waste form on the bottom of the waste package is unlikely. Therefore, only the bottom branch of this top event is activated and /MS-IC-34 and MS-IC-34[2] are each assigned a value of 1.00 and MS-IC-34[1] is assigned a value of 0.00.

6.4.2.3.5 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probability that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

An analysis of commercial SNF misload probabilities was performed in *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316]). The probabilities necessary to quantify the WF–MISLOAD top event for each of the waste package/waste form types are the same as those presented in Section 6.3.3.1.9.

6.4.2.3.6 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of in-package configuration subclasses IP-1A and IP-1B. For a seismic disruptive event, the waste form has been breached by the seismic event (BSC 2004 [DIRS 169183], Section 6.5.7.3) and converted (degraded) into a more reactive configuration. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

For the waste packages that are not misloaded, criticality analyses for in-package configuration subclasses IP-1A and IP-1B have shown that the calculated k_{eff} of these configurations is below the critical limit (refer to DOE SNF references in Table 6.2-1 and commercial SNF references (BSC 2004 [DIRS 171414] and BSC 2004 [DIRS 169963]). Therefore, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

For all waste package types that have neutron absorber material misloads, the resulting scenario is assumed to have criticality potential (Assumption 5.1.16). Therefore, only the lower branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 1.00.

For commercial SNF misloads, the resulting scenario is assumed to have criticality potential (Assumption 5.1.7). Based on the commercial SNF misload scenarios, an evaluation was conducted to calculate the probability of misloading a fuel assembly with sufficient reactivity to create a potential critical configuration. The evaluation of commercial SNF misload scenarios calculated a mean probability of 2.480×10^{-5} {Table 6.4-10, conservative preliminary value (BSC 2004 [DIRS 171622], Section 6)}. This evaluation was based on the fact that the resulting misloaded fuel assembly would create a potential critical configuration (BSC 2004 [DIRS 171622]). Therefore, for commercial SNF misload scenarios, /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 2.480×10^{-5}.

For the misload of DOE SNF, the resulting scenario is evaluated as having criticality potential (Assumption 5.1.7). Therefore, only the lower branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 1.00.

6.4.2.4 Quantification of Event Tree "CONFIG-IP5-B"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the in-package configuration event tree "CONFIG-IP5-B" (Figure B-12 of Appendix B). This event tree initiates the evaluation of the internal waste package configuration class IP-5. This event tree consists of four top events, of which only one is required for the evaluation of this waste package internal configuration class for the seismic disruptive event. Table 6.4-11 summarizes the event probability assignments discussed below.

Table 6.4-11. Event Probability Assignment for the "CONFIG-IP5-B" Event Tree for the Seismic Disrupt Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Hydrated waste form and waste package degraded internal components collect at bottom of the waste package			Section 6.4.2.4.1
/MS-IC-35	False [a]	1.00	
MS-IC-35[1] (configuration subclass IP-5A)	False	0.00	
MS-IC-35[2] (transfer to CONFIG-NF-F event tree)	True	1.00	
(MS-IC-35 top event)			

NOTE: [a] For events prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.4.1 Top Event MS-IC-35

The branching of top event MS-IC-35 represents the accumulation of the hydrated waste form and waste package degraded internal components at the bottom of the waste package. The upper branch of this top event indicates that the waste form and degraded components do not collect on the bottom of the waste package and the bottom two branches indicate that it does. The second branch initiates the evaluation of configuration subclass IP-5B. The bottom, or third, branch represent the transport of the hydrated waste form and degraded internal components to the near-field environment as indicated by the transfer to the "CONFIG-NF-F" event tree.

Because the Ni-Gd neutron absorber materials of the waste package and canister baskets have a low degradation rate (Assumption 5.1.9), these components will remain relatively intact for the duration of the regulatory period. Any degradation products generated from other internal components will most likely remain within the basket cells. The hydration and mobilization of the waste form in a flow-through condition will result in the transport of the waste form from the waste package into the near-field. Retention and accumulation of the waste form on the bottom of the waste package is unlikely. Therefore, only the bottom branch of this top event is activated and /MS-IC-35 and MS-IC-35[2] are each assigned a value of 1.00 and MS-IC-35[1] is assigned a value of 0.00.

6.4.2.5 Quantification of Event Tree "CONFIG-NF-F"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree "CONFIG-NF-F" (Figure B-14 of Appendix B). This event tree initiates the evaluation of the near-field configurations for the formation of potentially critical configurations. This event tree consists of four top events, all of which are required for the evaluation of near-field configurations. Table 6.4-12 summarizes the event probability assignments discussed below.

Table 6.4-12. Event Probability Assignment for the "CONFIG-NF-F" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Near-field configuration class			Section 6.4.2.5.1
/CONFIG-SCEN	False [a]	1.00	
CONFIG-SCEN[1]	True	1.00	
CONFIG-SCEN[2]	True	1.00	
CONFIG-SCEN[3]	True	1.00	
(CONFIG-SCEN top event)			
Initiate processing of near-field configuration class NF-1			Section 6.4.2.5.2
/MS-NF-6	False [a]	1.00	
MS-NF-6	True	1.00	
(MS-NF-6 top event)			
Initiate processing of near -field configuration class NF-2 if waste package bottom failure			Section 6.4.2.5.3
/MS-NF-7	False [a]	1.00	
MS-NF-7	True	1.00	
Otherwise, no processing of configuration class NF-2			
/MS-NF-7	True [a]	0.00	
MS-NF-7	False	0.00	
(MS-NF-7 top event)			
Initiate processing of near -field configuration class NF-3			Section 6.4.2.5.4
/MS-NF-8	False [a]	1.00	
MS-NF-8	True	1.00	
(MS-NF-8 top event)			

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.5.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of three of the five near-field configuration classes – NF-1, NF-2, and NF-3. These configuration classes are represented by the second, third and fourth branches from the top of this top event. The top branch is not utilized in these analyses and is included as a modeling convenience. The processing of all three configuration class branches of this top event are initiated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], and CONFIG-SCEN[3] a value of 1.00.

6.4.2.5.2 Top Event MS-NF-6

The branching of top event MS-NF-6 directs the evaluation of near-field configuration class NF-1. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class is evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF1 event tree. This near-field configuration class represents the transport of fissile material bearing solutes from the waste package to the near-field environment. The NF-1 configuration class is to be evaluated for either a waste package overflow or bottom breach scenario, therefore, /MS-NF-6 and MS-NF-6 are each assigned a value of 1.00.

6.4.2.5.3 Top Event MS-NF-7

The branching of top event MS-NF-7 directs the evaluation of near-field configuration class NF-2. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class is evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF2 event tree. Configuration class NF-2 represents the transport of fissile material bearing slurry effluent from the waste package into the near-field environment. A slurry effluent can only result from a bottom breach of the waste package. Therefore, when the bottom branch of top event MS-IC-12 of the “CONFIG-BATH” event tree is activated (refer to Section 6.4.2.2.8), /MS-NF-7 and MS-NF-7 are each assigned a value of 1.00. Otherwise, /MS-NF-7 and MS-NF-7 are each assigned a value of 0.00.

6.4.2.5.4 Top Event MS-NF-8

The branching of top event MS-NF-8 directs the evaluation of near-field configuration class NF-3. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class is evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF3 event tree. This near-field configuration class represents the transport of fissile material bearing colloids from the waste package to the near-field environment. The NF-3 configuration class is to be evaluated either for a waste package overflow or bottom breach scenario. Therefore, /MS-NF-8 and MS-NF-8 are each assigned a value of 1.00.

6.4.2.6 Quantification of Event Tree “CONFIG-NF1”

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree “CONFIG-NF1” (Figure B-15 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-1 representing the near-field accumulation of fissile materials into potentially critical configurations resulting from solution effluent discharges from the waste package. This event tree consists of five top events, four of which are required for the evaluation of this near-field configuration class. Table 6.4-13 summarizes the event probability assignments discussed below.

Table 6.4-13. Event Probability Assignment for the “CONFIG-NF1” Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Transport of solution effluent from waste package into invert for the formation of near-field configuration class NF-1 subclasses			Section 6.4.2.6.1
/MS-NF-9	False [a]	1.00	
MS-NF-9[1] (configuration class NF-1A)	True	1.00	
MS-NF-9[2] (configuration class NF-1B)	True	1.00	
MS-NF-9[3] (configuration class NF-1C)	True	1.00	
MS-NF-9[4] (transfer to far-field)	True	1.00	
(MS-NF-9 top event)			
Initiate processing of near-field configuration class NF-1A			Section 6.4.2.6.2
/MS-NF-10	False [a]	1.00	
MS-NF-10	True	1.00	
(MS-NF-10 top event)			
Initiate processing of near-field configuration class NF-1B			Section 6.4.2.6.3
/MS-NF-11	False [a]	1.00	
MS-NF-11	True	1.00	
(MS-NF-11 top event)			
Initiate processing of near-field configuration class NF-1C			Section 6.4.2.6.4
/MS-NF-12	False [a]	1.00	
MS-NF-12	True	1.00	
(MS-NF-12 top event)			
Criticality potential of NF-1A, NF-1B and NF-1C			Section 6.4.2.6.5
/CRIT-POT-WF	True [a]	0.00	
CRIT-POT-WF	False	0.00	
(CRIT-POT-WF top event)			

NOTE: [a] For event names prefixed by a slash “/” the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.6.1 Top Event MS-NF-9

The branching of top event MS-NF-9 directs the evaluation of the three configuration subclasses of configuration class NF-1 – NF-1A, NF-1B, and NF-1C. These configuration classes are represented by the second, third and fourth branches from the top of this top event. The upper branch is not utilized in these analyses and is included for modeling convenience. The lower branch of this top event represents the transport of fissile material from the near-field to the far-field. This branch immediately transfers to the CONFIG-FF-J event tree for far-field evaluation.

The processing of all three configuration subclass branches and the far-field transfer of this top event are initiated by assigning MS-NF-9[1], MS-NF-9[2], MS-NF-9[3], and MS-NF-9[4] a value of 1.00. To prevent further evaluation of the top branch of this top event, /MS-NF-9 is also assigned a value of 1.00 (the complement of 0.00).

6.4.2.6.2 Top Event MS-NF-10

The branching of top event MS-NF-10 directs the evaluation of near-field configuration class NF-1A. The upper branch of this top event indicates that fissile materials are not sorbed into the invert materials and the lower branch indicates that fissile materials are sorbed in the invert materials. The criticality potential of near-field configuration class NF-1A is evaluated for the seismic disruptive event. Therefore, /MS-NF-10 and MS-NF-10 are each assigned a value of 1.00.

6.4.2.6.3 Top Event MS-NF-11

The branching of top event MS-NF-11 directs the evaluation of near-field configuration class NF-1B. The upper branch of this top event indicates that fissile materials do not precipitate in the invert and the lower branch indicates that fissile materials do precipitate in the invert. The criticality potential of near-field configuration class NF-1B is evaluated for the seismic disruptive event. Therefore, /MS-NF-11 and MS-NF-11 are each assigned a value of 1.00.

6.4.2.6.4 Top Event MS-NF-12

The branching of top event MS-NF-12 directs the evaluation of near-field configuration class NF-1C. The upper branch of this top event indicates that fissile materials are not transported from one or more waste packages and deposited at an invert low point. The lower branch indicates that fissile materials are transported and deposited at an invert low point. The criticality potential of near-field configuration class NF-1C is evaluated for the seismic disruptive event. Therefore, /MS-NF-12 and MS-NF-12 are each assigned a value of 1.00.

6.4.2.6.5 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of a waste package with an advective failure. The cladding of a waste form in such a waste package is assumed to have breached and the waste form converted (degraded) into a more reactive configuration that has been flushed from the breached waste package. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does. This top event is queried for this event tree only for waste package advective failure conditions.

The criticality analyses of near-field configuration classes NF-1A, NF-1B and NF-1C have shown that the calculated k_{eff} of these configurations is below the critical limit (BSC 2004 [DIRS 170060]). Therefore, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

6.4.2.7 Quantification of Event Tree "CONFIG-NF2"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree "CONFIG-NF2" (Figure B-16 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-2 representing the near-field accumulation of fissile materials into potentially critical configurations resulting from slurry effluent discharging from the waste package. This event tree consists of three top events, of which only one is required for the evaluation of this near-field configuration class. Table 6.4-14 summarizes the event probability assignments discussed below.

Table 6.4-14. Event Probability Assignment for the "CONFIG-NF2" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Slurry effluent flows to conform to invert surface **/MS-NF-13** **MS-NF-13** (MS-NF-13 top event)	False [a] True	1.00 1.00	Section 6.4.2.7.1
Neutron absorber and fissile materials separate **/MS-NF-14** **MS-NF-14** (MS-NF-14 top event)	True [a] True	0.00 1.00	Section 6.4.2.7.2
Criticality potential of NF-1A, NF-1B and NF-1C **/CRIT-POT-WF** **CRIT-POT-WF** (CRIT-POT-WF top event)	True [a] False	0.00 0.00	Section 6.4.2.7.3

NOTES: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.7.1 Top Event MS-NF-13

The branching of top event MS-NF-13 directs the evaluation of near-field configuration class NF-2A. The upper branch of this top event indicates that fissile material contained in the slurry effluent does not flow and conform to the invert surface. The lower branch indicates that the slurry effluent does flow to conform to the invert surface. In order to evaluate near-field configuration subclass NF-2A, only the lower branch of this top event is evaluated – slurry effluent does flow to conform to the invert surface. Therefore, /MS-NF-13 and MS-NF-13 are each assigned a value of 1.00.

6.4.2.7.2 Top Event MS-NF-14

The branching of top event MS-NF-14 evaluates whether the neutron absorber and fissile materials separate as the slurry effluent flows to conform to the invert surface. The upper branch of this top event indicates that the neutron absorber and fissile materials do not separate and the lower branch indicates that they do. Both branches of this top event are evaluated in order to assess the criticality potential of the slurry effluent with and without neutron absorber materials. Therefore, /MS-NF-14 is assigned a value of 0.00 (i.e., the complement of 1.00) and MS-NF-14 is assigned a value of 1.00.

6.4.2.7.3 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclass NF-2A - a slurry effluent from the waste package is assumed to flow and conform to the invert surface with and without neutron absorber material separation. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does. The criticality analyses of near-field configuration classes has shown that the calculated k_{eff} of these classes is below the critical limit (BSC 2004 [DIRS 170060]). Therefore, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

6.4.2.8 Quantification of Event Tree "CONFIG-NF3"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree "CONFIG-NF3" (Figure B-17 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-3 representing the near-field accumulation of fissile material bearing colloids into potentially critical configurations. This event tree consists of seven top events, all of which are required for the evaluation of this near-field configuration class. Table 6.4-15 summarizes the event probability assignments discussed below.

6.4.2.8.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of the three subclasses of near-field configuration class NF-3 and the transport of fissile material containing colloids from the near-field to the far-field environments. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The three near-field configuration subclasses are represented by the second and third branches from the top of this top event. The second branch directs the evaluation of configuration subclass NF-3A and the third branch directs the evaluation of subclasses NF-3B and NF-3C. The fourth, or bottom, branch of this top event represents the transport of fissile material through the near-field environment to the far-field environment. The fourth branch immediately transfers to the "CONFIG-FF-K" event tree for far-field configuration evaluation. The processing of the bottom three branches of this top event are initiated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], and CONFIG-SCEN[3] a value of 1.00.

Table 6.4-15. Event Probability Assignment for the “CONFIG-NF3” Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Initiate evaluation of near-field configuration class NF-3 subclasses **/CONFIG-SCEN** **CONFIG-SCEN[1]** (configuration class NF-3A) **CONFIG-SCEN[2]** (configuration classes NF-3B and NF-3C) **CONFIG-SCEN[3]** (transfer to far-field configuration classes) (CONFIG-SCEN top event)	False [a] True True True	1.00 1.00 1.00 1.00	Section 6.4.2.8.1
Filtration and concentration of colloids on top of invert trapped by waste package corrosion products **/MS-NF-15** **MS-NF-15** (configuration class NF-3A) (MS-NF-15 top event)	False True	1.00 1.00	Section 6.4.2.8.2
Transport of colloids into invert **/MS-NF-16** **MS-NF-16[1]** (configuration class NF-3B and NF-3C) **MS-FF-16[2]** (transfer to far-field) (MS-NF-16 top event)	False True True	1.00 1.00 1.00	Section 6.4.2.8.3
Degradation of invert material **/MS-NF-19** **MS-NF-19** (MS-NF-19 top event)	0.10 0.90	0.90 0.90	Section 6.4.2.8.4
Hydrodynamic/chromatographic separation of fissile material colloids from neutron absorber materials **/MS-NF-17** (configuration class NF-3B) **MS-NF-17** (configuration class NF-3C) (MS-NF-17 top event)	True True	0.00 1.00	Section 6.4.2.8.5
Filtration and concentration of colloids in the invert **/MS-NF-18** **MS-NF-18** (MS-NF-18 top event)	False True	1.00 1.00	Section 6.4.2.8.6
Criticality potential of configuration subclass NF-3A, NF-3B, and NF-3C. **/CRIT-POT-WF** **CRIT-POT-WF** (CRIT-POT-WF top event)	True False	0.00 0.00	Section 6.4.2.8.7

NOTE: [a] For event names prefixed by a slash “/” the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.8.2 Top Event MS-NF-15

The branching of top event MS-NF-15 directs the evaluation of near-field configuration subclass NF-3A. The upper branch of this top event indicates that fissile material containing colloids are not filtered and concentrated on top of the invert, trapped by corrosion products. The lower branch indicates that the colloids are trapped on the invert surface. In order to evaluate near-field configuration subclass NF-3A, only the lower branch of this top event is evaluated. Therefore, /MS-NF-15 and MS-NF-15 are each assigned a value of 1.00.

6.4.2.8.3 Top Event MS-NF-16

The branching of top event MS-NF-16 determines whether fissile material containing colloids are transported into the invert. Activation of the upper branch of this top event indicates that fissile material containing colloids are not transported into the invert. The activation of the second branch indicates that fissile material containing colloids are transported into the invert. In order to evaluate near-field configuration subclasses NF-3B and NF-3C, the second branch of this event is activated. The third branch is activated, which allows the fissile material colloids to be transported into the far-field. Therefore, /MS-NF-16 and MS-NF-16[1] and MS-NF-[2] are each assigned a value of 1.00.

6.4.2.8.4 Top Event MS-NF-19

The branching of top event MS-NF-19 directs the evaluation of near-field configuration subclasses NF-3B and NF-3C. The upper branch of this top event evaluates configuration subclass NF-3B and indicates that the invert materials have not degraded prior to the release of the waste form materials following a seismic event. The lower branch evaluates near-field configuration subclass NF-3C and indicates that the invert materials have degraded prior to the release of waste form materials following a seismic event. The degradation of the drift invert materials will likely occur within several hundred years of repository closure due to the highly oxidizing drift environment. If it is assumed that drift material degradation does not occur for 1000 years (Assumption 5.2.5), the probability of fissile material being released to the invert due to a seismic event prior to drift degradation is calculated to be 0.10 (i.e., 1000 years to degrade drift divided by 10,000-year regulatory period) and the probability of fissile material release after drift degradation is 0.90. Therefore, /MS-NF-19 is assigned a value of 0.90 (i.e., the complement of 0.10) and MS-NF-19 is assigned a value of 0.90.

6.4.2.8.5 Top Event MS-NF-17

The branching of top event MS-NF-17 evaluates the likelihood of hydrodynamic or chromatographic separation of fissile material containing colloids from the neutron absorber materials for both near-field configuration subclasses NF-3B and NF-3C. The upper branch of this top event indicates that fissile material containing colloids are not separated from the neutron absorber materials and the lower branch indicates that they are. Although no known mechanism exists to separate the fissile materials from the neutron absorber materials, both branches of this top event are evaluated. Therefore, /MS-NF-17 is assigned a value of 0.00 (i.e., the complement of 1.00) and MS-NF-17 is assigned a value of 1.00.

6.4.2.8.6 Top Event MS-NF-18

The branching of top event MS-NF-18 represents the filtration and concentration of the fissile material containing colloids in the invert for both configuration subclasses NF-3B and NF-3C. The upper branch of this top event indicates that fissile material containing colloids are not filtered and concentrated in the invert and the lower branch indicates that they are. In order to evaluate both configuration classes, only the lower branch of this top event is activated. Therefore, /MS-NF-18 and MS-NF-18 are each assigned a value of 1.00.

6.4.2.8.7 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclasses NF-3A, NF-3B, and NF-3C – scenarios for the filtration and concentration of fissile material containing colloids in the near-field. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does. The criticality analyses of these near-field configuration subclasses have shown that the calculated k_{eff} of these subclasses is below the critical limit (BSC 2004 [DIRS 170060]). Therefore, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

6.4.2.9 Quantification of Event Tree "CONFIG-NF4"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree "CONFIG-NF4" (Figure B-18 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-4. This event tree consists of four top events, of which only two are required for the evaluation of the seismic disruptive event criticality FEPs. Table 6.4-16 summarizes the event probability assignments discussed below.

Table 6.4-16. Event Probability Assignment for the "CONFIG-NF4" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Water ponds on drift floor due to sealing and/or damming			Section 6.4.2.9.1
/MS-NF-2	True [a]	0.00	
MS-NF-2	False	0.00	
(MS-NF-2 top event)			
Dry transport of fissile material from the waste package transfers to the surface of the invert			Section 6.4.2.9.2
/MS-NF-DD	True [a]	0.00	
MS-NF-DD	False	0.00	
(MS-NF-DD top event)			

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.9.1 Top Event MS-NF-2

The branching of top event MS-NF-2 determines whether seepage water ponds on the drift floor due to sealing or damming. The upper branch of this top event indicates that ponding does not occur and the lower branch indicates that it does. As stated in *Engineered Barrier System Features, Events, and Processes* (BSC 2004 [DIRS 169898], Section 6.2.40), ponding in the invert has been excluded. Therefore, /MS-NF-2 and MS-NF-2 are each assigned a value of 0.00.

6.4.2.9.2 Top Event MS-NF-DD

The branching of top event MS-NF-DD determines whether fissile material can accumulate on the invert surface due to dry transport mechanisms from a failed waste package that does not experience advective flow. The upper branch of this top event indicates that fissile material does not accumulate on the invert surface and the lower branch indicates that it does. *EBS Radionuclide Transport Abstraction* (BSC 2004 [DIRS 169868], Executive Summary and Section 8.1) states that diffusive transport is the sole means of transport in a no-seep envirnment (no drip shield separation) for fissile material that to leave a failed waste package. This quantity is shown in Section 6.3.3.2.2 to be insignificant. Therefore, /MS-NF-DD and MS-NF-DD are each assigned a value of 0.00.

6.4.2.10 Quantification of Event Tree "CONFIG-FF-J"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the far-field event tree "CONFIG-FF-J" (Figure B-21 of Appendix B). This event tree initiates the evaluation of the far-field configuration class FF-1 representing the far-field accumulation of fissile material bearing solutes into potentially critical configurations. This event tree consists of nine top events, of which only seven are required for the evaluation of this far-field configuration class for the seismic disruptive event. Table 6.4-17 summarizes the event probability assignments discussed below.

Table 6.4-17. Event Probability Assignment for the “CONFIG-FF-J” Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Transport of fissile material solutes to far-field in carrier plume **/MS-FF-1** **MS-FF-1** (MS-FF-1 top event)	False [a] True	1.00 1.00	Section 6.4.2.10.1
Separation of fissile material from neutron absorber initiating formation of far-field configuration class subclasses **/MS-FF-2** **MS-FF-2[1]** (configuration subclass FF-1A) **MS-FF-2[2]** (configuration subclasses FF-1B and FF-1C) **MS-FF-2[3]** (transfer to configuration class FF-3) (MS-FF-2 top event)	False [a] True True True	1.00 1.00 1.00 1.00	Section 6.4.2.10.2
Fissile material solutes are transported to the water table (transfer to far-field event tree CONFIG-FF3) **/MS-FF-3** **MS-FF-3** (MS-FF-3 top event)	False [a] True	1.00 1.00	Section 6.4.2.10.3
Precipitation of fissile material as carrier plume is altered by rocks (far-field configuration class FF-1A) **/MS-FF-11** **MS-FF-11** (MS-FF-11 top event)	True [a] False	0.00 0.00	Section 6.4.2.10.4
Transport of fissile material solutes to altered TSbv **/MS-FF-12** **MS-FF-12[1]** (configuration class FF-1B) **MS-FF-12[2]** (configuration class FF-1C) (MS-FF-12 top event)	False [a] True True	1.00 1.00 1.00	Section 6.4.2.10.5
Sorption of fissile material on clays and zeolites in altered TSbv (configuration class FF-1B) **/MS-FF-13** **MS-FF-13** (MS-FF-13 top event)	True [a] False	0.00 0.00	Section 6.4.2.10.6
Accumulation of fissile material solute in topographic lows above altered TSbv (configuration class FF-1C) **/MS-FF-14** **MS-FF-14** (MS-FF-14 top event)	True [a] False	0.00 0.00	Section 6.4.2.10.7

NOTE: [a] For event names prefixed by a slash “/” the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.10.1 Top Event MS-FF-1

The branching of top event MS-FF-1 initiates the evaluation of far-field configuration class FF-1 representing the transport of fissile material containing solutes into the far-field's saturated and unsaturated zones. The upper branch represents that the fissile material bearing solutes are not transported to the far-field and the lower branch represents that they are transported to the far-field. Only the lower branch of this top event is activated to initiate the evaluation of this far-field configuration class. Therefore, /MS-FF-1 and MS-FF-1 are each assigned a value of 1.00.

6.4.2.10.2 Top Event MS-FF-2

The branching of top event MS-FF-2 determines whether the fissile materials entering the far-field environment are separated from the neutron absorber materials of the waste package or waste form. The upper branch indicates that the fissile material is not separated from the neutron absorber materials by the far-field environment. The remaining three branches evaluate far-field configuration classes for the separation of the fissile materials from the neutron absorber materials. The second branch from the top directs the evaluation of configuration subclass FF-1A and the third branch directs the evaluation of subclasses FF-1B and FF-1C. The fourth, or bottom, branch of this top event represents the transport of fissile material through the unsaturated zone and into the water table for the evaluation of configuration class FF-3. The fourth branch immediately transfers to the "CONFIG-FF3" event tree. The processing of the bottom three branches of this top event are activated by assigning MS-FF-2[1], MS-FF-2[2], and MS-FF-2[3] a value of 1.00. To prevent the evaluation of the upper branch of this top event, /MS-FF-2 will also assigned a value of 1.00 (i.e., the complement of 0.00).

6.4.2.10.3 Top Event MS-FF-3

The branching of top event MS-FF-3 represents the transport of fissile materials through the unsaturated zone to the water table. The upper branch of this top event indicates that fissile material is not transported to the water table. The lower branch of this top event indicates that fissile materials are transported directly to the water table. In order to allow for the evaluation of far-field configuration class FF-3, the lower branch of this top event is selected. Therefore, /MS-FF-3 and MS-FF-3 are each assigned a value of 1.00.

6.4.2.10.4 Top Event MS-FF-11

The branching of top event MS-FF-11 represents the precipitation of fissile material as the chemistry of the fissile material containing carrier plume is altered by the unsaturated zone host rock. This scenario represents far-field configuration subclass FF-1A. The upper branch of this top event indicates that fissile material is not precipitated and the lower branch of this top event indicates that it is. It is assumed there are no mechanisms that would cause any appreciable precipitation and accumulation of fissile material in the unsaturated zone (Assumption 5.5.3). Therefore, /MS-FF-11 and MS-FF-11 are each assigned a value of 0.00.

6.4.2.10.5 Top Event MS-FF-12

The branching of top event MS-FF-12 represents the transport of fissile material containing solutes to altered TSbv. The upper branch of this top event indicates that the fissile material is not transported to the altered TSbv. The second and third branches of this top event indicate that fissile materials are transported to the altered TSbv and initiate the evaluation of far-field configuration subclasses FF-1B and FF-1C, respectively. In order to allow for the evaluation of far-field configuration subclass FF-1B and FF-1C, the lower two branches of this top event are selected. Therefore, /MS-FF-12, MS-FF-12[1], and MS-FF-12[2] are each assigned a value of 1.00.

6.4.2.10.6 Top Event MS-FF-13

The branching of top event MS-FF-13 represents formation of the far-field configuration subclass FF-1B, which is defined as the sorption of fissile material in clays and zeolites in the altered TSbv. The upper branch of this top event indicates that fissile materials are not sorbed and the lower branch of this top event indicates that they are. Because the known quantities of clays and zeolites in the unsaturated zone will not result in any appreciable sorption of fissile materials (Assumption 5.5.4), the upper branch of this top event is selected. Therefore, /MS-FF-13 and MS-FF-13 are each assigned a value of 0.00.

6.4.2.10.7 Top Event MS-FF-14

The branching of top event MS-FF-14 represents the formation of far-field configuration subclass FF-1C, which is defined as the accumulation of fissile material containing solutes in topographical lows above altered TSbv. The upper branch of this top event indicates that fissile material containing solutes are not accumulated and the lower branch of this top event indicates that they are accumulated. Because there are no known fissile material accumulation mechanisms in the altered TSbv (Assumption 5.5.2), the upper branch of this top event is selected. Therefore, /MS-FF-14 and MS-FF-14 are each assigned a value of 0.00

6.4.2.11 Quantification of Event Tree “CONFIG-FF-K”

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the far-field event tree “CONFIG-FF-K” (Figure B-22 of Appendix B). This event tree initiates the evaluation of the far-field configuration class FF-2 representing the far-field accumulation of fissile material bearing colloids into potentially critical configurations. This event tree consists of seven top events, of which only six are required for the evaluation of this far-field configuration class for the seismic disruptive event. Table 6.4-18 summarizes the event probability assignments discussed below.

Table 6.4-18. Event Probability Assignment for the "CONFIG-FF-K" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Transport of fissile material colloids to (Topopah Spring welded hydrogeologic unit (TSw) in carrier plume			Section 6.4.2.11.1
/MS-FF-16	False [a]	1.00	
MS-FF-16	True	1.00	
(MS-FF-16 top event)			
Hydrodynamic/chromatographic separation of fissile material colloids from neutron absorber materials			Section 6.4.2.11.2
/MS-FF-17	False [a]	1.00	
MS-FF-17[1] (configuration class FF-2A)	True	1.00	
MS-FF-17[2] (configuration classes FF-2B and FF-2C)	True	1.00	
(MS-FF-17 top event)			
Trapping of fissile material colloids in dead-end fractures at boundary stress-relief zone (configuration class FF-2A)			Section 6.4.2.11.3
/MS-FF-18	True [a]	0.00	
MS-FF-18	False	0.00	
(MS-FF-18 top event)			
Transport of fissile material colloids to altered TSbv			Section 6.4.2.11.4
/MS-FF-19	False [a]	1.00	
MS-FF-19[1] (configuration class FF-2B)	True	1.00	
MS-FF-19[2] (configuration class FF-2C)	True	1.00	
(MS-FF-19 top event)			
Sorption of colloids on clays and zeolites in altered TSbv (configuration class FF-2B)			Section 6.4.2.11.5
/MS-FF-20	True [a]	0.00	
MS-FF-20	False	0.00	
(MS-FF-20 top event)			
Filtration of colloids in topographic lows above TSbv (configuration class FF-2C)			Section 6.4.2.11.6
/MS-FF-21	True [a]	0.00	
MS-FF-21	False	0.00	
(MS-FF-21 top event)			

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.11.1 Top Event MS-FF-16

The branching of top event MS-FF-16 initiates the evaluation of far-field configuration class FF-2 representing the transport of fissile material bearing colloids into the far-field's unsaturated zone. The upper branch represents that fissile material bearing colloids are not transported to the far-field and the lower branch represents that they are. Only the lower branch of this top event is activated to initiate the evaluation of this far-field configuration class. Therefore, /MS-FF-16 and MS-FF-16 are each assigned a value of 1.00.

6.4.2.11.2 Top Event MS-FF-17

The branching of top event MS-FF-17 determines whether the fissile material bearing colloids entering the unsaturated zone environment are hydrodynamically or chromatographically separated from the neutron absorber materials of the waste package or waste form. The upper branch indicates that the fissile material is not separated from the neutron absorber materials by the unsaturated zone environment. The remaining two branches represent the separation of the fissile materials from the neutron absorber materials and initiate the evaluation of the FF-2 configuration subclasses. The second branch from the top directs the evaluation of configuration subclass FF-2A and the third branch directs the evaluation of configuration subclasses FF-2B and FF-2C. The processing of the bottom two branches of this top event are accessed by assigning MS-FF-17[1] and MS-FF-17[2] a value of 1.00. To prevent evaluation of the upper branch of this top event, /MS-FF-17 will also be assigned a value of 1.00 (i.e., the complement of 0.00).

6.4.2.11.3 Top Event MS-FF-18

The branching of top event MS-FF-18 represents far-field configuration subclass FF-2A that is defined as the trapping of fissile material bearing colloids in altered TSbv. The upper branch of this top event indicates that fissile material bearing colloids are not trapped and the lower branch indicates that they are. Because there are no known mechanisms for trapping and accumulating any appreciable quantities of fissile material bearing colloids in altered TSbv (Assumption 5.5.2), only the top branch of this top event is activated. Therefore, /MS-FF-18 and MS-FF-18 are each assigned a value of 0.00.

6.4.2.11.4 Top Event MS-FF-19

The branching of top event MS-FF-19 represents the transport of fissile material containing colloids to altered TSbv. The upper branch of this top event indicates that fissile material containing colloids are not transported and the lower two branches indicate that they are. The second and third branches of this top event initiate the evaluation of far-field configuration subclasses FF-2B and FF-2C, respectively. In order to allow for the evaluation of these far-field configuration subclasses, the lower two branches of this top event are selected. Therefore, /MS-FF-19, MS-FF-19[1], and MS-FF-19[2] are each assigned a value of 1.00.

6.4.2.11.5 Top Event MS-FF-20

The branching of top event MS-FF-20 represents formation of the far-field configuration subclass FF-2B, which is defined as the sorption of fissile material containing colloids on clays and zeolites in the altered TSbv. The upper branch of this top event indicates that fissile materials are not sorbed and the lower branch of this top event indicates that they are. Because the known quantities of clays and zeolites in the unsaturated zone will not result in any appreciable sorption of fissile materials containing colloids (Assumption 5.5.4), the upper branch of this top event is selected. Therefore, /MS-FF-20 and MS-FF-20 are each assigned a value of 0.00.

6.4.2.11.6 Top Event MS-FF-21

The branching of top event MS-FF-21 represents the formation of far-field configuration subclass FF-2C, which is defined as the filtration and accumulation of fissile material containing colloids in topographical low above altered TSbv. The upper branch of this top event indicates that fissile material containing colloids are not filtered and accumulated and the lower branch of this top event indicates that they are. Because there are no known fissile material accumulation mechanisms in the altered TSbv (Assumption 5.5.2), the upper branch of this top event is selected. Therefore, /MS-FF-21 and MS-FF-21 are each assigned a value of 0.00.

6.4.2.12 Quantification of Event Tree "CONFIG-FF3"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the far-field event tree "CONFIG-FF3" (Figure B-23 of Appendix B). This event tree initiates the evaluation of the far-field configuration class FF-3 representing the accumulation of fissile material into potentially critical configurations in the far-field saturated zone. This event tree consists of nine top events, all of which are required for the evaluation of far-field configuration class FF-3 for the seismic disruptive event. Table 6.4-19 summarizes the event probability assignments discussed below.

Table 6.4-19. Event Probability Assignment for the "CONFIG-FF-3" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Initiate evaluation of far-field configuration class FF-3 subclasses **/CONFIG-SCEN** **CONFIG-SCEN[1]** (configuration class FF-3A) **CONFIG-SCEN[2]** (configuration class FF-3B) **CONFIG-SCEN[3]** (configuration class FF-3C) **CONFIG-SCEN[4]** (configuration class FF-3D) **CONFIG-SCEN[5]** (configuration class FF-3E) (CONFIG-SCEN top event)	False [a] True True True True True	1.00 1.00 1.00 1.00 1.00 1.00	Section 6.4.2.12.1
Fissile material precipitates in upwell zone of hydrothermal fluids at faults or in fractures (configuration class FF-3A) **/MS-FF-4** **MS-FF-4** (MS-FF-4 top event)	True [a] False	0.00 0.00	Section 6.4.2.12.2
Contaminant plume mixes below redox front (configuration class FF-3B) **/MS-FF-5** **MS-FF-5** (MS-FF-5 top event)	False [a] True	1.00 1.00	Section 6.4.2.12.3
Precipitation of fissile material (configuration class FF-3B) **/MS-FF-6** **MS-FF-6** (MS-FF-6 top event)	True [a] False	0.00 0.00	Section 6.4.2.12.4
Fissile material precipitates at reducing zone (configuration class FF-3C) **/MS-FF-7** **MS-FF-7** (MS-FF-7 top event)	True [a] False	0.00 0.00	Section 6.4.2.12.5
Fissile material precipitates at organic reducing zone at pinchout of tuff aquifer (configuration class FF-3D) **/MS-FF-8** **MS-FF-8** (MS-FF-8 top event)	True [a] False	0.00 0.00	Section 6.4.2.12.6

Table 6.4-19. Event Probability Assignment for the "CONFIG-FF-3" Event Tree for the Seismic Disruptive Event Criticality FEPs SAPHIRE Analyses (Continued)

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Fissile material solutes are transported to Franklin Lake Playa (configuration class FF-3E)			Section 6.4.2.12.7
/MS-FF-9	False [a]	1.00	
MS-FF-9	True	1.00	
(MS-FF-9 top event)			
Fissile material solutes precipitate in organic-rich zones of Franklin Lake Playa (configuration class FF-3E)			Section 6.4.2.12.8
/MS-FF-10	False [a]	1.00	
MS-FF-10	True	1.00	
(MS-FF-9 top event)			
Criticality potential of configuration class FF-3E			Section 6.4.2.12.9
/CRIT-POT-WF	True [a]	0.00	
CRIT-POT-WF	False	0.00	
(CRIT-POT-WF top event)			

NOTE: [a] For events prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.4.2.12.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of the five subclasses of far-field configuration class FF-3 defined as the transport of fissile material into the saturated zone. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The five far-field configuration subclasses are represented by the second through sixth branches from the top of this top event. These five branches direct the evaluation of configuration subclass FF-3A, FF-3B, FF-3C, FF-3D, and FF-3E, respectively. The processing of the bottom five branches of this top event are initiated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], CONFIG-SCEN[3], CONFIG-SCEN[4], and CONFIG-SCEN[5] a value of 1.00.

6.4.2.12.2 Top Event MS-FF-4

The branching of top event MS-FF-4 initiates the evaluation of far-field configuration subclass FF-3A defined as the precipitation of fissile material in the upwell zone of hydrothermal fluids at faults or in fractures. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that they are. Because no known mechanism exists for the appreciable precipitation of fissile material in the saturated zone (Assumption 5.5.3), only the upper branch of this top event is activated. Therefore, /MS-FF-4 and MS-FF-4 are each assigned a value of 0.00.

6.4.2.12.3 Top Event MS-FF-5

The branching of top event MS-FF-5 represents the mixing of the fissile material containing contaminant plume below the redox front. The effects of pH and pCO_2 in the UZ on uranium can lead to precipitation through reduction in the uranium solubility (Assumption 5.5.3). The upper branch indicates that mixing does not occur and the lower branch indicates that it does. In order to allow for the processing of far-field configuration subclass FF-3B, only the lower branch of this top event is activated. Therefore, /MS-FF-5 and MS-FF-5 are each assigned a value of 1.00.

6.4.2.12.4 Top Event MS-FF-6

The branching of top event MS-FF-6 initiates the evaluation of far-field configuration subclass FF-3B defined as the precipitation of fissile material as the contaminant plume mixes below the redox front. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that they are. Because no known mechanism exists for the appreciable precipitation of fissile material in the saturated zone (Assumption 5.5.3), only the upper branch of this top event is activated. Therefore, /MS-FF-6 and MS-FF-6 are each assigned a value of 0.00.

6.4.2.12.5 Top Event MS-FF-7

The branching of top event MS-FF-7 initiates the evaluation of far-field configuration subclass FF-3C defined as the precipitation of fissile materials at the reducing zone (i.e., the remains of organic materials). The upper branch indicates that fissile material is not precipitated and the lower branch indicates that it is. Because organic material is not known to exist in the saturated zone in any appreciable quantity, precipitation of fissile material is unlikely (Assumption 5.5.5). Therefore, only the upper branch of this top event is activated and /MS-FF-7 and MS-FF-7 are each assigned a value of 0.00.

6.4.2.12.6 Top Event MS-FF-8

The branching of top event MS-FF-8 initiates the evaluation of far-field configuration subclass FF-3D defined as the precipitation of fissile materials at the reducing zone of a pinchout of the tuff aquifer. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that it is. Because organic material is not known to exist in the saturated zone in any appreciable quantity, precipitation of fissile material is unlikely (Assumption 5.5.5). Therefore, only the upper branch of this top event is activated and /MS-FF-8 and MS-FF-8 are each assigned a value of 0.00.

6.4.2.12.7 Top Event MS-FF-9

The branching of top event MS-FF-9 represents the transport of fissile material containing solutes to Franklin Lake Playa. The upper branch indicates that transport does not occur and the lower branch indicates that it does. In order to allow for the processing of far-field configuration subclass FF-3E, only the lower branch of this top event is activated. Therefore, /MS-FF-9 and MS-FF-9 are each assigned a value of 1.00.

6.4.2.12.8 Top Event MS-FF-10

The branching of top event MS-FF-10 represents the precipitation of fissile material containing solutes in organic-rich zones of Franklin Lake. The upper branch indicates that precipitation does not occur and the lower branch indicates that it does. It is assumed (Assumption 5.5.1) that if fissile material is transported to Franklin Lake, organic-rich reducing zones within the lake will allow for the precipitation and accumulation of fissile materials. Therefore, only the lower branch of this top event is activated and /MS-FF-10 and MS-FF-10 are each assigned a value of 1.00.

6.4.2.12.9 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of the precipitated fissile material in the organic-rich zones of Franklin Lake. The upper branch indicates that precipitated material does not have a criticality potential and the lower branch indicates that it does. It is assumed that, over the regulatory period, insufficient fissile material could be transported and accumulated in the organic-rich zones of Franklin Lake to result in a potentially critical configuration (Assumption 5.5.1). Therefore, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

6.4.3 External Criticality Analysis Results for Seismic Disruptive Event

The minimum critical mass required to be accumulated in the invert has been calculated for a range of ^{235}U enrichments in *Critical Mass Search Calculation in the Invert* (BSC 2004 [DIRS 170060]). The critical mass results from this calculation are summarized in Table 6.4-20. *Critical Mass Search Calculation in the Invert* (BSC 2004 [DIRS 170060]) calculates that less than 11 kg of uranium will accumulate in the invert under a waste package. Based on the values presented in Table 6.4-20, 11 kg of uranium in the invert will not have criticality potential.

Table 6.4-20. Minimum ^{235}U Critical Mass

Invert Void Fraction (percent)	**Waste Form ^{235}U Enrichment (weight percent)**					
	5	**15**	**25**	**50**	**75**	**100**
27	N/A	20.85 kg	19.39 kg	17.63 kg	16.63 kg	16.23 kg
39	29.00 kg	29.19 kg	27.28 kg	25.50 kg	23.00 kg	21.83 kg

Source: BSC 2004 [DIRS 170060]

Note: N/A – not applicable; insufficient fissile material to result in a critical mass

6.4.4 Seismic Disruptive Event Criticality FEPs Analysis Results

Tables 6.4-21 and 6.4-22 summarize the SAPHIRE seismic disruptive event results of per waste package type criticality probabilities for seismic ground motion and faulting induced waste package damage, respectively.

The per waste package type criticality probabilities for seismic induced waste package damage due to ground motion are applicable to the entire population of these waste package types as the entire repository experiences the seismic event. However, the per waste package type criticality probabilities for seismic induced waste package damage due to faulting is only applicable to those waste packages located on the faults.

6.4.4.1 Probability of Waste Package Damage Due to Seismic Ground Motion

Because seismic induced waste package damage due to ground motion is applicable to the entire population of waste package, it is acceptable to use a binomial distribution analysis to determine the probability of criticality for each waste package type based on its total population. Using the binomial distribution equation (Equation 6.4-3) (Walpole, et al. 1998 [DIRS 152180], Section 5.3), the total probability of criticality for each waste package type can then be calculated.

$$b(x,n,p) = \binom{x}{n} p^{x} (1-p)^{n-x} \qquad \text{(Eq. 6.4-3)}$$

where:

x = number of waste packages with criticality potential
n = number of the waste package type being evaluated
p = per waste package probability of criticality for the waste package type being evaluated

A binomial distribution analysis can be used to calculate the probability of the occurrence of a criticality in one, two, three, … through x waste packages. However, Table 6.4-22 indicates that the per waste package probability of criticality is zero for all waste package types. Therefore, a binomial distribution analysis is not necessary for the determination of the total probability of criticality due to seismic ground motion for each waste package type.

6.4.4.2 Probability of Waste Package Damage Due to Seismic Fault Displacement

Seismic fault displacement is considered to have the potential to damage waste packages placed on the fault line. Multiple faults are in the vicinity of the Yucca Mountain repository and some intersect the drifts in a number of places. Within this latter group of faults, the Drill Hole, Pagany, Sever, Sundance, and 7a/8a faults have a sufficient displacement probability with sufficiently severe seismic events to damage waste packages lying on the fault lines. (Note that 7a/8a are generic locations that include hypothetical small faults with 2-meter offsets (BSC 2004 [DIRS 169183], Section 6.7.3)). Potential waste package damage from seismic faulting is dependent upon 1) the amount of clearance between the top of a waste package and the bottom of the drip shield, and 2) the amount of fault displacement. Damage to a waste package is considered possible when the fault displacement exceeds the clearance between a waste package located on the fault and drip shield. The clearance between the top of a waste package and the bottom of the drip shield is a function of the waste package diameter (Section 4.1.9). The amount of fault displacement is a function of the severity of the seismic event causing the fault displacement. Results from *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183]), based on hazard curves, identify what seismic event exceedance frequency is required to potentially damage commercial SNF, DOE, and NNPP waste package types (BSC 2004 [DIRS 169183], Section 6.7.3).

The probability of having one of "p" waste packages of a given type located at any one fault intersection for a total of "n" waste packages, is given by:

$$P(1;p,n)=\frac{\binom{n-1}{p-1}}{\binom{n}{p}} \qquad \text{(Eq. 6.4-4)}$$

where the numerator and denominator indicate binomial coefficients.

Equation 6.4-4 reduces to

$$P(1;p,n)=\frac{p}{n}\,. \qquad \text{(Eq. 6.4-5)}$$

As the identified faults that can potentially cause damage to waste packages have a number of intersections with the drifts, multiple fault intersections need to be considered. The probability of multiple waste packages of a particular type being on multiple fault intersections is the union of multiple events that is given by the sum of the individual probabilities minus the sum of the probability of (counting type) intersections. For two such events, this probability is given by:

$$P(A \cup B) = P(A) + P(B) - P(AB) \qquad \text{(Eq. 6.4-6)}$$

For three events, the probability is given by

$$P(A \cup B \cup C) = P(A) + P(B) + P(C) - P(AB) - P(AC) - P(BC) + P(ABC) \qquad \text{(Eq. 6.4-7)}$$

The sequence can be extended by induction.

Similarly, the probability that two units of a given waste package type are both on fault intersections is a conditional probability calculation. Given that one waste package is on one fault intersection, the probability that a second one is also on a fault intersection is given by:

$$P(2;\ p,\ n) = p/n \times (p-1)/(n-1) \qquad \text{(Eq. 6.4-8)}$$

In a similar manner, the probability that three units of a waste package type are all on fault intersections is given by

$$P(3;\ p,\ n) = p/n \times (p-1)/(n-1) \times (p-2)/(n-2) \qquad \text{(Eq. 6.4-9)}$$

In general, the probability that exactly "j" units of a waste package type are all on fault intersections is given by:

$$P(j;\ p,\ n) = \Pi\ \{(p-k)/(n-k)\},\ k = 0,\ j-1;\ j \le \text{Number of fault intersections} \qquad \text{(Eq. 6.4-10)}$$

Note that Equation 6.4-10 provides the intersection terms in Equations 6.4-6 and 6.4-7.

However, the mean number of waste packages of any given type residing on faults can be calculated using the hypergeometric distribution given in Equation 6.4-11 (Evans, et al., 1993 [DIRS 112115], p. 85).

$$P(n; X, N) = nX/N \qquad \text{(Eq. 6.4-11)}$$

where

X is the number of faults
n is the number of waste package of a given type
N is the total number of waste packages in the repository inventory

From *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Section 6.7.4), the number of faults that could impact the commercial SNF, NNPP, and 2-MCO/2-DHLW waste package types is 22 (Sundance, Drill Hole, Sever, and Pagany faults). The number of faults that could potentially impact 5-DHLW/DOE Long and 5-DHLW-DOE Short waste package types is 142 (Sundance, Drill Hole, Sever, Pagany, 7a, and 8a faults). The mean fractional waste package population residing on damaging inducing faults for any given waste package type is presented in Table 6.4-23.

The total probability of criticality for each waste package type is then estimated by multiplying the mean fractional number of waste packages and the total per waste package probability of criticality from Table 6.4-22. A more exact solution of this calculation could be performed using the binomial distribution of Equation 6.4-3. However, given the waste package type population numbers that include fractional populations of less than one, the binomial distribution is not applied because the product method is a sufficiently close approximation.

Table 6.4-21. Per Waste Package Criticality Probabilities Resulting from Seismic Ground Motion Induced Damage from SAPHIRE Analysis of Seismic Disruptive Event Criticality FEPs

Waste Package Type	Number of Waste Packages[a]	Per Waste Package Probability of Criticality[b]				Total
		Intact In-Package	Degraded In-Package	Near-Field	Far-Field	
21-PWR Absorber Plate	4299	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21-PWR Control Rod	95	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12-PWR Absorber Plate	163	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24-BWR Absorber Plate	84	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44-BWR Absorber Plate	2831	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ MOX	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ MOX	61	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U-Zr Hx	165	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U-Metal	16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U-Metal	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF MCO w/ U-Metal	220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ HEU Oxide	655	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ HEU Oxide	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U/Th Oxide	20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U/Th Oxide	73	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U/Th Carbide	605	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ Aluminum Based	1226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ Aluminum Based	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U-Zr/U-Mo Alloy	14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U-Zr/U-Mo Alloy	19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ LEU Oxide	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ LEU Oxide	344	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Source: [a] Values from Table 4.1-3

[b] SAPHIRE V. 7.18 (BSC 2002 [DIRS 160873]) analysis results (Appendix B, Section B.24) and Microsoft EXCEL spreadsheet “endstate.xls”. (Probability values below the screening criterion are set to 0.0.)

Table 6.4-22. Per Waste Package Criticality Probabilities Resulting from Seismic Faulting Induced Damage from SAPHIRE Analysis of Seismic Disruptive Event Criticality FEPs

Waste Package Type	Number of Waste Packages[a]	Per Waste Package Probability of Criticality[b]				Total
		Intact In-Package	Degraded In-Package	Near-Field	Far-Field	
21-PWR Absorber Plate	4299	0.00E+00	4.65E-11	0.00E+00	0.00E+00	4.65E-11
21-PWR Control Rod	95	0.00E+00	2.61E-10	0.00E+00	0.00E+00	2.61E-10
12-PWR Absorber Plate	163	0.00E+00	3.29E-13	0.00E+00	0.00E+00	3.29E-13
24-BWR Absorber Plate	84	0.00E+00	3.29E-13	0.00E+00	0.00E+00	3.29E-13
44-BWR Absorber Plate	2831	0.00E+00	3.28E-13	0.00E+00	0.00E+00	3.28E-13
DOE SNF Short w/ MOX	5	0.00E+00	8.44E-11	0.00E+00	0.00E+00	8.44E-11
DOE SNF Long w/ MOX	61	0.00E+00	8.44E-11	0.00E+00	0.00E+00	8.44E-11
DOE SNF Short w/ U-Zr Hx	165	0.00E+00	3.32E-13	0.00E+00	0.00E+00	3.32E-13
DOE SNF Short w/ U-Metal	16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U-Metal	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF MCO w/ U-Metal	220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ HEU Oxide	655	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ HEU Oxide	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U/Th Oxide	20	0.00E+00	2.23E-10	0.00E+00	0.00E+00	2.23E-10
DOE SNF Long w/ U/Th Oxide	73	0.00E+00	2.23E-10	0.00E+00	0.00E+00	2.23E-10
DOE SNF Long w/ U/Th Carbide	605	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ Aluminum Based	1226	0.00E+00	3.32E-13	0.00E+00	0.00E+00	3.32E-13
DOE SNF Long w/ Aluminum Based	1	0.00E+00	3.32E-13	0.00E+00	0.00E+00	3.32E-13
DOE SNF Short w/ U-Zr/U-Mo Alloy	14	0.00E+00	2.23E-10	0.00E+00	0.00E+00	2.23E-10
DOE SNF Long w/ U-Zr/U-Mo Alloy	19	0.00E+00	2.23E-10	0.00E+00	0.00E+00	2.23E-10
DOE SNF Short w/ LEU Oxide	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ LEU Oxide	344	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Source: [a] Values from Table 4.1-3
[b] SAPHIRE V. 7.18 (BSC 2002 [DIRS 160873]) analysis results (Appendix B, Section B.24) and Microsoft EXCEL spreadsheet “endstate.xls”. (Probability values below the screening criterion are set to 0.0.)

Table 6.4-23. Per Waste Package Type Total Probability of Criticality Resulting from Seismic Induced Faulting Damage

Waste Package Type	Number of Waste Packages[a]	Number on Damaging Inducing Faults [b]	Mean Fractional Waste Package Population Residing on Damaging Inducing Faults [c]	Per Waste Package Probability of Criticality [d]	Waste Package Type Total Probability of Criticality Due to Seismic Faulting
21-PWR Absorber Plate	4,299	22	8.407	4.65E-11	3.91E-10
21-PWR Control Rod	95	22	0.186	2.61E-10	4.84E-11
12-PWR Absorber Plate	163	22	0.319	3.29E-13	1.05E-13
24-BWR Absorber Plate	84	22	0.164	3.29E-13	5.40E-14
44-BWR Absorber Plate	2,831	22	5.536	3.28E-13	1.82E-12
DOE SNF Short w/ MOX	5	142	0.063	8.44E-11	5.32E-12
DOE SNF Long w/ MOX	61	142	0.770	8.44E-11	6.50E-11
DOE SNF Short w/ U-Zr Hx	165	142	2.083	3.32E-13	6.92E-13
DOE SNF Short w/ U-Metal	16	142	0.202	0.00E+00	0.00E+00
DOE SNF Long w/ U-Metal	4	142	0.050	0.00E+00	0.00E+00
DOE SNF MCO w/ U-Metal	220	22	0.430	0.00E+00	0.00E+00
DOE SNF Short w/ HEU Oxide	655	142	8.268	0.00E+00	0.00E+00
DOE SNF Long w/ HEU Oxide	42	142	0.530	0.00E+00	0.00E+00
DOE SNF Short w/ U/Th Oxide	20	142	0.252	2.23E-10	5.62E-11
DOE SNF Long w/ U/Th Oxide	73	142	0.921	2.23E-10	2.05E-10
DOE SNF Long w/ U/Th Carbide	605	142	7.636	0.00E+00	0.00E+00
DOE SNF Short w/ Aluminum Based	1,226	142	15.475	3.32E-13	5.14E-12
DOE SNF Long w/ Aluminum Based	1	142	0.013	3.32E-13	4.19E-15
DOE SNF Short w/ U-Zr/U-Mo Alloy	14	142	0.177	2.23E-10	3.94E-11
DOE SNF Long w/ U-Zr/U-Mo Alloy	19	142	0.240	2.23E-10	5.34E-11
DOE SNF Short w/ LEU Oxide	8	142	0.101	0.00E+00	0.00E+00
DOE SNF Long w/ LEU Oxide	344	142	4.342	0.00E+00	0.00E+00
TOTAL	11,250				8.71E-10

Source: [a] Values from Table 4.1-3
[b] BSC 2004 [DIRS 169183], Section 6.7.4
[c] calculated using Equation 6.4-11
[d] column 7 of Table 6.4-22 (Probability values below the screening criterion are set to 0.0.)

6.5 ANALYSIS OF ROCK FALL DISRUPTIVE EVENT CRITICALITY FEPS

Rock fall disruptive event criticality FEPs are presented in Table 6.5-1.

Table 6.5-1. Rock Fall Disruptive Event Criticality FEPs

FEP Number	FEP Title	FEP Description
2.1.14.21.0A	In-package criticality resulting from rock fall (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a rock fall event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.
2.1.14.22.0A	In-package criticality resulting from rock fall (degraded configurations)	Either during, or as a result of, a rock fall event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.23.0A	Near-field criticality resulting from rock fall	Either during, or as a result of, a rock fall event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.11.0A	Far-field criticality resulting from rock fall	Either during, or as a result of, a rock fall event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Source: Table 6.1-1

6.5.1 Rock Fall Impacts on Waste Packages and Waste Forms

Rock fall disruptive event criticality FEPs 2.1.14.21.0A, 2.1.14.22.0A, 2.1.14.23.0A, and 2.2.14.11.0A require an assessment of the probability of criticality due to rock fall. A rock fall event can occur as result of normal drift degradation, as well as the result of a seismic event. Because the frequency of rock fall due to static drift degradation cannot be readily predicted, the probability of this disruptive event should be assigned a value of 1.00. However, because the rock fall SAPHIRE analysis will not result in the generation of any unique results beyond those generated for the base case, an initiating event probability of 0.0 is assigned to this disruptive event.

A rock fall event could potentially result in drip shield damage depending on the size of the rock fall, the impact velocity and drip shield impact location. Because the drip shield covers the waste package, no waste package damage is predicted due to a rock fall event. However, for the rock fall disruptive event, the probability of drip shield damage does not correlate to the probability of drip shield failure. Drip shield failure is defined as the failure of the drip shield to perform its primary function – to prevent advective flow from contacting the waste package. Drip shield failure may be the result of a stress corrosion crack or complete structural failure. Although rock fall will result in stress corrosion cracking of the drip shield, the resulting cracks are predicted to be plugged with corrosion products or precipitates (BSC 2004 [DIRS 169985], Section 6.3.7) causing the probability of advective flow through the cracks to approach zero

(BSC 2004 [DIRS 169985], Section 6.3.7). Therefore, the probability of drip shield failure resulting from a rock fall disruptive event is negligible. This is the same value assigned to this drip shield failure mechanism for the quantification of top event MS-IC-2 in the base case.

Seepage flux is not predicted to be influenced by a rock fall disruptive event. Therefore, the seepage probabilities are also unchanged from that calculated for the base case.

As was stated in the base case in Section 6.3.3.1.4, condensation does not occur on the underside of the drip shield and, therefore, is unavailable to enter a failed waste package. In addition, because rock fall does not cause drip shield failure, no advective flow path is created for condensation on the drift walls to enter a failed waste package. Therefore, the event probability for condensation calculated for the base case is also valid for the rock fall disruptive event.

Finally, since rock fall does not impact the waste package, the only viable waste package failure mechanism during the rock fall disruptive event results from fabrication errors and localized corrosion – the same failure mechanisms identified for the base case.

6.5.2 SAPHIRE Event Probability Modifications for Rock Fall Analysis

Based on the information previously presented, it is not necessary to modify any event probabilities for the rock fall criticality FEPs SAPHIRE analysis from those specified for the base case analysis.

6.5.3 Rock Fall Criticality FEPs Analysis Results

Because it is not necessary to modify any event probabilities from those specified for the base case, the SAPHIRE results that would be calculated for the rock fall disruptive event SAPHIRE analysis are the same as those that have been reported for the base case analysis. For this reason, no evaluation of the rock fall disruptive event is necessary and the probability of criticality resulting from a rock fall disruptive event is negligible.

6.6 ANALYSIS OF IGNEOUS DISRUPTIVE EVENT CRITICALITY FEP

The igneous disruptive event criticality FEPs are presented in Table 6.6-1.

Table 6.6-1. Igneous Disruptive Event Criticality FEPs

FEP Number	FEP Name	FEP Description
2.1.14.24.0A	In-package criticality resulting from an igneous event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after an igneous disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.
2.1.14.25.0A	In-package criticality resulting from an igneous event (degraded configurations)	Either during, or as a result of, an igneous disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.1.14.26.0A	Near-field criticality resulting from an igneous event	Either during, or as a result of, an igneous disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).
2.2.14.12.0A	Far-field criticality resulting from an igneous event	Either during, or as a result of, an igneous disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Source: Table 6.1-1

The igneous disruptive event (intersection of the LA repository footprint by a volcanic dike) is described in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2004 [DIRS 169989], Section 6.5.3.1 and Table 7-1) as having a frequency of 1.7×10^{-8} per year. This frequency corresponds to a probability of 1.7×10^{-4} for the 10,000-year regulatory postclosure period. Two different igneous disruption scenarios have been evaluated. The first is an intrusion scenario where an igneous basaltic dike intersects one or more repository drifts, followed by effusive (liquid) magma flow or pyroclastic flow (clots of melt in a stream of gas) into the drifts (BSC 2004 [DIRS 169960], Section 6.1.3.2). The second igneous scenario is a violent Strombolian basaltic volcanic eruption through the repository that carries radioactive waste to the ground surface and into the atmosphere (BSC 2004 [DIRS 170026], Section 5.2.4). Given an igneous intrusion into the repository, there is an estimated 78 percent probability (BSC 2004 [DIRS 169989], Table 7−1), or a frequency of 1.3×10^{-8} per year, of at least one eruptive center will form within the repository boundary (BSC 2004 [DIRS 169989], Table 7-1).

Evaluation of the probability of a criticality resulting from an igneous event accounts for the probability of immediate or delayed waste package damage, presence of a moderator during the event or upon magma cooling, separation of fissionable material from the neutron absorber material during magma transport, and the accumulation of a critical mass of fissionable material from, or within, the transporting magma.

Eruptive Scenario

The eruptive scenario at Yucca Mountain is based on the observation that most basaltic eruptions begin as fissure eruptions, discharging magma where a dike intersects the earth’s surface, and rapidly become focused into roughly cylindrical conduit eruptions (BSC 2004 [DIRS 169980], Section 6.3.1.1). From *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2004 [DIRS 170001], Section 6.4), the number of conduits that may be formed during the eruptive igneous scenario ranges from zero through 13, with one being the most likely number. As stated in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2004 [DIRS 170026], Section 1.3), the volcanic eruption is assumed conservatively to have both effusive and pyroclastic phases lasting throughout the duration of the event (Assumption 5.4.5). Such volcanic activity typically consists of gas and effusive Strombolian and violent Strombolian phases. In a violent Strombolian eruption, rapid exsolution of gas from liquid magma creates a rapidly expanding and rising magma-gas mixture that erupts from a conduit vent, rises in a convective eruption column, and disperses by prevailing winds. The waste packages within the conduit are assumed to be completely destroyed and the waste form pulverized (BSC 2004 [170026], Section 5.2.4). Consideration is given here to the unlikely scenario that the dispersed fissionable materials become mobilized by future precipitation and accumulated in a potentially critical configuration.

As noted, eruptive conduits begin with fissure eruptions from igneous dikes. Hence, in the eruptive scenario, one or more dikes have intersected emplacement drifts and filled the affected drifts with effusive magma or pyroclastic material before the conduit forms and the violent eruption begins. Although the melting temperatures of waste package materials (cask or canister) are higher than expected magma temperatures, the materials nevertheless would weaken at the elevated temperatures and likely deform, leading to waste package failure *Dike/Drift Interactions* (BSC 2004 [DIRS 170028] Section 6.4.8.1). However, because the waste packages are expected to deform rather than disintegrate in the presence of magma, and because the waste packages are more dense than the magma, it is assumed that the non-vitrified waste packages adjacent to the conduit will remain in place and not be entrained in the eruptive conduit (Assumption 5.4.6, and Assumption 5.3 (BSC 2004 [DIRS 170001], Section 5.3). Thus, it is reasonable to assume that the waste packages that are adjacent to the conduit will remain in place in the magma-filled drift and will not be captured by the ascending magma in the eruption conduit (Assumption 5.4.6). Therefore, the number of waste packages destroyed in an eruption is limited to the number of waste packages intersected by conduits (BSC 2004 [DIRS 170001], Section 5.3). Using probability distributions for the number, location, and diameter of conduits, the layout of the waste emplacement drifts, and the average density of waste packages in the waste emplacement drifts, the median number of waste packages destroyed in a volcanic eruption is calculated to be six (BSC 2004 [DIRS 170001, Section 7.2).

Intrusion Scenario

It is expected for igneous intrusion events that the drip shields, invert and waste packages of the affected drifts are compressed and damaged and that magma or pyroclastic debris will occupy the entire emplacement drift volume (BSC 2004 [DIRS 170028] Section 6.4.7.5). The waste packages within the drift could be severely damaged through material softening, creeping, and intergranular breakdown due to the intrusive igneous material's temperature and entry force. Potentially critical configurations could be generated internal to or external to the waste package upon the reintroduction of seepage and the subsequent degradation of the waste package and waste form, transport of the fissionable material out of the waste package, and accumulation of the fissionable material in the near-field or far-field environments.

The intruding magma or pyroclastic flow is predicted to have a maximum temperature between 1050 to 1100°C. This is based on an expected water content of 4.0 weight percent or less of the intruding material (BSC 2004 [DIRS 169980], Section 6.3.2.2). As stated in *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Section 6.4.8.1), at these temperatures the tensile strength of the waste package and internal components are decreased significantly and the materials are expected to creep readily and fail by mechanical rupture under very small loads, such as the static load from the intrusive material-filled drifts. It is expected that the creep failures will not be limited to the upper portions of the waste package, but as the upper portions collapse, the load imparted on the internals are sufficient to cause rupture of the waste package's lower half. Because the magma is expected to maintain these elevated temperatures for several months (BSC 2004 [DIRS 170028] Section 6.7.1.2), the waste package internals would attain these temperatures and similar creep failure of the internal components would occur. This slumping of the waste package and internals would result in the elimination of most of the waste package's internal void spaces. This would include the interstitial space between fuel rods of waste form assemblies as well as the voids within the waste package basket assembly cells. Although the internal components are expected to fail and slump, there is no expectation that any of the components or materials will relocate from their locations relative to each other. This is reasonable given that intrusion temperatures do not exceed the melt temperatures of any of the waste package or waste form component materials.

Possible effects of magma intrusion into a drift on waste package internals in addition to those described above include accelerated corrosion of Zircaloy components and the formation of Zr-Fe and Zr-Ni liquid eutectics (BSC 2004 [170028], Section 6.4.8.3). The accelerated corrosion of Zircaloy is caused by the presence of magmatic gases that enter the drift in association with the magma intrusion and make contact with the Zircaloy while temperatures are around 1100°C. The liquid eutectics begin to form around 940°C but, in addition, require contact between the materials.

As discussed in this section, while the waste packages and waste forms are expected to fail from the magma intrusion, components and materials are not expected to relocate significantly. The presence of the magmatic gases could excerbate cladding damage and mineral transformation of the fissile material but not significantly affect the absorber material distribution. Similarly, the design for the DOE and commercial waste package basket assemblies (BSC 2004 [DIRS 170803], Section 4.1.1.1.3) consists, in part, of a carbon steel guide tube separating the Ni-Gd absorber plates from the fuel assembly Zircaloy components preventing formation of significant amounts of the Zr-Ni eutectic that could lead to relocation of the neutron absorbing material.

For magmatic intrusions, the waste package pallet would also be expected to fail at the elevated temperatures. This would result in the slumping and flattening of the waste package onto the invert surface. It is expected that the magma underneath the waste package would be displaced by the slumping waste package. This is expected since 100 percent deformation of the waste package materials would occur within 1000 hours of the intrusive event and stresses of 2 Mpa, based on creep data available for Hastelloy X (Haynes International [DIRS 170316]).

Radionuclides in the waste could be incorporated into crystallizing silicate mineral phases, or form higher oxide phases (BSC 2004 [DIRS 170028], Section 6.4.8.3). The thermodynamic stability of secondary phases likely to form in cooling basalt is poorly known and it is difficult to predict which phases, if any, might form. Fission products (cesium, technetium, etc.) may also be incorporated into new mineral phases, with the size and charge of fission-product ions exerting primary control as to the resulting minerals that might contain them. Because of the uncertainty in the formation of mineral or oxide phases, the waste is conservatively treated as unchanged in TSPA-LA calculations.

For pyroclastic intrusions, the intrusive material is not fluid. Under this condition, the intrusive material underneath the waste package would not be displaced as the waste package slumps. Rather the waste package would slump into itself, also resulting in the elimination of the waste package internal void spaces.

However, for either magma or pyroclastic intrusion events, the waste package surface is expected to fail. After the magma cools sufficiently to allow seepage to return, it will not be possible to create and maintain a bathtub configuration (forming a pool or closed-bottom container) due to the waste package surface failure. It is also unlikely that any appreciable quantity of water could be accumulated within the waste package due to the barrier failure and the collapse of the internal void spaces.

The number of waste packages potentially affected by an igneous intrusion is assessed in the model report, *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2004 [DIRS 170001]). The assessment is based on probability distributions for the number, length, spacing, and azimuth of intruding igneous dikes, the layout of the waste emplacement drifts, and the average linear density of waste packages in the waste emplacement drifts. The number of affected waste packages ranges from zero to nearly the entire waste package inventory, with a median value of 1612 (BSC 2004 [DIRS 170001], Section 6.3.4).

6.6.1 Igneous Impacts on Zone 2 Waste Packages and Waste Forms

The TSPA-LA approach to implementing the models for waste package and waste form response during igneous intrusion considers two impact regions: (1) Zone 1, which includes the emplacement drifts directly contacted by the eruptive conduits and intrusive dikes; and (2) Zone 2, which includes the emplacement drift adjacent to the directly impacted drifts (BSC 2004 [DIRS 170028], Section 6.6.1).

The waste package damage scenarios resulting from a Zone 1 eruptive or intrusive event are discussed above. Analyses of possible impacts from thermal and volatile gas migration from Zone 1 to Zone 2 (adjacent drifts) have been performed. The analyses indicate that these gases do not migrate between Zone 1 and 2 drifts (BSC 2004 [DIRS 170028], Section 6.6.6). Thus, they do not provide the potential for elevated corrosion rates due to a deleterious environment. From the spatial and temporal heat conduction simulations and analyses, the high temperatures after a magma event attenuate rapidly with distance. The maximum temperature rise in an adjacent drift is small (less than 10°C), and the rock provides effective thermal insulation to the impacts of high temperature (BSC 2004 [DIRS 170028] Section 6.7.1.2). From the gas transport simulations, the maximum gas concentrations entering the Zone 2 emplacement drifts are extremely low. It is concluded that there are no impacts from thermal or volatile gases on waste packages and waste forms in Zone 2 (BSC 2004 [DIRS 170028], Sections 6.6.6 and 6.7.1.2).

Since the drip shields, waste packages, and fuel cladding in Zone 2 remain intact during an igneous event, criticality evaluation of the waste packages and waste forms in Zone 2 are not required as these results would be encompassed by the base case analysis of Section 6.3.

6.6.2 SAPHIRE Event Probability Assignment for Igneous Scenarios

Assignment of the event probabilities for the igneous SAPHIRE criticality FEPs evaluation is presented in the following sections. The events presented in these sections are used to quantify:

- The igneous event trees “IGNEOUS”, “IG-ERUPTIVE”, “IG-INTRUSIVE”, and “IG-INTRUSIVE2” (Appendix B, Figures B-24 through B-28)
- The near-field event trees “CONFIG-NF-F”, “CONFIG-NF1”, CONFIG-NF2”, and “CONFIG-NF3” (Appendix B, Figures B-14 through B-17)
- The far-field event trees “CONFIG-FF-J”, CONF-FF-K” and “CONFIG-FF3” (Appendix B, Figures B-21 through B23).

Justification for the probability values assigned to these events are, in part, based on the information presented in the discussions above.

6.6.2.1 Quantification of Event Tree “IGNEOUS”

The following subsections provide justification for the probabilities assigned to the events used in the quantification of event tree “IGNEOUS” (Figure B-24 of Appendix B). This event tree is accessed as part of the igneous disruptive event and directs the evaluation of the eruptive and intrusive igneous scenarios. All three top events of this event tree are required to quantify the igneous phenomenological processes. Table 6.6-2 summarizes the event probability assignments discussed below.

Table 6.6-2. Event Probability Assignment for the "IGNEOUS" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Type of igneous event **/IG-EVENT-TYPE** **IG-EVENT-TYPE** (IG-EVENT TYPE top event)	 0.78 True	 0.22 1.00	Section 6.6.2.1.1
Initial waste package location (for either eruptive or intrusive igneous events) **/IG-WP-LOC** **IG-WP-LOC** (IG-WP-LOC top event)	 True [a] True	 0.00 1.00	Section 6.6.2.1.2
Final waste package location for waste packages beyond conduit intersection point during an eruptive event **/IG-WP-RELOC** **IG-WP-RELOC** (IG-WP-RELOC top event)	 True [a] False	 0.00 0.00	Section 6.6.2.1.3

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Probability of neutron absorber material misload in the waste package or waste form			Section 6.6.2.1.4
For the 21-PWR Control Rod waste package type			
/NA-MISLOAD	~1	3.758E-9	
NA-MISLOAD	3.758E-9	3.758E-9	
For the 21-PWR Absorber Plate waste package type			
/NA-MISLOAD	~1	4.576E-8	
NA-MISLOAD	4.576E-8	4.576E-8	
For the 12-PWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For the 44-BWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For the 24-BWR Absorber Plate waste package type			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For DOE SNF Group 1 waste package types with neutron absorber materials in the canister basket [b]			
/NA-MISLOAD	~1	6.217E-11	
NA-MISLOAD	6.217E-11	6.217E-11	
For DOE SNF Group 2 waste package types with neutron absorber materials in filler [c]			
/NA-MISLOAD	~1	3.906E-8	
NA-MISLOAD	3.906E-8	3.906E-8	
For DOE SNF Group 3 waste package types with neutron absorber materials in canister basket and filler [d]			
/NA-MISLOAD	~1	3.912E-8	
NA-MISLOAD	3.912E-8	3.912E-8	
For DOE SNF waste package types without neutron absorber materials [e]			
/NA-MISLOAD	True [a]	0.00	
NA-MISLOAD	False	0.00	
(MS-IC-3B top event)			

NOTES: [a] For event names prefixed by a slash "/," the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1-value) of the assigned value.

[b] Aluminum Based, MOX, and U-Zr Hx DOE SNF waste forms with neutron absorber materials in the canister basket assembly

[c] U/Th Oxide DOE SNF waste form with neutron absorber material in the canister filler materials

[d] U-Zr/U-Mo Alloy DOE SNF waste form with neutron absorber material in the canister basket and filler materials

[e] HEU Oxide, LEU Oxide, U-Metal, and U/Th Carbide DOE SNF waste forms without neutron absorber materials

6.6.2.1.1 Top Event IG-EVENT-TYPE

The upper branch of the IG-EVENT-TYPE top event represents the eruptive igneous scenario. There is a 0.78 probability of having at least one eruptive conduit given an igneous event at the repository (BSC 2004 [DIRS 169989], Table 7-1). The complement of an eruptive event's probability of occurrence is calculated to be 0.22 (i.e., 1-0.78=0.22). Therefore, /IG-EVENT-TYPE is assigned a value of 0.22.

The lower branch of the IG-EVENT-TYPE top event represents the intrusive igneous scenario. Given an igneous event, an intrusive scenario is expected to occur (BSC 2004 [DIRS 169989], Table 7-1). Therefore, IG-EVENT-TYPE is assigned a value of 1.00.

6.6.2.1.2 Top Event IG-WP-LOC

The branches of the IG-WP-LOC top event directs the evaluation of waste packages at the dike (intrusive event) or conduit (eruptive event) intersection point. The upper branch of this top event directs the evaluation of a waste package at the dike or conduit intersection points. The lower branch of this top event directs the evaluation of waste packages beyond the dike or conduit intersection points. Both waste package locations are evaluated in this analysis. This is accomplished by assigning /IG-WP-LOC a value of 0.00 (i.e., the complement of 1.00) and IG-WP-LOC a value of 1.00.

6.6.2.1.3 Top Event IG-WP-RELOC

The purpose of this top event is to represent the possibility that, for an eruptive igneous scenario, waste packages initially beyond the conduit intersection point may at some point get pulled into the conduit. As stated in *Number of Waste Packages Hit by Igneous Intrusion* (BSC 2004 [DIRS 170001], Section 5.3), waste packages that are adjacent to the conduit will remain in place in the magma-filled drift and will not be captured by the ascending magma in the eruption conduit. Since waste packages beyond the conduit intersection will remain in the drift, only the upper branch of this top event is activated. Therefore, /IG-WP-RELOC and IG-WP-RELOC are each assigned a value of 0.00.

6.6.2.1.4 Top Event NA–MISLOAD

The presence of neutron absorber materials in a waste package is important to criticality control during the regulatory period for the majority of the waste forms proposed for disposal in the repository. Misload of the neutron absorber materials is associated with top event NA–MISLOAD of the "MSL–ET2" event tree (Figure B-5 of Appendix B). The lower branch of this top event indicates the occurrence of a misload of neutron absorber materials in the waste package or waste form and the upper branch indicates that no misload occurred. This top event is queried for this event tree only for waste package diffusive failure conditions.

Neutron absorber material misloads can occur as the result of several mechanisms during the waste package fabrication and loading processes. These processes include the use of wrong materials, failure to load the neutron absorber materials into the waste package or waste form, and selection of the wrong waste package type. The probabilities necessary to quantify the NA–

MISLOAD top event for each of the waste package/waste form types are the same as those presented in Section 6.3.3.1.8.

Assessment of the neutron absorber material misload event only accounts for the potential to load no neutron absorber material or less than the designed mass. No penalty is assigned for loading additional neutron absorber materials into a waste package or waste form.

6.6.2.2 Quantification of Event Tree "IG-ERUPTIVE"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of event tree "IG-ERUPTIVE" (Figure B-25 of Appendix B). This event tree is accessed as part of the evaluation of an eruptive igneous scenario for those waste packages intersected by the eruptive conduit or those waste packages that are initially beyond the conduit, but are subsequently pulled into the conduit. Although this event tree has seven top events, the eruptive event phenomenological process only requires the quantification of three of these top events. Table 6.6-3 summarizes the event probability assignments discussed below.

Table 6.6-3. Event Probability Assignment for the "IG-ERUPTIVE" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value[a] (per waste package)	Justification
Waste package configuration on surface after an eruptive event **/IG-CONFIG** **IG-CONFIG** (IG-CONFIG top event)	True [a] False	0.00 0.00	Section 6.6.2.2.1
Rainfall Occurs after an eruptive event **/IG-RAINFALL** **IG-RAINFALL** (IG-RAINFALL top event)	False [a] True	1.00 1.00	Section 6.6.2.2.2
Fissile material accumulates in sufficient quantity after rainfall **/IG-FM-ACCUM** **IG-FM-ACCUM** (IG-FM-ACCUM top event)	True [a] False	0.00 0.00	Section 6.6.2.2.3

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.2.1 Top Event IG-CONFIG

The IG-CONFIG top event establishes the configuration of the waste packages ejected from the repository during an eruptive igneous event. Waste packages in the eruptive conduit can be either destroyed and the waste form pulverized during the eruptive process and the remains ejected and dispersed across the surface (the branch of this top event) or it can be ejected breached, but relatively intact and lying on the surface (the failure branch of this top event). In a violent Strombolian eruption, rapid exsolution of gas from liquid magma creates a rapidly expanding and rising magma-gas mixture that erupts from a conduit vent, rises in a convective eruption column, and disperses by prevailing winds. According to *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2004 [DIRS 170026], Section 5.2.4), the waste packages within the conduit are assumed to be destroyed completely and the waste form pulverized (Assumption 5.4.10). Therefore, /IG-CONFIG and IG-CONFIG are each assigned a value of 0.00.

6.6.2.2.2 Top Event IG-RAINFALL

The purpose of top event IG-RAINFALL is to determine the probability that rainfall occurs at some point in time after an eruptive event. The upper branch of this top event indicates that rainfall does not occur and the lower branch indicates that it does. It is expected that rainfall will occur and, therefore, /IG-RAINFALL and IG-RAINFALL are each assigned a value of 1.00.

6.6.2.2.3 Top Event IG-FM-ACCUM

The purpose of this top event is to represent the possibility that, after an eruptive igneous event disperses the waste form on the surface, subsequent rainfall mobilizes the waste form and it accumulates into a potentially critical configuration. As stated in *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2004 [DIRS 170026], Figures 1-1 and 7-3), the eruptive debris, including the waste form, is scattered over a wide area with decreasing deposition depth with distance. It is highly improbable that given the dispersal area of the waste form that any appreciable quantity of fissile material could be mobilized and accumulated into a potentially critical configuration. Therefore, only the upper branch of this top event is activated and /IG-FM-ACCUM and IG-FM-ACCUM are each assigned a value of 0.00.

6.6.2.3 Quantification of Event Tree "IG-INTRUSIVE"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of event tree "IG-INTRUSIVE" (Figure B-26 of Appendix B). This event tree is accessed as part of the eruptive and intrusive igneous scenario evaluations for those waste packages that are in the drift beyond the eruptive conduit or for those waste packages that are at or beyond the dike intersection point. Although this event tree has eight top events, the intrusive phenomenological process only requires the quantification of three of these top events. Table 6.6-4 summarizes the event probability assignments discussed below.

Table 6.6-4. Event Probability Assignment for the "IG-INTRUSIVE" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Waste package destroyed during intrusive event **/IG-WP-DESTRYD** **IG-WP-DESTRYD** (IG-WP-DESTRYD top event)	True [a] False	0.00 0.00	Section 6.6.2.3.1
Waste Package completely slumped **/IG-WP-SLUMP** (no slumping) **IG-WP-SLUMP[1]** (partially slumped) **IG-WP-SLUMP[2]** (completely slumped) (IG-WP-SLUMP top event)	False [a] False True	1.00 0.00 1.00	Section 6.6.2.3.2
Magma intrusion into breached waste package **/IG-MAGMA-INT** **IG-MAGMA-INT** (IG-MAGMA-INT top event)	True [a] False	0.00 0.00	Section 6.6.2.3.3

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.3.1 Top Event IG-WP-DESTRYD

This top event quantifies the probability that the waste package is destroyed as a result of the entry force of intrusive material. Separate consideration is given for those waste packages at the dike intersection point where the forces would be greatest versus those waste packages lying beyond the dike or conduit intersection points. According to *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Section 6.4.8.1), under intrusive conditions, even at the dike intersection point, the waste packages are expected to deform rather than disintegrate in the presence of magma. Therefore, only the upper branch of this top event is activated and /IG-WP-DESTRYD and IG-WP-DESTRYD are each assigned a value of 0.00.

6.6.2.3.2 Top Event IG-WP-SLUMP

The IG-WP-SLUMP top event evaluates whether the waste package will remain intact (upper branch), partially slump (middle branch), or completely slump (lower branch) as a result of the high temperatures of the intruding materials. Because the intruding materials will maintain their elevated temperatures for a substantial period (up to approximately two months (BSC 2004 [DIRS 170028], Appendix D), it is reasonable to expect that the temperature of the waste package and its internals will approach the intrusive material's temperature. As stated in *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Section 6.4.8.1), at these temperatures the tensile strength of the waste package and internal components would be decreased significantly and the materials are expected to creep readily and fail by mechanical rupture under very small load. This would result in the slumping and flattening of the waste package. Given the materials used in waste package and internal component construction, 100 percent deformation of the waste package materials would occur within 1000 hours of the intrusive event and under stresses of 2 MPa based on creep data available for Hastelloy X (Haynes International [DIRS 170316]). Since the waste package is expected to completely slump as a result of igneous intrusive conditions, only the bottom branch of top event IG-WP-SLUMP is activated. Therefore, /IG-WP-SLUMP and IG-WP-SLUMP[2] are each assigned a value of 1.00 and IG-WP-SLUMP[1] is assigned a value of 0.00.

6.6.2.3.3 Top Event IG-MAGMA-INT

The purpose of this top event is to quantify the possibility that, because of waste package breach following an intrusive igneous event, intrusive material can enter the breached waste package. The upper branch represents that magma does not intrude into the waste package upon its failure and the lower branch represents that it does. It is assumed that a limited quantity of magma may enter the waste package through the breach area but that no flushing (flow-through) occurs (Assumption 5.4.7). Initial waste package breach is expected to occur soon after the intrusion event because of the elevated temperature of the waste package and the external pressure being exerted on the waste package surface by the intrusive material filling the drifts. However, the waste temperature quickly exceeds the yield point of the waste package materials. As the waste package/waste form deforms and slumps, the internal void areas are collapsed, thereby preventing the intrusion of any additional magma. Therefore, only the upper branch of this top event is activated and /IG-MAGMA-INT and IG-MAGMA-INT are each assigned a value of 0.00.

6.6.2.4 Quantification of Event Tree “IG-INTRUSIVE2”

The following subsections provide justification for the probabilities assigned to the events used in the quantification of event tree “IG-INTRUSIVE2” (Figure B-27 of Appendix B). This event tree is a continuation of the evaluation of an intrusive igneous event for those waste packages not destroyed by the force of the intrusive event. This event tree consists of seven top events, all of which are required for the quantification of this scenario. Table 6.6-5 summarizes the event probability assignments discussed below.

Table 6.6-5. Event Probability Assignment for the "IG-INTRUSIVE2" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Magma cooled **/IG-MAGMA-COOL** **IG-MAGMA-COOL** (IG-MAGMA-COOL top event)	True [a] True	0.00 1.00	Section 6.6.2.4.1
Magma fractures after cooling **/IG-MAGMA-FRAC** **IG-MAGMA-FRAC** (IG-MAGMA-FRAC top event)	False [a] True	1.00 1.00	Section 6.6.2.4.2
Seepage returns after magma cools For the lithophysal zone: **/IG-SEEPAGE-NWL** (no seepage scenario) **IG-SEEPAGE-LL** (lower-bound seepage scenario) **IG-SEEPAGE-ML** (mean seepage scenario) **IG-SEEPAGE-UL** (upper-bound seepage scenario) For the nonlithophysal zone: **/IG-SEEPAGE-NWNL** (no seepage scenario) **IG-SEEPAGE-LNL** (lower-bound seepage scenario) **IG-SEEPAGE-MNL** (mean seepage scenario) **IG-SEEPAGE-UNL** (upper-bound seepage scenario) (IG-SEEPAGE top event)	5.184E-1 4.622E-2 2.111E-1 2.243E-1 2.629E-1 1.062E-1 3.244E-1 3.065E-1	4.816E-1 4.622E-2 2.111E-1 2.243E-1 7.371E-1 1.062E-1 3.244E-1 3.065E-1	Section 6.6.2.4.3
Waste package bathtub configuration formed **/IG-BATHTUB** **IG-BATHTUB** (IG-BATHTUB top event)	True [a] False	0.00 0.00	Section 6.6.2.4.4
Fissile material transported from breached waste package **/IG-FM-TRANSPT** **IG-FM-TRANSPT** (IG-FM-TRANSPT top event)	True [a] True	0.00 1.00	Section 6.6.2.4.5

Table 6.6-5. Event Probability Assignment for the "IG-INTRUSIVE2" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	**Probability Values**	**SAPHIRE Assigned Event Value [a] (per waste package)**	**Justification**
Probability of waste package misload:			Section 6.6.2.4.6
For the 21-PWR Absorber Plate waste package			
/WF-MISLOAD	~1	1.18E-5	
WF-MISLOAD	1.18E-5	1.18E-5	
For the 21-PWR Control Rod waste package			
/WF-MISLOAD	1.0	0.0	
WF-MISLOAD	0.0	0.0	
For the 12-PWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 44-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For the 24-BWR Absorber Plate waste package			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
For DOE waste package types with misload potential [b]			
/WF-MISLOAD	~1	1.475E-5	
WF-MISLOAD	1.475E-5	1.475E-5	
For DOE waste package types without misload potential [c]			
/WF-MISLOAD	True [a]	0.00	
WF-MISLOAD	False	0.00	
(WF-MISLOAD top event)			

Table 6.6-5. Event Probability Assignment for the "IG-INTRUSIVE2" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analysis (Continued)

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Criticality potential of waste package dry diffusion configuration			Section 6.6.2.4.7
For all non-misload scenarios (neutron absorber material nor waste form)			
/CRIT-POT-WF	True [a]	0.00	
CRIT-POT-WF	False	0.00	
For neutron absorber material or DOE SNF misload scenarios			
/CRIT-POT-WF	False [a]	1.00	
CRIT-POT-WF	True	1.00	
For commercial SNF misload scenarios			
/CRIT-POT-WF	~1	2.480E-5 [d]	
CRIT-POT-WF	2.480E-5	2.480E-5	
(CRIT-POT-WF top event)			

NOTES: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

[b] MOX DOE SNF waste form with misload potential

[c] Aluminum Based, HEU Oxide, LEU Oxide, U-Metal, U/Th Carbide, U/Th Oxide, and U-Zr Hx, and U-Zr/U-Mo Alloy DOE SNF waste forms without misload potential

[d] Conservative value, i.e., probability of criticality from a misload in a 21-PWR Absorber Plate waste package is calculated as 7.80E-6 in *Probability of Assembly Compensation for a Misloaded Waste Package* (BSC 2004 [DIRS 171622], Section 6).

6.6.2.4.1 Top Event IG-MAGMA-COOL

The branching of top event IG-MAGMA-COOL establishes the temperature of the intrusive material. The upper branch indicates that the temperature is above 100°C. The lower branch indicates that the temperature is below 100°C. Both branches of this top event are processed for the determination of the waste package's pre- and post-cooling criticality potential. In order to process both branches of this top event, /IG-MAGMA-COOL is assigned a value of 0.00 (i.e., the complement of 1.00) and IG-MAGMA-COOL is assigned a value of 1.00.

6.6.2.4.2 Top Event IG-MAGMA-FRAC

The branching of top event IG-MAGMA-FRAC indicates whether or not the intrusive material fractures upon cooling. The upper branch of this top event indicates that no fracturing of the intrusive material occurs and the bottom branch indicates that fracturing does occur. According to *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Section 5.4.2), the cooled intrusive basalt will likely fracture into blocks on the order of a meter in size. Given the expected fracturing of the intrusive material, only the bottom branch is activated and, therefore, /IG-MAGMA-FRAC and IG-MAGMA-FRAC are each assigned a value of 1.00.

6.6.2.4.3 Top Event IG-SEEPAGE

The purpose of top event IG-SEEPAGE is to represent the possibility that, after the cooling and fracturing of the intrusive material, seepage returns and enters the breached waste package. The upper branch of this top event indicates that seepage does not occur and the bottom three branches indicates that seepage does occur for the lower-bound, mean and upper-bound seepage scenarios, respectively. According to *Abstraction of Drift Seepage* (BSC 2003 [DIRS 169131], Section 6.5.1.7), given the uncertainty about in drift conditions after an igneous event, use of the more conservative seepage estimates for collapsed rubble-filled drifts are recommended. A Latin Hypercube Sampling process of the information provided in DTN: LB0310AMRU0120.002 [DIRS 166116] was performed for 20,000 realizations to quantify the seepage scenario branch probabilities. The results of the sampling process are documented in Appendix C, Sections C.3 and C.5 for the lithophysal and nonlithophysal geological zones, respectively. Because of differences in the seepage abstraction for the lithophysal and nonlithophysal geologic zones, it is necessary to perform Latin Hypercube sampling for each zone.

The results reported in Appendix C, Sections C.3 and C.5 are the drift fractional probability of seepage given the specified seepage scenario (i.e., lower-bound, mean, or upper-bound). The probability of the individual seepage scenarios is specified in *Analysis of Infiltration Uncertainty* (BSC 2003 [DIRS 165991], Table 7-1). The seepage scenario probability is calculated by taking the seepage fraction for each scenario (i.e., lower-bound, mean, and upper-bound) and multiplying it to the probability of being in that seepage scenario. This calculation has been performed in the EXCEL spreadsheet "Probability of Seepage" (Appendix G). The appropriate seepage probability is then substituted into the SAPHIRE analysis based on the sequence branching of top event DRIFT-ZONE of the "YMP-INIT-EVENT" event tree. The results of this calculation are assigned as follows:

Lithophysal Zone Igneous Seepage Probabilities

/IG-SEEPAGE-NWL = 4.816E-1 (no seepage probability — SAPHIRE takes the complement of this value)
IG-SEEPAGE-LL = 4.622E-2 (lower-bound seepage scenario probabilities)
IG-SEEPAGE-ML = 2.111E-1 (mean seepage scenario probabilities)
IG-SEEPAGE-UL = 2.243E-1 (upper-bound seepage scenario probabilities)

Nonlithophysal Zone Igneous Seepage Probabilities

/IG-SEEPAGE-NWNL = 7.371E-1 (no seepage probability — SAPHIRE takes the complement of this value)
IG-SEEPAGE-LNL = 1.062E-1 (lower-bound seepage scenario probabilities)
IG-SEEPAGE-MNL = 3.244E-1 (mean seepage scenario probabilities)
IG-SEEPAGE-UNL = 3.065E-1 (upper-bound seepage scenario probabilities)

6.6.2.4.4 Top Event IG-BATHTUB

The purpose of top event IG-BATHTUB is to represent the possibility that, after the cooling and fracturing of the intrusive material and seepage returns and enters the breached waste package, a bathtub configuration is formed within the waste package. The upper branch of this top event indicates that a bathtub configuration does not form and the lower branch indicates that it does. It is expected that failure of the waste package will not be limited to the upper portions of the waste package since the waste package will be immersed in magma and failures are non-directional (Assumption 5.4.7). Given this expectation, only the upper branch of this top event is activated. Therefore, /IG-BATHTUB and IG-BATHTUB are each assigned a value of 0.00.

6.6.2.4.5 Top Event IG-FM-TRANSPT

The branching of top event IG-FM-TRANSPT establishes whether fissile material remains internal to the waste package or is transported external to the waste package to the near-field environment. The upper branch indicates the evaluation of fissile material remaining in the waste package. The lower branch indicates that the fissile material is transported external to the waste package. Both scenarios are evaluated in this analysis as being equiprobable for the determination of each configurations criticality potential. In order to process both branches of this top event, /IG-FM-TRANSPT is assigned a value of 0.00 (i.e., the complement of 1.00) and IG-FM-TRANSPT is assigned a value of 1.00.

6.6.2.4.6 Top Event WF-MISLOAD

The WF-MISLOAD top event represent the probability that a waste form was incorrectly placed into a waste packaged during the preclosure loading process. The quantification of this top event is identical to the quantification in Section 6.3.3.1.9. As stated in Section 6.3.3.1.9, the probability of waste package misload is dependent on the waste form being evaluated.

6.6.2.4.7 Top Event CRIT-POT-WF

Quantification of the CRIT-POT-WF top event establishes the criticality potential of a given igneous configuration. Activation of the upper branch indicates that the configuration has no criticality potential and activation of the lower branch indicates that there is criticality potential.

As discussed below in Section 6.6.3, for waste packages that are not misloaded (either waste form or neutron absorber material), pre- and post-cooling igneous configurations without misloads have been determined to have no criticality potential. Therefore, for no misload scenarios, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

For neutron absorber material misloads, the resulting scenario is assumed to have criticality potential (Assumption 5.1.16). Therefore, only the lower branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 1.00.

Evaluation of commercial SNF misload scenarios calculate a mean probability of 2.480×10^{-5} {Table 6.6-5, conservative preliminary value (BSC 2004 [DIRS 171622], Section 6)}that the resulting misloaded configuration has criticality potential (BSC 2004 [DIRS 171622]).

Therefore, for commercial SNF misload scenarios, /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 2.480×10^{-5}.

For the misload of DOE SNF, the resulting scenario is evaluated as having criticality potential. Therefore, only the lower branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 1.00.

6.6.2.5 Quantification of Event Tree "CONFIG-NF-F"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree "CONFIG-NF-F" (Figure B-14 of Appendix B). This event tree initiates the evaluation of the near-field configurations for the formation of potentially critical configurations. This event tree consists of four top events, all of which are required for the evaluation of near-field configurations. Table 6.6-6 summarizes the event probability assignments discussed below.

Table 6.6-6. Event Probability Assignment for the "CONFIG-NF-F" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Near-field configuration class			Section 6.6.2.5.1
/CONFIG-SCEN	False [a]	1.00	
CONFIG-SCEN[1]	True	1.00	
CONFIG-SCEN[2]	True	1.00	
CONFIG-SCEN[3]	True	1.00	
(CONFIG-SCEN top event)			
Initiate processing of near-field configuration class NF-1			Section 6.6.2.5.2
/MS-NF-6	False [a]	1.00	
MS-NF-6	True	1.00	
(MS-NF-6 top event)			
Initiate processing of near -field configuration class NF-2			Section 6.6.2.5.3
/MS-NF-7	False [a]	1.00	
MS-NF-7	True	1.00	
(MS-NF-7 top event)			
Initiate processing of near -field configuration class NF-3			Section 6.6.2.5.4
/MS-NF-8	False [a]	1.00	
MS-NF-8	True	1.00	
(MS-NF-8 top event)			

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.5.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of three of the five near-field configuration classes – NF-1, NF-2, and NF-3. These configuration classes are represented by the second, third, and fourth branches from the top of this top event. The upper branch is not utilized in these analyses and is included as a modeling convenience. The processing of all three configuration class branches of this top event are initiated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], and CONFIG-SCEN[3] a value of 1.00.

6.6.2.5.2 Top Event MS-NF-6

The branching of top event MS-NF-6 directs the evaluation of near-field configuration class NF-1. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class is evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF1 event tree. The NF-1 configuration class is to be evaluated for the igneous disruptive event and, therefore, /MS-NF-6 and MS-NF-6 are each assigned a value of 1.00.

6.6.2.5.3 Top Event MS-NF-7

The branching of top event MS-NF-7 directs the evaluation of near-field configuration class NF-2. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class is evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF2 event tree. The NF-2 configuration class is to be evaluated for the igneous disruptive event and, therefore, /MS-NF-7 and MS-NF-7 are each assigned a value of 1.00.

6.6.2.5.4 Top Event MS-NF-8

The branching of top event MS-NF-8 directs the evaluation of near-field configuration class NF-3. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class is evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF3 event tree. The NF-3 configuration class is to be evaluated for the igneous disruptive event and, therefore, /MS-NF-8 and MS-NF-8 are each assigned a value of 1.00.

6.6.2.6 Quantification of Event Tree "CONFIG-NF1"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree "CONFIG-NF1" (Figure B-15 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-1 representing the near-field accumulation of fissile materials into potentially critical configurations resulting from solution effluent discharges from the waste package. This event tree consists of five top events, four of which are required for the evaluation of this near-field configuration class. Table 6.6-7 summarizes the event probability assignments discussed below.

Table 6.6-7. Event Probability Assignment for the "CONFIG-NF1" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Transport of solution effluent from waste package into invert for the formation of near-field configuration class NF-1 subclasses **/MS-NF-9** **MS-NF-9[1]** (configuration class NF-1A) **MS-NF-9[2]** (configuration class NF-1B) **MS-NF-9[3]** (configuration class NF-1C) **MS-NF-9[4]** (transfer to far-field) (MS-NF-9 top event)	False [a] True True True True	1.00 1.00 1.00 1.00 1.00	Section 6.6.2.6.2
Initiate processing of near-field configuration class NF-1A **/MS-NF-10** **MS-NF-10** (MS-NF-10 top event)	True [a] False	0.00 0.00	Section 6.6.2.6.3
Initiate processing of near-field configuration class NF-1B **/MS-NF-11** **MS-NF-11** (MS-NF-11 top event)	True [a] False	0.00 0.00	Section 6.6.2.6.4
Initiate processing of near-field configuration class NF-1C **/MS-NF-12** **MS-NF-12** (MS-NF-12 top event)	True [a] False	0.00 0.00	Section 6.6.2.6.5

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.6.1 Top Event MS-NF-9

The branching of top event MS-NF-9 directs the evaluation of the three configuration subclasses of configuration class NF-1 – NF-1A, NF-1B, and NF-1C. These configuration classes are represented by the second, third, and fourth branches from the top of this top event. The top branch is not utilized in these analyses and is included for completeness. The bottom, or fifth, branch of this top event represents the transport of fissile material from the near-field to the far-field. This branch immediately transfers to the CONFIG-FF-J event tree for far-field evaluation. The processing of all three configuration subclass branches and the far-field transfer of this top event are initiated by assigning MS-NF-9[1], MS-NF-9[2], MS-NF-9[3], and MS-NF-9[4] a value of 1.00. To prevent further evaluation of the top branch of this top event, /MS-NF-9 is also assigned a value of 1.00 (the complement of 0.00).

6.6.2.6.2 Top Event MS-NF-10

The branching of top event MS-NF-10 directs the evaluation of near-field configuration class NF-1A. The upper branch of this top event indicates that fissile materials are not sorbed into the invert materials and the lower branch indicates that fissile materials are sorbed in the invert materials. It is assumed that the post-igneous water chemistry in the drift invert does not support this fissile material accumulation mechanism (Assumption 5.4.12). Therefore, /MS-NF-10 and MS-NF-10 are each assigned a value of 0.00.

6.6.2.6.3 Top Event MS-NF-11

The branching of top event MS-NF-11 directs the evaluation of near-field configuration class NF-1B. The upper branch of this top event indicates that fissile materials do not precipitate in the invert and the lower branch indicates that fissile materials do precipitate in the invert. It is assumed that the post-igneous water chemistry in the drift invert does not support this fissile material accumulation mechanism (Assumption 5.4.12). Therefore, /MS-NF-11 and MS-NF-11 are each assigned a value of 0.00.

6.6.2.6.4 Top Event MS-NF-12

The branching of top event MS-NF-12 directs the evaluation of near-field configuration class NF-1C. The upper branch of this top event indicates that fissile materials are not transported from one or more waste packages and deposited at an invert low point. The lower branch indicates that fissile materials are transported and deposited at an invert low point. *Engineered Barrier Systems Features, Events and Processes* (BSC 2004 [DIRS 169898], Section 6.2.40) indicates that, because of the porosity of the invert, pooling in the invert cannot occur. In addition, it is assumed that the post-igneous water chemistry in the drift invert does not support this fissile material accumulation mechanism (Assumption 5.4.12). Therefore, /MS-NF-12 and MS-NF-12 are each assigned a value of 0.00.

6.6.2.7 Quantification of Event Tree “CONFIG-NF2”

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree “CONFIG-NF2” (Figure B-16 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-2 representing the near-field accumulation of fissile materials into potentially critical configurations resulting from slurry effluent discharges from the waste package. This event tree consists of three top events, of which only one is required for the evaluation of this near-field configuration class. Table 6.6-8 summarizes the event probability assignments discussed below.

Table 6.6-8. Event Probability Assignment for the “CONFIG-NF2” Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Slurry effluent flows to conform to invert surface			Section 6.6.2.7.1
/MS-NF-13	True [a]	0.00	
MS-NF-13	False	0.00	
(MS-NF-13 top event)			

NOTE: [a] For event names prefixed by a slash “/” the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.7.1 Top Event MS-NF-13

The branching of top event MS-NF-13 directs the evaluation of near-field configuration class NF-2A. The upper branch of this top event indicates that fissile material containing slurry effluent do not flow and conform to the invert surface. The lower branch indicates that the slurry effluent does flow to conform to the invert surface. Because the intrusive magma fills the drift (BSC 2004 [DIRS 170028], Section 6.4.7.5), no volume is available between the failed waste package and the surface of the drift to allow for the accumulation of the slurry effluent. Because of this, only the upper branch of this top event is activated and, therefore, /MS-NF-13 and MS-NF-13 are each assigned a value of 0.00.

6.6.2.8 Quantification of Event Tree “CONFIG-NF3”

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the near-field event tree “CONFIG-NF3” (Figure B-17 of Appendix B). This event tree initiates the evaluation of the near-field configuration class NF-3 representing the near-field accumulation of fissile material bearing colloids into potentially critical configurations. This event tree consists of seven top events, all of which are required for the evaluation of this near-field configuration class. Table 6.6-9 summarizes the event probability assignments discussed below.

Table 6.6-9. Event Probability Assignment for the “CONFIG-NF3” Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	**Probability** Value	**SAPHIRE Assigned Event Value** [a] **(per waste package)**	**Justification**
Initiate evaluation of near-field configuration class NF-3 subclasses **/CONFIG-SCEN** **CONFIG-SCEN[1]** (configuration class NF-3A) **CONFIG-SCEN[2]** (configuration classes NF-3B and NF-3C) (CONFIG-SCEN top event)	False [a] True True	1.00 1.00 1.00	Section 6.6.2.8.1
Filtration and concentration of colloids on top of invert trapped by waste package corrosion products **/MS-NF-15** **MS-NF-15** (configuration class NF-3A) (MS-NF-15 top event)	True [a] False	0.00 0.00	Section 6.6.2.8.2
Transport of colloids into invert **/MS-NF-16** **MS-NF-16[1]** (configuration class NF-3B and NF-3C **MS-NF-16[2]** (transfer to far-field) (MS-NF-16 top event)	False [a] True True	1.00 1.00 1.00	Section 6.6.2.8.3
Degradation of invert material **/MS-NF-19** **MS-NF-19** (MS-NF-19 top event)	0.10 0.90	0.90 0.90	Section 6.6.2.8.4
Hydrodynamic/chromatographic separation of fissile material colloids from neutron absorber materials **/MS-NF-17** (configuration class NF-3B) **MS-NF-17** (configuration class NF-3C) (MS-NF-17 top event)	True [a] False	0.00 0.00	Section 6.6.2.8.5
Filtration and concentration of colloids in the invert **/MS-NF-18** **MS-NF-18** (MS-NF-18 top event)	True [a] False	0.00 0.00	Section 6.6.2.8.6

NOTE: [a] For event names prefixed by a slash “/” the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.8.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of the three subclasses of near-field configuration class NF-3 and the transport of fissile material containing colloids from the near-field to far-field environments. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The three near-field configuration subclasses are represented by the second and third branches from the top of this top event. The second branch directs the evaluation of configuration subclass NF-3A and the third branch directs the evaluation of subclasses NF-3B and NF-3C. The bottom, or fourth, branch of this top event represents the transport of fissile material through the near-field environment to the far-field environment. The fourth branch immediately transfers to the "CONFIG-FF-K" event tree for far-field configuration evaluation. The processing of the bottom three branches of this top event are initiated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], and CONFIG-SCEN[3] a value of 1.00.

6.6.2.8.2 Top Event MS-NF-15

The branching of top event MS-NF-15 directs the evaluation of near-field configuration subclass NF-3A. The upper branch of this top event indicates that fissile material containing colloids are not filtered and concentrated on top of the invert, trapped by corrosion products. The lower branch indicates that the colloids are trapped on the invert surface. Because the intrusive igneous material completely fills the drift from the top of the invert to the crown of the drift (BSC 2004 [DIRS 170028], Section 6.4.7.5), no volume is available between the failed waste package and the surface of the drift to allow for the accumulation of the colloids. Because of this, only the upper branch of this top event is activated. Therefore, /MS-NF-15 and MS-NF-15 are each assigned a value of 0.00.

6.6.2.8.3 Top Event MS-NF-16

The branching of top event MS-NF-16 determines whether fissile material containing colloids are transported into the invert. Activation of the upper branch of this top event indicates that fissile material containing colloids are not transported into the invert. The activation of the second branch indicates that fissile material containing colloids are transported into the invert. In order to evaluate near-field configuration subclasses NF-3B and NF-3C, the second branch of this event is activated. The third branch is activated, which allows the fissile material colloids are transported into the far-field. Therefore, /MS-NF-16 and MS-NF-16[1] and MS-NF-[2] are each assigned a value of 1.00.

6.6.2.8.4 Top Event MS-NF-19

The branching of top event MS-NF-19 directs the evaluation of near-field configuration subclasses NF-3B and NF-3C. The upper branch of this top event evaluates configuration subclass NF-3B and indicates that the invert materials have not degraded prior to the release of the waste form materials following a seismic event. The lower branch evaluates near-field configuration subclass NF-3C and indicates that the invert materials have degraded prior to the release of waste form materials following an igneous event. The degradation of the drift invert materials will likely occur within several hundred years of repository closure due to the highly oxidizing drift environment. If it is assumed that drift material degradation does not occur for 1000 years (Assumption 5.2.5), the probability of fissile material being released to the invert due to an igneous event prior to drift degradation is calculated to be 0.10 (i.e., 1000 years to degrade drift divided by 10,000-year regulatory period) and the probability of release after drift degradation is 0.90. Therefore, /MS-NF-19 is assigned a value of 0.90 (i.e., the complement of 0.10) and MS-NF-19 is assigned a value of 0.90.

6.6.2.8.5 Top Event MS-NF-17

The branching of top event MS-NF-17 evaluates the likelihood of hydrodynamic or chromatographic separation of fissile material containing colloids from the neutron absorber materials for both near-field configuration subclasses NF-3B and NF-3C. The upper branch of this top event indicates that fissile material containing colloids are not separated from the neutron absorber materials and the lower branch indicates that they are. Because the intrusive igneous material completely fills the drift from the top of the invert to the crown of the drift (BSC 2004 [DIRS 170028], Section 6.4.7.5), no volume is available between the failed waste package and the surface of the drift to allow for the accumulation of the colloids. Because of this, only the upper branch of this top event is activated. Therefore, /MS-NF-17 and MS-NF-17 are each assigned a value of 0.00.

6.6.2.8.6 Top Event MS-NF-18

The branching of top event MS-NF-18 directs the evaluation of near-field configuration subclass NF-3A. The upper branch of this top event indicates that fissile material containing colloids are not filtered and concentrated on top of the invert. The lower branch indicates that the colloids are trapped on the invert surface. Because the intrusive igneous material completely fills the drift from the top of the invert to the crown of the drift (BSC 2004 [DIRS 170028], Section 6.4.7.5), no volume is available between the failed waste package and the surface of the drift to allow for the accumulation of the colloids. Because of this, only the upper branch of this top event is activated. Therefore, /MS-NF-18 and MS-NF-18 are each assigned a value of 0.00.

6.6.2.9 Quantification of Event Tree "CONFIG-FF-J"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the far-field event tree "CONFIG-FF-J" (Figure B-21 of Appendix B). This event tree initiates the evaluation of the far-field configuration class FF-1 representing the far-field accumulation of fissile material bearing solutes into potentially critical configurations. This event tree consists of nine top events, of which only seven are required for the evaluation of this far-field configuration class for the igneous disruptive event. Table 6.6-10 summarizes the event probability assignments discussed below.

Table 6.6-10. Event Probability Assignment for the "CONFIG-FF-J" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Value	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Transport of fissile material solutes to far-field in carrier plume **/MS-FF-1** **MS-FF-1** (MS-FF-1 top event)	False [a] True	1.00 1.00	Section 6.6.2.9.1
Separation of fissile material from neutron absorber initiating formation of far-field configuration class subclasses **/MS-FF-2** **MS-FF-2[1]** (configuration class FF-1A) **MS-FF-2[2]** (configuration class FF-1B) **MS-FF-2[3]** (transfer to configuration class FF-3) (MS-FF-2 top event)	False [a] True True True	1.00 1.00 1.00 1.00	Section 6.6.2.9.2
Fissile material solutes are transported to the water table (transfer to far-field event tree CONFIG-FF3) **/MS-FF-3** **MS-FF-3** (MS-FF-3 top event)	False [a] True	1.00 1.00	Section 6.6.2.9.3
Precipitation of fissile material as carrier plume is altered by rocks (far-field configuration class FF-1A) **/MS-FF-11** **MS-FF-11** (MS-FF-11 top event)	True [a] False	0.00 0.00	Section 6.6.2.9.4
Transport of fissile material solutes to altered TSbv **/MS-FF-12** **MS-FF-12[1]** (configuration class FF-1B) **MS-FF-12[2]** (configuration class FF-1C) (MS-FF-12 top event)	False [a] True True	1.00 1.00 1.00	Section 6.6.2.9.5
Sorption of fissile material on clays and zeolites in altered TSbv (configuration class FF-1B) **/MS-FF-13** **MS-FF-13** (MS-FF-13 top event)	True [a] False	0.00 0.00	Section 6.6.2.9.6
Accumulation of fissile material solute in topographic lows above altered TSbv (configuration class FF-1C) **/MS-FF-14** **MS-FF-14** (MS-FF-14 top event)	True [a] False	0.00 0.00	Section 6.6.2.9.7

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.9.1 Top Event MS-FF-1

The branching of top event MS-FF-1 initiates the evaluation of far-field configuration class FF-1 representing the transport of fissile material containing solutes into the far-field's saturated and unsaturated zones. Only the lower branch of this top event is activated to initiate the evaluation of this far-field configuration class. Therefore, /MS-FF-1 and MS-FF-1 are each assigned a value of 1.00.

6.6.2.9.2 Top Event MS-FF-2

The branching of top event MS-FF-2 determines whether the fissile materials entering the far-field environment are separated from the neutron absorber materials of the waste package or waste form. The upper branch indicates that the fissile material is not separated from the neutron absorber materials by the far-field environment. The remaining three branches evaluate far-field configuration classes for the separation of the fissile materials from the neutron absorber materials. The second branch from the top directs the evaluation of configuration subclass FF-1A and the third branch directs the evaluation of subclasses FF-1B and FF-1C. The fourth, or bottom branch of this top event represents the transport of fissile material through the unsaturated zone and into the water table for the evaluation of configuration class FF-3. The fourth branch immediately transfers to the "CONFIG-FF3" event tree. The processing of the bottom three branches of this top event are equiprobable and are accessed by assigning MS-FF-2[1], MS-FF-2[2], and MS-FF-2[3] a value of 1.00. To prevent further evaluation of the upper branch of this top event, /MS-FF-2 will also assigned a value of 1.00 (the complement of 0.00).

6.6.2.9.3 Top Event MS-FF-3

The branching of top event MS-FF-3 represents the transport of fissile materials through the unsaturated zone to the water table. The upper branch of this top event indicates that fissile material is not transported to the water table. The lower branch of this top event indicates that fissile materials are transported directly to the water table. In order to allow for the evaluation of far-field configuration class FF-3, the lower branch of this top event is selected. Therefore, /MS-FF-3 and MS-FF-3 are each assigned a value of 1.00.

6.6.2.9.4 Top Event MS-FF-11

The branching of top event MS-FF-11 represents the precipitation of fissile material as the chemistry of the fissile material containing carrier plume is altered by the unsaturated zone host rock. This scenario represents far-field configuration subclass FF-1A. The upper branch of this top event indicates that fissile material is not precipitated and the lower branch of this top event indicates that it is precipitated. It is assumed that there are no mechanisms that would cause any appreciable precipitation and accumulation of fissile material in the unsaturated zone (Assumption 5.5.3). Therefore, /MS-FF-11 and MS-FF-11 are each assigned a value of 0.00.

6.6.2.9.5 Top Event MS-FF-12

The branching of top event MS-FF-12 represents the transport of fissile material containing solutes to altered TSbv. The upper branch of this top event indicates that the fissile material is not transported to the altered TSbv. The second and third branches of this top event indicate that fissile materials are transported to the altered TSbv and initiate the evaluation of far-field configuration subclasses FF-1B and FF-1C, respectively. In order to allow for the evaluation of far-field configuration subclass FF-1B and FF-1C, the lower two branches of this top event are selected. Therefore, /MS-FF-12, MS-FF-12[1], and MS-FF-12[2] are each assigned a value of 1.00.

6.6.2.9.6 Top Event MS-FF-13

The branching of top event MS-FF-13 represents formation of the far-field configuration subclass FF-1B, which is defined as the sorption of fissile material in clays and zeolites in the altered TSbv. The upper branch of this top event indicates that fissile materials are not sorbed and the lower branch of this top event indicates that they are. Because the known quantities of clays and zeolites in the unsaturated zone will not result in any appreciable sorption of fissile materials (Assumption 5.5.4), the upper branch of this top event is selected. Therefore, /MS-FF-13 and MS-FF-13 are each assigned a value of 0.00.

6.6.2.9.7 Top Event MS-FF-14

The branching of top event MS-FF-14 represents the formation of far-field configuration subclass FF-1C, which is defined as the accumulation of fissile material containing solutes in topographical lows above altered TSbv. The upper branch of this top event indicates that fissile material containing solutes are not accumulated and the lower branch of this top event indicates that they are. Because there are no known fissile material accumulation mechanisms in the altered TSbv (Assumption 5.5.2), the upper branch of this top event is selected. Therefore, /MS-FF-14 and MS-FF-14 are each assigned a value of 0.00.

6.6.2.10 Quantification of Event Tree “CONFIG-FF-K”

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the far-field event tree “CONFIG-FF-K” (Figure B-22 of Appendix B). This event tree initiates the evaluation of the far-field configuration class FF-2 representing the far-field accumulation of fissile material bearing colloids into potentially critical configurations. This event tree consists of seven top events, of which only six are required for the evaluation of this far-field configuration class for the igneous disruptive event. Table 6.6-11 summarizes the event probability assignments discussed below.

Table 6.6-11. Event Probability Assignment for the "CONFIG-FF-K" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analysis

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Transport of fissile material solutes to TSw in carrier plume **/MS-FF-16** **MS-FF-16** (MS-FF-16 top event)	 False [a] True	 1.00 1.00	Section 6.6.2.10.1
Hydrodynamic/chromatographic separation of fissile material colloids from neutron absorber materials **/MS-FF-17** **MS-FF-17[1]** (configuration class FF-2A) **MS-FF-17[2]** (configuration classes FF-2B and FF-2C) (MS-FF-17 top event)	 False [a] True True	 1.00 1.00 1.00	Section 6.6.2.10.2
Trapping of fissile material colloids in dead-end fractures at boundary stress-relief zone (configuration class FF-2A) **/MS-FF-18** **MS-FF-18** (MS-FF-18 top event)	 True [a] False	 0.00 0.00	Section 6.6.2.10.3
Transport of fissile material colloids to altered TSbv **/MS-FF-19** **MS-FF-19[1]** (configuration class FF-2B) **MS-FF-19[2]** (configuration class FF-2C) (MS-FF-19 top event)	 False [a] True True	 1.00 1.00 1.00	Section 6.6.2.10.4
Sorption of colloids on clays and zeolites in altered TSbv (configuration class FF-2B) **/MS-FF-20** **MS-FF-20** (MS-FF-20 top event)	 True [a] False	 0.00 0.00	Section 6.6.2.10.5
Filtration of colloids in topographic lows above TSbv (configuration class FF-2C) **/MS-FF-21** **MS-FF-21** (MS-FF-21 top event)	 True [a] False	 0.00 0.00	Section 6.6.2.10.6

NOTE: [a] For event names prefixed by a slash "/" the actual event probability used in processing the SAPHIRE logic model is the complement (i.e., 1 – value) of the assigned value

6.6.2.10.1 Top Event MS-FF-16

The branching of top event MS-FF-16 initiates the evaluation of far-field configuration class FF-2 representing the transport of fissile material bearing colloids into the far-field's unsaturated zone. Only the lower branch of this top event is activated to initiate the evaluation of this far-field configuration class. Therefore, /MS-FF-16 and MS-FF-16 are each assigned a value of 1.00.

6.6.2.10.2 Top Event MS-FF-17

The branching of top event MS-FF-17 determines whether the fissile material bearing colloids entering the unsaturated zone environment are hydrodymically or chromatographically separated from the neutron absorber materials of the waste package or waste form. The upper branch indicates that the fissile material is not separated from the neutron absorber materials by the unsaturated zone environment. The remaining two branches represent the separation of the fissile materials from the neutron absorber materials and initiate the evaluation of the FF-2 configuration subclasses. The second branch from the top directs the evaluation of configuration subclass FF-2A and the third branch directs the evaluation of configuration subclasses FF-2B and FF-2C. The processing of the bottom two branches of this top event are equiprobable and are activated by assigning MS-FF-17[1] and MS-FF-17[2] a value of 1.00. To prevent evaluation of the upper branch of this top event, /MS-FF-17 will also be assigned a value of 1.00 (the complement of 0.00).

6.6.2.10.3 Top Event MS-FF-18

The branching of top event MS-FF-18 represents far-field configuration subclass FF-2A that is defined as the trapping of fissile material bearing colloids in altered TSbv. The upper branch of this top event indicates that fissile material bearing colloids are not trapped and the lower branch indicates that they are. Because there are no known mechanisms for trapping and accumulating any appreciable quantities of fissile material bearing colloids in altered TSbv (Assumption 5.5.2), only the top branch of this top event is activated. Therefore, /MS-FF-18 and MS-FF-18 are each assigned a value of 0.00.

6.6.2.10.4 Top Event MS-FF-19

The branching of top event MS-FF-19 represents the transport of fissile material containing colloids to altered TSbv. The upper branch of this top event indicates that fissile material containing colloids are not transported and the lower two branches indicate that they are. The second and third branches of this top event initiate the evaluation of far-field configuration subclasses FF-2B and FF-2C, respectively. In order to allow for the evaluation of these far-field configuration subclasses, the lower two branches of this top event are selected. Therefore, /MS-FF-19, MS-FF-19[1], and MS-FF-19[2] are each assigned a value of 1.00.

6.6.2.10.5 Top Event MS-FF-20

The branching of top event MS-FF-20 represents formation of the far-field configuration subclass FF-2B which is defined as the sorption of fissile material containing colloids on clays and zeolites in the altered TSbv. The upper branch of this top event indicates that fissile materials are not sorbed and the lower branch of this top event indicates that they are. Because the known quantities of clays and zeolites in the unsaturated zone will not result in any appreciable sorption of fissile materials containing colloids (Assumption 5.5.4), the upper branch of this top event is activated. Therefore, /MS-FF-20 and MS-FF-20 are each assigned a value of 0.00.

6.6.2.10.6 Top Event MS-FF-21

The branching of top event MS-FF-21 represents the formation of far-field configuration subclass FF-2C, which is defined as the filtration and accumulation of fissile material containing colloids in topographical lows above altered TSbv. The upper branch of this top event indicates that fissile material containing colloids are not filtered and accumulated and the lower branch of this top event indicates that they are. Because there are no known fissile material accumulation mechanisms in the altered TSbv (Assumption 5.5.2), the upper branch of this top event is selected. Therefore, /MS-FF-21 and MS-FF-21 are each assigned a value of 0.00.

6.6.2.11 Quantification of Event Tree "CONFIG-FF3"

The following subsections provide justification for the probabilities assigned to the events used in the quantification of the far-field event tree "CONFIG-FF3" (Figure B-23 of Appendix B). This event tree initiates the evaluation of the far-field configuration class FF-3 representing the accumulation of fissile material into potentially critical configurations in the far-field saturated zone. This event tree consists of nine top events, all of which are required for the evaluation of far-field configuration class FF-3 for the igneous disruptive event. Table 6.6-12 summarizes the event probability assignments discussed below.

Table 6.6-12. Event Probability Assignment for the "CONFIG-FF3" Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Initiate evaluation of far-field configuration class FF-3 subclasses			Section 6.6.2.11.1
/CONFIG-SCEN	False [a]	1.00	
CONFIG-SCEN[1] (configuration class FF-3A)	True	1.00	
CONFIG-SCEN[2] (configuration class FF-3B)	True	1.00	
CONFIG-SCEN[3] (configuration class FF-3C)	True	1.00	
CONFIG-SCEN[4] (configuration class FF-3D)	True	1.00	
CONFIG-SCEN[5] (configuration class FF-3E)	True	1.00	
(CONFIG-SCEN top event)			
Fissile material precipitates in upwell zone of hydrothermal fluids at faults or in fractures (configuration class FF-3A)			Section 6.6.2.11.2
/MS-FF-4	True [a]	0.00	
MS-FF-4	False	0.00	
(MS-FF-4 top event)			

Table 6.6-12. Event Probability Assignment for the “CONFIG-FF3” Event Tree for the Igneous Disruptive Event Criticality FEPs SAPHIRE Analyses (Continued)

Event Name and Description	Probability Values	SAPHIRE Assigned Event Value [a] (per waste package)	Justification
Contaminant plume mixes below redox front (configuration class FF-3B) **/MS-FF-5** **MS-FF-5** (MS-FF-5 top event)	False [a] True	1.00 1.00	Section 6.6.2.11.3
Precipitation of fissile material (configuration class FF-3B) **/MS-FF-6** **MS-FF-6** (MS-FF-6 top event)	True [a] False	0.00 0.00	Section 6.6.2.11.4
Fissile material precipitates at reducing zone (configuration class FF-3C) **/MS-FF-7** **MS-FF-7** (MS-FF-7 top event)	True [a] False	0.00 0.00	Section 6.6.2.11.5
Fissile material precipitates at organic reducing zone at pinchout of tuff aquifer (configuration class FF-3D) **/MS-FF-8** **MS-FF-8** (MS-FF-8 top event)	True [a] False	0.00 0.00	Section 6.6.2.11.6
Fissile material solutes are transported to Franklin Lake Playa (configuration class FF-3E) **/MS-FF-9** **MS-FF-9** (MS-FF-9 top event)	False [a] True	1.00 1.00	Section 6.6.2.11.7
Fissile material solutes precipitate in organic-rich zones of Franklin Lake Playa (configuration class FF-3E) **/MS-FF-10** **MS-FF-10** (MS-FF-9 top event)	False [a] True	1.00 1.00	Section 6.6.2.11.8
Criticality potential of configuration class FF-3E **/CRIT-POT-WF** **CRIT-POT-WF** (CRIT-POT-WF top event)	True [a] False	0.00 0.00	Section 6.6.2.11.9

NOTE: [a] For event names prefixed by a slash “/” the actual event probability is the complement (i.e., 1 – value) of the assigned value

6.6.2.11.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of the five subclasses of far-field configuration class FF-3 defined as the transport of fissile material into the saturated zone. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The five far-field configuration subclasses are represented by the second through sixth branches from the top of this top event. These five branches direct the evaluation of configuration subclass FF-3A, FF-3B, FF-3C, FF-3D, and FF-3E, respectively. The processing of the bottom five branches of this top event are initiated by assigning CONFIG-SCEN[1], CONFIG-SCEN[2], CONFIG-SCEN[3], CONFIG-SCEN[4], and CONFIG-SCEN[5] a value of 1.00.

6.6.2.11.2 Top Event MS-FF-4

The branching of top event MS-FF-4 initiates the evaluation of far-field configuration subclass FF-3A defined as the precipitation of fissile material in the upwell zone of hydrothermal fluids at faults or in fractures. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that they are. Because no known mechanism exists for the appreciable precipitation of fissile material in the saturated zone (Assumption 5.5.3), only the upper branch of this top event is activated. Therefore, /MS-FF-4 and MS-FF-4 are each assigned a value of 0.00.

6.6.2.11.3 Top Event MS-FF-5

The branching of top event MS-FF-5 represents the mixing of the fissile material containing contaminant plume below the redox front. The effects of pH and pCO_2 in the UZ on uranium can lead to precipitation through reduction in the uranium solubility (Assumption 5.5.3). The upper branch indicates that mixing does not occur and the lower branch indicates that it does. In order to allow for the processing of far-field configuration subclass FF-3B, only the lower branch of this top event is activated. Therefore, /MS-FF-5 and MS-FF-5 are each assigned a value of 1.00.

6.6.2.11.4 Top Event MS-FF-6

The branching of top event MS-FF-6 initiates the evaluation of far-field configuration subclass FF-3B defined as the precipitation of fissile material as the contaminant plume mixes below the redox front. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that they are. Because no known mechanism exists for the appreciable precipitation of fissile material in the saturated zone (Assumption 5.5.3), only the upper branch of this top event is activated. Therefore, /MS-FF-6 and MS-FF-6 are each assigned a value of 0.00.

6.6.2.11.5 Top Event MS-FF-7

The branching of top event MS-FF-7 initiates the evaluation of far-field configuration subclass FF-3C defined as the precipitation of fissile materials at the reducing zone (i.e., the remains of organic materials). The upper branch indicates that fissile material is not precipitated and the lower branch indicates that it is. Because organic material is not known to exist in the saturated zone in any appreciable quantity, precipitation of fissile material is unlikely (Assumption 5.5.5). Therefore, only the upper branch of this top event is activated and /MS-FF-7 and MS-FF-7 are each assigned a value of 0.00.

6.6.2.11.6 Top Event MS-FF-8

The branching of top event MS-FF-8 initiates the evaluation of far-field configuration subclass FF-3D defined as the precipitation of fissile materials at the reducing zone of a pinchout of the tuff aquifer. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that it is. Because organic material is not known to exist in the saturated zone in any appreciable quantity, precipitation of fissile material is unlikely (Assumption 5.5.5). Therefore, only the upper branch of this top event is activated and /MS-FF-8 and MS-FF-8 are each assigned a value of 0.00.

6.6.2.11.7 Top Event MS-FF-9

The branching of top event MS-FF-9 represents the transport of fissile material containing solutes to Franklin Lake Playa. The upper branch indicates that transport does not occur and the lower branch indicates that it does. In order to allow for the processing of far-field configuration subclass FF-3E, only the lower branch of this top event is activated. Therefore, /MS-FF-9 and MS-FF-9 are each assigned a value of 1.00.

6.6.2.11.8 Top Event MS-FF-10

The branching of top event MS-FF-10 represents the precipitation of fissile material containing solutes in organic-rich zones of Franklin Lake. The upper branch indicates that precipitation does not occur and the lower branch indicates that it does. It is assumed (Assumption 5.5.1) that if fissile material is transported to Franklin Lake, organic-rich reducing zones within the lake will allow for the precipitation and accumulation of fissile materials. Therefore, only the lower branch of this top event is activated and /MS-FF-10 and MS-FF-10 are each assigned a value of 1.00.

6.6.2.11.9 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of the precipitated fissile material in the organic-rich zones of Franklin Lake. The upper branch indicates that precipitated material does not have a criticality potential and the lower branch indicates that it does.

It is assumed that, over the regulatory period, amount of fissile material that could be transported and accumulated in the organic-rich zones of Franklin Lake would be insufficient to result in a potential critical configuration (Assumption 5.5.1). Therefore, only the upper branch of this top event is activated and /CRIT-POT-WF and CRIT-POT-WF are each assigned a value of 0.00.

6.6.3 Internal and External Criticality Analysis Results

Criticality calculations were performed for igneous intrusion scenarios in *Criticality Potential of Waste Packages Affected by Igneous Intrusion* (BSC 2004 [DIRS 171690]). Waste packages for two types of DOE SNF were considered in these calculations – U-Zr/U-Mo Alloy and U-Zr H_x. The calculation considers three different waste package damage configurations: (1) intact configuration; (2) partial slump configuration; and (3) complete slump configuration. In all three configurations, the DHLW glass liquefies due to the igneous intrusion temperatures and is capable of migrating from its original location within the waste package. In the intact configuration, the waste package has not breached or deformed. In the partial slump configuration, the waste package has deformed under the weight of the surrounding magma until the voids in the waste package are eliminated. In the complete slump case, the waste package is assumed to have breached, and some of the DHLW glass has been forced out of the waste package. Calculations were also performed with the waste package outer barrier and/or the DHLW glass removed to simulate magma entering and filling the waste package.

In addition, a range of variables is examined in this calculation, including:

- Magma temperature (from maximum intrusion temperature and cooled to ambient), and
- Water concentration of the intruding magma (from 0.5 to 4.0 weight percent).

Intact waste package configurations utilizing fresh fuel, degraded flow-through configurations, and degraded bathtub configurations were also analyzed. The maximum predicted k_{eff} calculated from these analyses is lower than the calculated critical limit.

6.6.4 Igneous Criticality FEPs Analysis Results

The quantification of the SAPHIRE igneous disruptive event resulted in the calculation of the waste package fractional probabilities presented in Table 6.6-13. These fractional probabilities are summarized from the SAPHIRE results presented in Appendix B, Section B.5. Because the k_{eff} values for the likely igneous scenarios internal to the waste package are calculated to be below the predicted critical limit, the probability of criticality is insignificant. For external igneous scenarios, it is assumed (Assumptions 5.4.12, 5.5.1, 5.5.2, 5.5.3, 5.5.4, and 5.5.5) that there are no mechanisms to allow for significant accumulation of fissile material in the near-field or far-field environments (i.e., accumulation is below critical mass required). Therefore, the probability of criticality is also insignificant for scenarios external to the waste package. These results are applicable to all igneous criticality FEPs regardless of analysis location (internal or external to the waste package) or waste form/waste package type.

The total criticality probability of each waste package type is dependent on the number of each waste package type that are involved in the igneous event. For an igneous eruptive event, the mean number of waste packages within the eruptive conduit is six (BSC 2004 [DIRS 170001], Section 7.2). For an igneous intrusion event, the number of waste packages in drifts intersected by intrusive dikes ranges from zero to nearly the entire waste package inventory with a median value of 1612 (BSC 2004 [DIRS 170001], Section 6.3.4). From the SAPHIRE results reported in Table B-2 of Appendix B, the per waste package criticality probabilities for all igneous induced waste package damage results from intrusion scenarios as indicated by igneous intrusive configuration class end state suffixes IGI1 and IGI2.

The mean number of waste packages of any given type that are potentially impacted by an igneous intrusion event can be calculated using the hypergeometric distribution of Equation 6.6-1 which is a reiteration of Equation 6.4-11 (Evans, et al., 1993 [DIRS 112115], p. 85).

$$P(n; X, N) = nX/N \qquad \text{(Eq. 6.6-1)}$$

where

X is the number of waste packages impacted by an igneous intrusion event
n is the number of waste package of a given type
N is the total number of waste packages in the repository inventory

Using this equation, the fraction number of waste packages impacted by an igneous intrusion event is presented in Table 6.6-14. The total probability of criticality for each waste package type is then estimated by multiplying the mean fractional number of waste packages and the total per waste package probability of criticality from Table 6.6-13. A more exact solution of this calculation could be performed using the binomial distribution of Equation 6.4-3. However, given the waste package type population numbers that include fractional populations of less than one, the binomial distribution is not applied because the product method is a sufficiently close approximation.

Table 6.6-13. Per Waste Package Criticality Probabilities from SAPHIRE Analysis of Igneous Disruptive Event Criticality FEPs

Waste Package Type	Number of Waste Packages[a]	Per Waste Package Probability of Criticality[b]				Total
		Intact In-Package	Degraded In-Package	Near-Field	Far-Field	
21-PWR Absorber Plate	4299	0.00E+00	3.84E-12	0.00E+00	0.00E+00	3.84E-12
21-PWR Control Rod	95	0.00E+00	2.15E-11	0.00E+00	0.00E+00	2.15E-11
12-PWR Absorber Plate	163	0.00E+00	2.64E-14	0.00E+00	0.00E+00	2.64E-14
24-BWR Absorber Plate	84	0.00E+00	2.64E-14	0.00E+00	0.00E+00	2.64E-14
44-BWR Absorber Plate	2831	0.00E+00	2.64E-14	0.00E+00	0.00E+00	2.64E-14
DOE SNF Short w/ MOX	5	0.00E+00	6.97E-12	0.00E+00	0.00E+00	6.97E-12
DOE SNF Long w/ MOX	61	0.00E+00	6.97E-12	0.00E+00	0.00E+00	6.97E-12
DOE SNF Short w/ U-Zr Hx	165	0.00E+00	2.64E-14	0.00E+00	0.00E+00	2.64E-14
DOE SNF Short w/ U-Metal	16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U-Metal	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF MCO w/ U-Metal	220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ HEU Oxide	655	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ HEU Oxide	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U/Th Oxide	20	0.00E+00	1.84E-11	0.00E+00	0.00E+00	1.84E-11
DOE SNF Long w/ U/Th Oxide	73	0.00E+00	1.84E-11	0.00E+00	0.00E+00	1.84E-11
DOE SNF Long w/ U/Th Carbide	605	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ Aluminum Based	1226	0.00E+00	2.64E-14	0.00E+00	0.00E+00	2.64E-14
DOE SNF Long w/ Aluminum Based	1	0.00E+00	2.64E-14	0.00E+00	0.00E+00	2.64E-14
DOE SNF Short w/ U-Zr/U-Mo Alloy	14	0.00E+00	1.84E-11	0.00E+00	0.00E+00	1.84E-11
DOE SNF Long w/ U-Zr/U-Mo Alloy	19	0.00E+00	1.84E-11	0.00E+00	0.00E+00	1.84E-11
DOE SNF Short w/ LEU Oxide	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ LEU Oxide	344	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Source: [a] Values from Table 4.1-3

[b] SAPHIRE V. 7.18 (BSC 2002 [DIRS 160873]) analysis results (Appendix B, Section B.24) and Microsoft EXCEL spreadsheet “endstate.xls”. (Probability values below the screening criterion are set to 0.0.)

Table 6.6-14. Per Waste Package Type Total Probability of Criticality Resulting from an Igneous Event

Waste Package Type	Total Number of Waste Packages in Repository Inventory[a]	Total Number of Waste Package Impacted by an Igneous Intrusion Event [b]	Mean Fractional Waste Package Population Impacted by an Igneous Intrusion Event [c]	Total Per Waste Package Probability of Criticality Due to an Igneous Event [d]	Waste Package Type Total Probability of Criticality Due to an Igneous Event
21-PWR Absorber Plate	4299	1612	616.00	3.84E-12	2.37E-09
21-PWR Control Rod	95	1612	13.61	2.15E-11	2.93E-10
12-PWR Absorber Plate	163	1612	23.36	2.64E-14	6.17E-13
24-BWR Absorber Plate	84	1612	12.04	2.64E-14	3.18E-13
44-BWR Absorber Plate	2831	1612	405.65	2.64E-14	1.07E-11
DOE SNF Short w/ MOX	5	1612	0.72	6.97E-12	4.99E-12
DOE SNF Long w/ MOX	61	1612	8.74	6.97E-12	6.09E-11
DOE SNF Short w/ U-Zr Hx	165	1612	23.64	2.64E-14	6.25E-13
DOE SNF Short w/ U-Metal	16	1612	2.29	0.00E+00	0.00E+00
DOE SNF Long w/ U-Metal	4	1612	0.57	0.00E+00	0.00E+00
DOE SNF MCO w/ U-Metal	220	1612	31.52	0.00E+00	0.00E+00
DOE SNF Short w/ HEU Oxide	655	1612	93.85	0.00E+00	0.00E+00
DOE SNF Long w/ HEU Oxide	42	1612	6.02	0.00E+00	0.00E+00
DOE SNF Short w/ U/Th Oxide	20	1612	2.87	1.84E-11	5.27E-11
DOE SNF Long w/ U/Th Oxide	73	1612	10.46	1.84E-11	1.92E-10
DOE SNF Long w/ U/Th Carbide	605	1612	86.69	0.00E+00	0.00E+00
DOE SNF Short w/ Aluminum Based	1226	1612	175.67	2.64E-14	4.64E-12
DOE SNF Long w/ Aluminum Based	1	1612	0.14	2.64E-14	3.79E-15
DOE SNF Short w/ U-Zr/U-Mo Alloy	14	1612	2.01	1.84E-11	3.69E-11
DOE SNF Long w/ U-Zr/U-Mo Alloy	19	1612	2.72	1.84E-11	5.01E-11
DOE SNF Short w/ LEU Oxide	8	1612	1.15	0.00E+00	0.00E+00
DOE SNF Long w/ LEU Oxide	344	1612	49.29	0.00E+00	0.00E+00
TOTAL	11,250				3.08E-09

Source: [a] Values from Table 4.1-3
[b] BSC 2004 [DIRS 170001], Section 6.3.4
[c] calculated using Equation 6.6-1
[d] column 7 of Table 6.6-13. (Probability values below the screening criterion are set to 0.0.)

6.7 CRITICALITY FEPS RESULTS

Evaluation of SAPHIRE event trees for the base case events, seismic disruptive event, rock fall disruptive event, and igneous disruptive event resulted in the generation of the per waste package probabilities presented in Table 6.7-1. Table 6.7-1 summarizes the SAPHIRE analysis results presented in Tables 6.3-11, 6.4-23, and 6.6-14. The total per waste package probability of criticality results of Table 6.7-1 is the sum of the initiating event per waste package criticality probabilities for each waste package type (i.e., Total = Base Case + Seismic + Rock Fall + Igneous).

The NNPP is responsible for assessing the criticality potential of the naval SNF waste package types that is provided in their Technical Support Document for License Application (McKenzie 2004 [DIRS 170742]) as the total probability of criticality for the NNPP long waste package type as 4.4 × 10^{-9} and for the NNPP short waste package type as 6.0 × 10^{-9}. Accounting for these additional factors, the total probability of criticality is still calculated to be below the regulatory probability criterion at 1.44 × 10^{-8}.

Table 6.7-1. Total Per Waste Package Probability of Criticality of Each Waste Package Type for Each Criticality FEPs Case

Waste Package Type	**Per Case Total Probability of Criticality**				**Total Probability of Criticality**
	Base Case[a]	**Seismic**[b]	**Rock Fall** [c]	**Igneous**[d]	
21-PWR Absorber Plate	0.00E+00	3.91E-10	0.00E+00	2.37E-09	2.76E-09
21-PWR Control Rod	0.00E+00	4.84E-11	0.00E+00	2.93E-10	3.42E-10
12-PWR Absorber Plate	0.00E+00	1.05E-13	0.00E+00	6.17E-13	7.22E-13
24-BWR Absorber Plate	0.00E+00	5.40E-14	0.00E+00	3.18E-13	3.72E-13
44-BWR Absorber Plate	0.00E+00	1.82E-12	0.00E+00	1.07E-11	1.25E-11
DOE SNF Short w/ MOX	0.00E+00	5.32E-12	0.00E+00	4.99E-12	1.03E-11
DOE SNF Long w/ MOX	0.00E+00	6.50E-11	0.00E+00	6.09E-11	1.26E-10
DOE SNF Short w/ U-Zr Hx	0.00E+00	6.92E-13	0.00E+00	6.25E-13	1.32E-12
DOE SNF Short w/ U-Metal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ U-Metal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF MCO w/ U-Metal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ HEU Oxide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ HEU Oxide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ U/Th Oxide	0.00E+00	5.62E-11	0.00E+00	5.27E-11	1.09E-10
DOE SNF Long w/ U/Th Oxide	0.00E+00	2.05E-10	0.00E+00	1.92E-10	3.97E-10
DOE SNF Long w/ U/Th Carbide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Short w/ Aluminum Based	0.00E+00	5.14E-12	0.00E+00	4.64E-12	9.79E-12
DOE SNF Long w/ Aluminum Based	0.00E+00	4.19E-15	0.00E+00	3.79E-15	7.98E-15
DOE SNF Short w/ U-Zr/U-Mo Alloy	0.00E+00	3.94E-11	0.00E+00	3.69E-11	7.63E-11
DOE SNF Long w/ U-Zr/U-Mo Alloy	0.00E+00	5.34E-11	0.00E+00	5.01E-11	1.04E-10
DOE SNF Short w/ LEU Oxide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DOE SNF Long w/ LEU Oxide	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Naval Short	0.00E+00	6.0E-09	0.00E+00	0.00E+00	6.0E-09
Naval Long	0.00E+00	4.4E-09	0.00E+00	0.00E+00	4.4E-09
TOTAL					1.44E-08

Source: [a] Table 6.3-12
[b] Table 6.4-23
[c] Section 6.5
[d] Table 6.6-14 (Probability values below the screening criterion are set to 0.0.)

6.8 CRITICALITY FEATURES, EVENTS AND PROCESSES SCREENING DOCUMENTATION

Documentation of the screening decisions for each of the sixteen criticality FEPs is contained in the following sections.

6.8.1 In-Package Criticality (Intact Configuration) (FEP 2.1.14.15.0A)

FEP Description:	The waste package internal structures and the waste form remain intact. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ. In-package criticality resulting from disruptive events is addressed in separate FEPs.
Screening Decision:	Excluded - Low Probability.
Screening Argument:	For a criticality event to occur, the proper combination of materials (neutron moderators, neutron absorbers, fissile materials) and geometric configuration must exist. A critical system for the geological repository is defined as one having an effective neutron multiplication factor (k_{eff}), larger than the critical limit. The critical limit is the value of k_{eff} at which a system (configuration of fissile material) is considered critical as characterized by statistical tolerance limits (BSC 2004 [DIRS 168553], Section 6.3.1). Waste form criticality analyses demonstrate that an intact, fully flooded with water (a neutron moderator), waste package configuration will not achieve criticality (CRWMS M&O 1999 [DIRS 125206], CRWMS M&O 2000 [DIRS 147650], CRWMS M&O 2000 [DIRS 147651], BSC 2004 [DIRS 171414], CRWMS M&O 2000 [DIRS 151742], CRWMS M&O 2000 [DIRS 151743], CRWMS M&O 2001 [DIRS 154194], BSC 2001 [DIRS 157733], BSC 2001 [DIRS 157734], BSC 2004 [DIRS 169963], BSC 2004 [DIRS 168935]). Additionally, intact, fully loaded, fully flooded waste packages are precluded from achieving criticality by design to satisfy a preclosure operations requirement that the MGR provides means to ensure criticality control during SNF/HLW handling operations, including waste package loading (Curry 2004 [DIRS 170557], Requirement 1.1.6-4). Therefore, the probability of criticality for a nominal waste package configuration is zero. This result is applicable for all waste form/waste package types.
TSPA-LA Disposition:	Not Applicable
Supporting Reports:	Not Applicable

6.8.2 In-Package Criticality (Degraded Configuration) (FEP 2.1.14.16.0A)

FEP Description: The waste package internal structures and the waste form may degrade. If a critical configuration (sufficient fissile material, neutron moderator and reduction in neutron absorbers) develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). In-package criticality resulting from disruptive events is addressed in separate FEPs.

Screening Decision: Excluded – Low Probability.

Screening Argument: For a criticality event to occur, the proper combination of materials (neutron moderators, neutron absorbers, fissile materials) and geometric configuration must exist. A critical system for the geological repository is defined as one having an effective neutron multiplication factor (k_{eff}), larger than the critical limit. The critical limit is the value of k_{eff} at which a system (configuration of fissile material) is considered critical as characterized by statistical tolerance limits (BSC 2004 [DIRS 168553], Section 6.3.1).

All postclosure criticality FEPs, internal and external, require water infiltration to degrade the waste package internals and waste form. Neutron absorber material loss and a flooded waste package condition for neutron moderation is the scenario that could most likely result in a potentially critical configuration in any of the in-situ criticality FEPs. Seepage flow-through and humid air conditions internal to the waste package may degrade waste package internal components and waste forms. However, sufficient neutron absorber material loss (Assumption 5.1.9) and adequate neutron moderation are unlikely under these conditions and the generation of an internal criticality configuration is improbable.

Water, silica, and carbon are the only potential moderating materials for internal configurations available within the repository. Water, which can enter the waste package as seepage flow or be present in the pores of the rock, is the most effective neutron-moderating material. Silica is present in appreciable quantities in the high-level radioactive waste glass canisters and in the repository rock. Silica can also be introduced into the waste package through entrainment in and precipitation from the seepage flow. Carbon is present in less than 20 percent of the DOE SNF waste package types (DOE 2004 [DIRS 170071]) and then in only limited amounts. Carbon, therefore, has a limited impact on the potential for criticality. The loading of the DOE-standardized SNF canisters, the design of the basket structure inside the canisters, and the addition of neutron absorber materials take into account the presence and effect of degraded glass in DOE

SNF waste packages. Silica from the degradation of high-level radioactive waste glass, therefore, has no impact on the potential for criticality in DOE SNF waste packages.

Silica is a much less effective moderator than water and its introduction into commercial SNF waste packages from seepage infiltration will displace water and effectively reduce the reactivity of the system, thus reducing the potential for criticality. Additionally, silica can act as a neutron reflector. However, inside the waste package its reflector effects, which increase reactivity, are secondary to its water displacement effects, which decrease reactivity.

In addition, criticality without water infiltration is unlikely for the repository because the waste package is designed such that a criticality event in an intact waste package configuration is not possible. This results from satisfying a preclosure operations requirement that the MGR provide means to ensure criticality control during SNF/HLW handling operations, including waste package loading (Curry 2004 [DIRS 170557], Requirement 1.1.6-4).

Some of the DOE SNF waste forms have potential to support unmoderated (fast) criticality if (1) the fissile material is concentrated beyond its design concentration in the waste form, and (2) the neutron absorber materials are removed. Concentration of the fissile material beyond its design concentration could result from either the degradation of the waste form resulting from water infiltration or a disruptive event. However, removal of the neutron absorber materials from a DOE SNF waste package would require a breach of the waste package and a removal mechanism. The most likely neutron absorber material removal mechanism is through water infiltration resulting in degradation of the waste package internal components, dissolving of the neutron absorber material in the water, and flushing of the material from the waste package. Since water infiltration does not occur for base case criticality FEPs conditions, the concentration of sufficient fissile material from DOE SNF waste forms to support unmoderated criticality is improbable and unmoderated criticality can be excluded based on low probability.

The methodology for determining the probability of criticality accounts for factors such as early failures, manufacturing defects, fuel assembly misloads, neutron absorber material misloads, etc. However, it may not be necessary to directly account for these factors if the total probability of criticality is calculated to be sufficiently below the regulatory probability criterion without utilizing them. For example, if the calculated waste package flooding probability were below the regulatory probability criterion, incorporation of the probability of a waste package misload would only result in a lower probability of criticality than has already been calculated.

Fuel assembly misloads (enrichment and/or burnup) could result in more (or less) fissile material being loaded into the waste package than permitted by the design loading curves. Additional fissile material in the waste package results in a higher criticality potential of the in-package degraded configurations. However, because no water (i.e., neutron moderator) enters the waste package for base case criticality FEP conditions, the additional fissile material that could result from a fuel assembly misload cannot result in the formation of a critical configuration (CRWMS M&O 1999 [DIRS 125206], CRWMS M&O 2000 [DIRS 147650], CRWMS M&O 2000 [DIRS 147651], BSC 2004 [DIRS 171414], CRWMS M&O 2000 [DIRS 151742], CRWMS M&O 2000 [DIRS 151743], CRWMS M&O 2001 [DIRS 154194], BSC 2001 [DIRS 157733], BSC 2001 [DIRS 157734], BSC 2004 [DIRS 169963], BSC 2004 [DIRS 168935]). This is especially true for low enriched uranium systems such as the commercial SNF waste packages (BSC 2004 [DIRS 171414] and BSC 2004 [DIRS 169963]).

Ten percent of the waste packages in the base case scenario are assumed to fail as a result of early waste package failure mechanisms (BSC 2004 [DIRS 170024]) and localized corrosion (Assumption 5.1.1). However, the probability function for drip shield damage area is zero for the base case (i.e., no drip shield failures) and there is no advective flow path into the waste package. Without an advective flow path through the drip shield, the only other potential source of water infiltration into a failed waste package would be condensation on the underside of the drip shield. However, condensation infiltration into a failed waste package has been determined to be improbable (BSC 2004 [DIRS 164327], Section 6.3.7.2.3). Therefore, without water infiltration into a failed waste package, the probability of criticality for this base case FEP is zero. Based on assumptions requiring confirmation, this result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.3 Near-Field Criticality (FEP 2.1.14.17.0A)

FEP Description: Near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). Near-field criticality resulting from disruptive events is addressed in separate FEPs.

Screening Decision: Excluded – Low Probability.

Screening Argument: Near-field criticality cannot occur unless the waste package and waste form are degraded (as discussed previously in Section 6.8.2). It then follows that the probability of near-field criticality must be less than the probability of water entering the waste package. This is because, in addition to the events evaluated to calculate the probability of water infiltrating a failed waste package, the probability of the following events must also be considered for near-field external criticality:

- Waste form degrading during the regulatory period
- Removing the fissile materials from the waste package
- Accumulating sufficient fissile material into a potentially critical configuration in the near-field environment
- Having sufficient neutron moderator available.

Ten percent of the waste packages in the base case scenario are assumed to fail as a result of early waste package failure mechanisms (BSC 2004 [DIRS 170024]) and localized corrosion (Assumption 5.1.1). However, the probability function for drip shield damage area is zero for the base case (i.e., no drip shield failures) and there is no advective flow path into the waste package. Without an advective flow path through the drip shield, the only other potential source of water infiltration into a failed waste package would be condensation on the underside of the drip shield. However, condensation infiltration into a failed waste package has been determined to be improbable (BSC 2004 [DIRS 164327], Section 6.3.7.2.3). Therefore, without water infiltration into a failed waste package, the probability of criticality for this base case FEP is zero. Based on assumptions requiring confirmation, this result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.4 Far-Field Criticality (FEP 2.2.14.09.0A)

FEP Description: Far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]). Far-field criticality resulting from disruptive events is addressed in separate FEPs.

Screening Decision: Excluded – Low Probability.

Screening Argument: Like near-field criticality, far-field criticality cannot occur unless the waste package and waste form are degraded (as discussed previously in Section 6.8.2). Given an advective flow path into the waste package, fissile material can be transported into the near-field environment and, to a certain extent, continue into the far-field environment. However, it is unlikely that fissile material can accumulate in the far-field environment in any appreciable quantities due to a lack of accumulation mechanisms (Assumptions 5.5.1 through 5.5.5).

Ten percent of the waste packages in the base case scenario are assumed to fail as a result of early waste package failure mechanisms (BSC 2004 [DIRS 170024]) and localized corrosion (Assumption 5.1.1). However, the probability function for drip shield damage area is zero for the base case (i.e., no drip shield failures) and there is no advective flow path into the waste package. Without an advective flow path through the drip shield, the only other potential source of water infiltration into a failed waste package would be condensation on the underside of the drip shield. However, condensation infiltration into a failed waste package has been determined to be improbable (BSC 2004 [DIRS 164327], Section 6.3.7.2.3). Therefore, without water infiltration into a failed waste package, the probability of criticality for this base case FEP is zero. Based on assumptions requiring confirmation, this result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.5 In-Package Criticality Resulting from a Seismic Event (Intact Configuration) (FEP 2.1.14.18.0A)

FEP Description: The waste package internal structures and the waste form remain intact either during or after a seismic disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.

Screening Decision: Excluded – Low Probability.

Screening Argument: As discussed previously in Section 6.8.1, waste form criticality analyses demonstrate that an intact, fully flooded with water (a neutron moderator), waste package configurations will not achieve criticality. Additionally, intact, fully loaded, fully flooded waste packages are precluded from achieving criticality by design to satisfy a preclosure operations requirement that the MGR provide means to ensure criticality control during SNF/HLW handling operations, including waste package loading (Curry 2004 [DIRS 170557], Requirement 1.1.6-4).

Therefore, the probability of criticality for an intact waste package configuration for the seismic disruptive event is zero. This result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.6 In-Package Criticality Resulting from a Seismic Event (Degraded Configuration) (FEP 2.1.14.19.0A)

FEP Description: Either during, or as a result of, a seismic disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: As previously discussed in Section 6.8.2, without water infiltration into a failed waste package, the probability of criticality for all degraded waste package / waste form types is zero. Seismic events may alter the conditions described in the base case.

Vibratory ground motion and rock fall induced by a seismic event have been conjectured as initiating events that could cause drip shield failure through separation and/or corrosion leading to subsequent waste package failure. Such failures may allow the influx of seepage (either advective or diffusive) into the waste package, which, in turn, has the potential to cause a criticality. These failure mechanisms have been determined not to affect the criticality potential of the repository since there is no mechanism for them to occur and thus no contribution to the criticality potential for the repository since neither drip shield separation due to seismic events (BSC 2004 [DIRS 169183], Section 6.5.4) nor corrosion related mechanisms for drip shield failure resulting in advective flow paths (Section 6.3.4) are expected to occur.

A seismic event can, however, induce fault displacement that can potentially lead to drip shield and waste package failure for those structures intersecting the fault, which can then potentially allow advective or diffusive flow into the waste package and lead to conditions conducive to criticality. Additionally, new fractures that intersect the drift segments and the collapsing of the drift due to a seismic event will have an affect on the seepage as to both location and rate. However, these changes in seepage have no impact on the repository's potential for criticality without drip shield failure resulting from fault displacement. Thus, fault displacement (Section 6.4.4.1) is the only seismic disruptive event affecting the criticality potential of the repository.

However, the probability of criticality for these configurations is determined to be below the regulatory threshold and this seismic disruptive event criticality FEP can be excluded based on low probability. Based on assumptions requiring confirmation, this result is applicable to all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.7 Near-Field Criticality Resulting from a Seismic Event (FEP 2.1.14.20.0A)

FEP Description: Either during, or as a result of, a seismic disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: Near-field criticality cannot occur unless the waste package and waste form are degraded (as discussed previously in Sections 6.8.3 and 6.8.6). Based on *Seismic Consequence Abstraction* (BSC 2004 [DIRS 169183], Section 6.5.7.3), the cladding of all commercial SNF is damaged during seismic events with annual exceedance frequencies less than 5×10^{-5} per year. Exposure of the fuel will increase its availability for transport to locations external to the waste package. However, it is calculated that less than 11 kg of uranium will accumulate in the near-field under a waste package, less than the uranium mass required for a criticality in those configurations (BSC 2004 [DIRS 170060]).

Given the considerations listed above, criticality in the near-field environment is improbable. Therefore, the seismic disruptive event FEP can be excluded based on low probability. Based on assumptions requiring confirmation, this result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.8 Far-Field Criticality Resulting from a Seismic Event (FEP 2.2.14.10.0A)

FEP Description: Either during, or as a result of, a seismic disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: Like near-field criticality, far-field criticality cannot occur unless the waste package and waste form are degraded (as discussed previously in Sections 6.8.4 and 6.8.6). As a result of seismic events that create advective flow paths into the waste package, fissile material is transported into the near-field environment and, to a certain extent, continued on into the far-field environment. However, it is unlikely that fissile material can accumulate in the far-field environment in any appreciable quantities due to a lack of accumulation mechanisms (Assumptions 5.5.1 through 5.5.5). Therefore, for the seismic disruptive event, this far-field criticality FEP can be excluded based on low probability. Based on assumptions requiring confirmation, this result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.9 In-Package Criticality Resulting from Rock Fall (Intact Configuration) (FEP 2.1.14.21.0A)

FEP Description: The waste package internal structures and the waste form remain intact either during or after a rock fall event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.

Screening Decision: Excluded – Low Probability.

Screening Argument: As discussed previously in Section 6.8.1, waste form criticality analyses demonstrate that an intact, fully flooded with water (a neutron moderator), waste package configuration cannot achieve criticality. Additionally, intact, fully loaded, fully flooded waste packages are precluded from achieving criticality by design to satisfy a preclosure operations requirement that the MGR provide means to ensure criticality control during SNF/HLW handling operations, including waste package loading (Curry 2004 [DIRS 170557], Requirement 1.1.6-4). Waste package failure due to rockfall is not credible since drip shield failures are not expected to occur, thus, waste package flooding can not occur (Section 6.3.3.1.5).

Therefore, the probability of criticality for a nominal waste package configuration during a rock fall disruptive event is zero. This result is applicable for all waste form/waste package types

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.10 In-Package Criticality Resulting from Rock Fall (Degraded Configuration) (FEP 2.1.14.22.0A)

FEP Description: Either during, or as a result of, a rock fall event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: The degraded waste package and waste form base case in-package criticality is previously discussed in Section 6.8.2. Rock fall disruptive events do not create advective flow paths, which allow water to penetrate through the drip shield and into the waste package since there is no mechanism for drip shield failure due to this event. Without an advective flow path through the drip shield, the only other potential source of waste infiltration into a failed waste package would be condensation on the underside of the drip shield. However, condensation infiltration into a failed waste package has been determined to be improbable (BSC 2004 [DIRS 164327], Section 6.3.7.2.3). Ten percent of the waste packages in the base case scenario are assumed to fail as a result of early waste package failure mechanisms (BSC 2004 [DIRS 170024]) and localized corrosion (Assumption 5.1.1). However, without water infiltration, the probability of criticality for this rock fall disruptive event FEP is zero. The screening argument for the rock fall disruptive event is the same as for the base case criticality FEP 2.1.14.16.0A. Based on assumptions requiring confirmation, this result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.11 Near-Field Criticality Resulting from Rock Fall (FEP 2.1.14.23.0A)

FEP Description: Either during, or as a result of, a rock fall event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: The degraded waste package and waste form base case near-field criticality is previously discussed in Section 6.8.3. Rock fall disruptive events do not create advective flow paths from the drift through the drip shield (i.e., no drip shield failures) and into the failed waste package. Moreover, condensation infiltration into a failed waste package has been determined to be improbable (BSC 2004 [DIRS 164327], Section 6.3.7.2.3). The probability of water infiltrating and flooding a failed waste package is zero for this rock fall disruptive event, near-field criticality FEP. Without water to enter the failed waste packages, there is no mechanism to degrade the waste package internals and waste form, and transport fissile material into the near-field environment for accumulation and the formation of a potentially critical configuration. Therefore, the probability of criticality for this rock fall disruptive event, near-field criticality FEP is zero. Based on assumptions requiring confirmation, this result is applicable for all waste form / waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.12 Far-Field Criticality Resulting from Rock Fall (FEP 2.2.14.11.0A)

FEP Description: Either during, or as a result of, a rock fall event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: The degraded waste package and waste form base case far-field criticality is previously discussed in Section 6.8.4. Rock fall disruptive events do not create advective flow paths from the drift through the drip shield (i.e., no drip shield failures) and into the failed waste package. Moreover, condensation infiltration into a failed waste package has been determined to be improbable (BSC 2004 [DIRS 164327], Section 6.3.7.2.3). The probability of water infiltrating and flooding a failed waste package is zero for this rock fall disruptive event, far-field criticality FEP. Without water to enter the failed waste packages, there is no mechanism to degrade the waste package internals and waste form, and transport fissile material into the near-field and far-field environments. In addition, it is unlikely that fissile material can accumulate in the far-field environment in any appreciable quantities due to a lack of accumulation mechanisms (Assumptions 5.5.1 through 5.5.5). Therefore, the probability of criticality for this rock fall disruptive event, far-field criticality FEP is zero. Based on assumptions requiring confirmation, this result is applicable for all waste form / waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.13 In-Package Criticality Resulting from an Igneous Event (Intact Configuration) (FEP 2.1.14.24.0A)

FEP Description: The waste package internal structures and the waste form remain intact either during or after an igneous disruptive event. If there is a breach (or are breaches) in the waste package which allows water to either accumulate or flow-through the waste package then criticality could occur in situ.

Screening Decision: Excluded – Low Probability.

Screening Argument: As discussed previously in Section 6.8.1, waste form criticality analyses demonstrate that an intact, fully flooded with water (a neutron moderator), waste package configuration cannot achieve criticality. Additionally, intact, fully loaded, fully flooded waste packages are precluded from achieving criticality by design to satisfy a preclosure operations requirement that the MGR provide means to ensure criticality control during SNF/HLW handling operations, including waste package loading (Curry 2004 [DIRS 170557], Requirement 1.1.6-4).

For the igneous disruptive event, waste packages have been segregated into two zones defined by the impact of the igneous event (refer to Section 6.6.1 of this report). In Zone 1, consisting of the drift(s) intersected by the volcanic dike, the waste packages within the conduit are assumed to be completely disassembled (Section 6.6). The remaining waste packages in zone 1 are expected to deform rather than disintegrate, allowing the waste packages to slump and flatten onto the invert. All waste packages in zone 1 outside the conduit area are presumed to have failed allowing seepage water access to the waste packages when the drifts have cooled sufficiently (Section 6.8.14). However, for intact configurations, the absorber material remains in place and, thus, the probability of criticality is zero.

In Zone 2, the igneous event does not impact the waste packages which remain intact (nominal waste package configuration) (BSC 2004 [DIRS 170028], Section 8.2.3). Therefore, for Zone 2 waste packages, the probability of criticality is zero.

The igneous disruptive event criticality FEP can be excluded based on low probability. This result is applicable for all waste form / waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.14 In-Package Criticality Resulting from an Igneous Event (Degraded Configuration) (FEP 2.1.14.25.0A)

FEP Description: Either during, or as a result of, an igneous disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in situ critical configurations are defined in Figures 3.2a and 3.2b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: The degraded waste package and waste form base case in-package criticality is previously discussed in Section 6.8.2. Expanding the base case for the igneous disruptive event, waste packages are segregated into two zones defined by the impact of the igneous event. In Zone 1, the waste packages are in drifts that are directly involved in the igneous event. In Zone 2, the waste packages are in drifts that are not directly involved in the igneous event. The performance of Zone 2 waste packages has been determined to remain intact with no adverse short-term or long-term impacts resulting from the igneous (BSC 2004 [DIRS 170028], Section 8.2.3).

Zone 1 waste packages can be impacted by one of two igneous scenarios. The first scenario is a violent Strombolian basaltic volcanic eruption through the repository. The waste packages that are intersected by the eruptive conduit are completely pulverized and the radioactive waste form carried to the surface, ejected into the atmosphere, and dispersed by the prevailing winds (BSC 2004 [DIRS 170026], Section 5.2.4 and Assumption 5.4.10). Once dispersed, it is highly unlikely that sufficient fissile material can be accumulated into a critical configuration.

The second igneous scenario is an igneous basaltic dike intersecting one or more emplacement drifts followed by the intrusion of effusive (liquid) magma flow or pyroclastic flow (clots of melt in a stream of gas) into the drifts. The intrusive material is expected to enter and fill the drifts at temperatures of about 1100°C. Although the intrusive temperature is below the melting points of the waste package barrier materials, these materials are severely damaged at the intrusion temperature through softening and creep deformation. The drifts are expected to remain at this elevated temperature for several months, allowing adequate time for the complete slumping of the waste package barriers and internals. The waste package outer barrier is expected to be sufficiently fractured along its entire surface that, once the intrusive material cools and seepage returns, the slumped configuration is incapable of capturing and retaining appreciable quantities of water.

Criticality is not possible for Zone 1 waste packages in an eruptive conduit. The waste packages in the eruptive conduit are completely disassembled and the waste form ejected from the conduit and dispersed by the prevailing winds. Criticality for this igneous scenario is not possible because of the low probability to reaccumulate sufficient fissile material into a critical configuration once it has been dispersed.

For Zone 1 waste packages during an intrusive event, the waste packages are completely slumped into a configuration that cannot retain water while the neutron absorber materials are retained among the waste form. Liquid eutectics can be formed from Zr-Fe and, possibly, Zr-Ni but are not expected to provide any mechanisms causing appreciable removal of the neutron absorber materials from the waste form. Criticality, slow or fast, is determined to be unlikely for this igneous scenario. This determination is based on insufficient water being retained within the waste package for moderation and the retention of sufficient neutron absorber materials.

In Zone 2, the waste packages remain intact and the screening argument of FEP 2.1.14.24.0A applies. The igneous disruptive event criticality FEP can be excluded based on low probability. This result is applicable for all waste form / waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.15 Near-Field Criticality Resulting from an Igneous Event (FEP 2.1.14.26.0A)

FEP Description: Either during, or as a result of, an igneous disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: Near-field criticality cannot occur unless the waste package and waste form are degraded (as discussed previously in Sections 6.8.3 and 6.8.14). Once the drifts cool, and seepage returns, the in-package and near-field water chemistries are dominated by the igneous material such that it is unlikely that any fissile material that is transported from the waste package slumped mass can be accumulated in the invert. Given the lack of accumulation mechanisms (Assumption 5.4.12), it is improbable that a critical configuration could form in the near-field environment. Therefore, this igneous disruptive event, near-field criticality FEP can be excluded based on low probability. Based on assumptions requiring confirmation, this result is applicable for all waste form/waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

6.8.16 Far-Field Criticality Resulting from an Igneous Event (FEP 2.2.14.12.0A)

FEP Description: Either during, or as a result of, an igneous disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003 [DIRS 165505]).

Screening Decision: Excluded – Low Probability.

Screening Argument: Like near-field criticality, far-field criticality cannot occur unless the waste package and waste form are degraded (as discussed previously in Sections 6.8.4 and 6.8.14). The flow-through condition of a waste package following an intrusive event will allow fissile material to be transported into the near-field environment. Given the lack of invert accumulation mechanisms, the fissile material will continue into the far-field environment. However, it is unlikely that fissile material can accumulate in the far-field environment in any appreciable quantities due to a lack of accumulation mechanisms (Assumptions 5.5.1 through 5.5.5) in the far-field environment. Therefore, this igneous disruptive event, far-field criticality FEP can be excluded based on low probability. Based on assumptions requiring confirmation, this result is applicable for all waste form / waste package types.

TSPA-LA Disposition: Not Applicable

Supporting Reports: Not Applicable

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7. CONCLUSIONS

Using the available geologic repository and engineered barrier systems information and several assumptions requiring confirmation, criticality can be screened from further consideration in TSPA-LA on the sole basis of the low probability. The results of this analysis indicate that, for all waste package types, the calculated total probability of criticality is below the regulatory probability criterion for inclusion of events of at least one chance in 10,000 of occurring over 10,000 years (10 CFR 63.114(d) [DIRS 156605]).

Information currently being updated that could influence the results of this analysis include the failure potential of the drip shield and waste package due to the various corrosion mechanisms (i.e., general, localized, and stress corrosion cracking). Although the models for these failure mechanisms have been developed, evaluation of these models is dependent on the drift environment to be modeled in the TSPA-LA analyses. Future results in these areas have the potential to impact the analysis results. Also having the potential to impact the analysis results are updates to the qualified data, product outputs and technical information used in this analysis and the results from the activities required for the confirmation of assumptions in Section 5, e.g., testing, design, and analysis.

7.1 SUMMARY

The safety strategy for the geological repository relies on a multiple barrier system for the long-term isolation of the emplaced waste packages from the general environment. Over time, waste packages emplaced in the geological repository as part of the engineered barrier systems can undergo various degradation processes that modify the waste package structural and mineral content and, thus, affect the potential for a criticality event. These degradation processes have major effects on the waste package's radionuclide content (through flushing) and spatial distribution of the waste form within the affected waste package (through component degradation). Separation of neutron absorbers from fissile material, volume changes, shape changes, loss of fissile and/or absorber material from the waste package, and rearrangement of degraded components are potential effects of the degradation processes.

This screening analysis report:

1. Contributes to the Yucca Mountain scenario development methodology by screening the FEPs related to criticality.
2. Develops screening arguments for these FEPs.
3. Provides information for the YMP FEP database and guidance to TSPA-LA analyses applicable to the license application document.

Screening decisions reached in this report are summarized in Table 7.2-1.

7.2 CRITICALITY FEPS SCREENING RECOMMENDATIONS FOR THE LICENSE APPLICATION

Screening decisions recommended for the criticality FEPs and their reference sections are provided in Table 7.2-1. These recommendations for the base case in situ and external criticality FEPs evaluations are applicable to all waste package/waste form combinations. This is because the probability of water entering any waste package during the regulatory period is negligible for all base case criticality FEPs because there are no drip shield failures predicted during the regulatory period.

The evaluation of the rock fall and igneous disruptive event criticality FEPs are applicable to all waste package/waste form combinations. This is because the probability of water entering any waste package during the regulatory period is negligible for the rock fall disruptive event (no drip shield failures) and because it is improbable that a critical configuration could be formed during an igneous disruptive event.

For the evaluation of the seismic disruptive event criticality FEPs, it is necessary to calculate the results for the individual commercial and DOE SNF waste package types. This is because of the differences in the internal configurations and compositions of the waste package design variants that degrade at different rates. The result of the FEPs evaluation is the calculation of a total probability of waste package flooding and of neutron absorber material removal that is below the regulatory probability criterion for inclusion of events [10 CFR 63.114(d)] [DIRS 156605]. Because the total probability of flooding and degrading the waste package internals is below the regulatory probability criterion, the total probability of criticality, which cannot exceed the causative probabilities, is also below the regulatory probability criterion.

The NNPP is responsible for the assessment of criticality potential of the naval SNF Short and naval SNF Long waste package types in their Technical Support Document for the License Application (McKenzie 2004 [DIRS 170742]).

The conclusions from this document (FEP Screening Decision, TSPA Disposition for included FEPs, or Screening Argument for excluded FEPs), is incorporated in the Yucca Mountain TSPA-LA FEP database. The FEP database will contain all Yucca Mountain FEPs considered for TSPA-LA with FEP Number, Name, Description, and relevant FEP AMRs where the documentation of the screening of specific FEPs is summarized. The FEP database will also contain Screening Decisions (Include or Exclude), Screening Arguments, and TSPA Dispositions quoted from this and all other FEP AMRs.

All FEP information, including the 16 criticality FEPs considered in this report, is submitted to Technical Data Management System by the Yucca Mountain FEP database team as a final LA FEP list represented by a Data Tracking Number (DTN). Documentation of the FEP database is given in a separate technical report, *The Development of the Total System Performance Assessment License Application Features, Events, and Processes* (BSC 2004 [DIRS 168706]). These final data are qualified as Technical Product Output from the referenced LP-3.11Q-BSC report. The final LA FEP list DTN will supersede all of the previous DTNs (e.g., DTN: MO0407SEPFEPLA.000 DIRS [170760]).

Table 7.2-1. Summary of Criticality FEPs Screening Decisions

FEP Number	FEP Name	TSPA-LA Screening Decision	Section Screening Addressed
2.1.14.15.0A	In-package criticality (intact configuration)	Excluded – Low Probability	Section 6.8.1
2.1.14.16.0A	In-package criticality (degraded configurations)	Excluded – Low Probability	Section 6.8.2
2.1.14.17.0A	Near-field criticality	Excluded – Low Probability	Section 6.8.3
2.2.14.09.0A	Far-field criticality	Excluded – Low Probability	Section 6.8.4
2.1.14.18.0A	In-package criticality resulting from a seismic event (intact configuration)	Excluded – Low Probability	Section 6.8.5
2.1.14.19.0A	In-package criticality resulting from a seismic event (degraded configurations)	Excluded – Low Probability	Section 6.8.6
2.1.14.20.0A	Near-field criticality resulting from a seismic event	Excluded – Low Probability	Section 6.8.7
2.2.14.10.0A	Far-field criticality resulting from a seismic event	Excluded – Low Probability	Section 6.8.8
2.1.14.21.0A	In-package criticality resulting from rock fall (intact configuration)	Excluded – Low Probability	Section 6.8.9
2.1.14.22.0A	In-package criticality resulting from rock fall (degraded configurations)	Excluded – Low Probability	Section 6.8.10
2.1.14.23.0A	Near-field criticality resulting from rock fall	Excluded – Low Probability	Section 6.8.11
2.2.14.11.0A	Far-field criticality resulting from rock fall	Excluded – Low Probability	Section 6.8.12
2.1.14.24.0A	In-package criticality resulting from an igneous event (intact configuration)	Excluded – Low Probability	Section 6.8.13
2.1.14.25.0A	In-package criticality resulting from an igneous event (degraded configurations)	Excluded – Low Probability	Section 6.8.14
2.1.14.26.0A	Near-field criticality resulting from an igneous event	Excluded – Low Probability	Section 6.8.15
2.2.14.12.0A	Far-field criticality resulting from an igneous event	Excluded – Low Probability	Section 6.8.16

Source: Section 6.8

7.3 UNCERTAINTIES AND RESTRICTIONS

The conclusions of this document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities is reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System (DIRS) database.

7.3.1 Restriction #1: This Screening Analysis is a Draft Demonstration of the Screening Methodology

Waste package specific information has been utilized for the evaluation of 21–PWR Absorber Plate, 12–PWR Absorber Plate, 44–BWR Absorber Plate, 24–BWR Absorber Plate, and 5-DHLW/DOE Short waste package types.

Although assumptions have been made extending other waste package type information inputs to the 5–DHLW/DOE Long and 2–MCO/2–DHLW waste package types (Assumption 5.1.13) and additional assumptions have been made regarding the 21–PWR Control Rod waste package type (Assumptions 5.1.3 and 5.1.6), these assumptions require confirmation through additional analysis.

7.3.2 Restriction #2: Time-Dependent Corrosion will not be Available until the TSPA-LA is Performed

Because of the use of corrosion-resistant materials, it is important to assume for this screening analysis, corrosion damage to the drip shields and the waste packages is caused only by an early failure mechanism (improper heat treatment) and not by the time-dependent corrosion mechanisms typically resulting from water dripping onto the drip shield and the waste package (Assumptions 5.1.1, 5.1.12, and 5.2.7). Additionally, the detailed time-dependent corrosion information for (1) general corrosion, (2) localized corrosion (crevice corrosion and pitting corrosion), and (3) stress corrosion cracking, will not be available until the TSPA-LA is performed.

This assumption requires further verification and confirmation when the TSPA-LA calculations are published.

8. INPUTS AND REFERENCES

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9. APPENDICES

Appendix	Title
A	Glossary
B	SAPHIRE Model Used for Criticality FEPs Screening Analysis
C	Seepage Analysis Spreadsheets (Output from MATHCAD Files)
D	Waste Package Filling Probabilities (Output from MATHCAD File)
E	Description of Event Tree Top Events
F	Listing of Files on CD-ROM
G	Read-Only Compact Disc (CD-ROM)

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APPENDIX A

GLOSSARY

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APPENDIX A - GLOSSARY

Absorption	(1) To take in and make part of an existent whole. (2) To receive without recoil.
Advection	(1) The usually horizontal movement of a mass of fluid (as air or an ocean current). (2) The process in which solutes are transported by groundwater movement.
Aleatory	Having a random character, in the sense that the likelihood of taking place over various intervals of time can be estimated, but it is not possible to determine whether or not, they will actually occur. See *epistemic*.
Burnup[1]	A measure of nuclear reactor fuel consumption expressed either as the percentage of fuel atoms that have undergone fission or as the amount of energy produced per unit weight of fuel.
Chain reaction[1]	A continuing series of nuclear fission events. Neutrons produced by a split nucleus collide with and split other nuclei causing a chain of fission events.
Cladding[1]	The metal outer sheath of a fuel rod generally made of a zirconium alloy, and in the early nuclear power reactors, of stainless steel. Intended to protect the uranium dioxide pellets, which are the nuclear fuel, from dissolution by exposure to high temperature water under operating conditions in a reactor.
Critical condition	A self-sustaining nuclear fission chain reaction: When the number of neutrons resulting from fission in each generation equals the number of neutrons lost by both absorption and leakage in the preceding generation. In this circumstance the effective neutron multiplication factor equals one ($k_{eff}= 1$).
Critical limit	The value of k_{eff} at which a configuration is considered potentially critical, as characterized by statistical tolerance limits.
Criticality[1]	(1) A condition that would require the original waste form, which is part of the waste package, to be exposed to degradation, followed by conditions that would allow concentration of sufficient nuclear fuel, the presence of neutron moderators, the absence of neutron absorbers, and favorable geometry. (2) The condition in which a fissile material sustains a chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle. The state is considered critical when a self-sustaining nuclear chan reaction is ongoing.

Criticality analysis	A mathematical analysis, usually performed with a computer, of the neutron multiplication factor of a system or configuration that contains material capable of undergoing a self-sustaining chain reaction.
Criticality control	The suite of measures taken to control the occurrence of self-sustaining nuclear chain reactions in fissionable materials, including spent nuclear fuel. For postclosure disposal applications, criticality control is ensuring that the probability of a criticality event is so small that the occurrence is unlikely, and the risk that any criticality will violate repository performance objectives is negligible.
Criticality, fast	A critical condition where fast (high-energy) neutrons sustain the fission process.
Criticality, thermal	A critical condition where thermal (low-energy) neutrons sustain the fission process.
Disposal[2]	The emplacement of radioactive waste in a geological repository with the intent of leaving it in there permanently.
Disruptive event[1]	An off-normal event that, in the case of the repository, includes volcanic activity, seismic activity, and nuclear criticality. Disruptive events have two possible effects: (1) direct release of radioactivity to the surface, or (2) alteration of the nominal behavior of the system. For the purposes of screening features, events, and processes for total system performance assessment, a disruptive event is defined as an event that has a significant effect on the expected annual dose and that has a probability of occurrence during the 10,000 year period of performance less than 1.0, but greater than a cutoff of 0.0001.
Drift[1]	From mining terminology, a horizontal, underground, passage. The nearly horizontal underground passageways from the shaft(s) to the alcoves and rooms. Drifts includes excavations for emplacement (emplacement drifts) and access (access mains).
Effective neutron multiplication factor	See *critical condition*.
Engineered barrier system[2]	The waste packages, including engineered components and systems other than the waste package (e.g., drip shields), and the underground facility.
Epistemic	Refers to the state of knowledge about a parameter because the data may be limited or because there may be alternative interpretations of the available data. The state of knowledge about the exact value of the parameter can increase through testing and data collection such that the uncertainty is "reducible." See *aleatory*.

Events[1]	(1) Occurrences that have a specific starting time and, usually, a duration shorter than the time being simulated in a model. (2) Uncertain occurrences that take place within a short time relative to the time frame of the model. For the purposes of screening features, events, and processes for total system performance assessment, an event is defined to be a natural or human-caused phenomenon that has a potential to affect disposal system performance and that occurs during an interval that is short compared with the period of performance.
Far-field	With reference to processes, those occurring at the scale of the mountain. The area of the geosphere and biosphere far enough away from the geological repository that, when numerically modeled, represents releases from the geological repository as a homogeneous, single-source effect.
Far-field for criticality	Far-field for criticality is defined as the space beyond the drift wall (i.e., in the host rock of the geological repository).
Features[1]	Physical, chemical, thermal or temporal characteristics of the site or repository system. For the purpose of screening features, events, and processes for total system performance assessment, a feature is defined to be an object, structure or condition that has a potential to affect disposal system performance.
Fissile materials	Fissile materials are those materials that will undergo fission with thermal (slow) neutrons. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239.
Fissionable materials	Fissionable materials are those materials that will undergo fission by neutrons with sufficient energy. Note that while all fissile materials are fissionable, the reverse is not true. Although "fissile," rather than "fissionable," is used in most places in this report, "fissionable" may be applicable in some configurations.
High-level waste	See *high-level radioactive waste*.
High-level radioactive waste	(1) The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing, and any solid material derived from such liquid waste that contains fission products in sufficient concentration. (2) Other highly radioactive materials that the U.S. Nuclear Regulatory Commission, consistent with existing law, determines by rule require permanent isolation.
Initiating event[2]	A natural or human induced event that causes an event sequence.
k_{eff}	Effective neutron multiplication factor.
License application[1]	An application to the U.S. Nuclear Regulatory Commission for a license to construct and operate a repository.

Lithophysae	Voids having concentric shells of finely crystalline alkali feldspar, quartz, and other materials that were formed by entrapped gas that later escaped.
Lithophysal	Pertaining to tuff units with *lithophysae*.
Near-field[1]	The area and conditions within the geological repository including the drifts and waste packages and the rock immediately surrounding the drifts. The region around the repository where the natural hydrogeologic system has been significantly impacted by the excavation of the repository and the emplacement of waste.
Near-field for criticality	The area outside the waste package and inside the drift wall (including the drift liner and invert).
Neutron, fast	A neutron with kinetic energy greater than its surroundings when released during fission.
Neutron, thermal	A neutron that has (by collision with other particles) been slowed to an energy state equal to that of its surroundings, typically on the order of 0.025 eV (electron volts) and having a velocity of approximately 2,200 m/s.
Neutron leakage	The fraction of neutrons lost as result of escape from a fissile system.
Neutron moderator	A material such as ordinary water, heavy water, or graphite that is used to slow down fast (high-energy) neutrons to thermal (low-energy) neutrons, thus increasing the likelihood of fission.
Nuclear fission	The act of splitting a nucleus into two or more nuclei, resulting in the release of two or more neutrons and a relatively large amount of energy.
Performance assessment[2]	A probabilistic analysis that: (1) Identifies the features, events, and processes that might affect the performance of the geological repository; (2) Examines the effects of those features, events, and processes on the performance of the geological repository; and (3) Estimates the consequences (e.g., radiological exposures to the reasonably maximally exposed individual, radionuclide releases to the accessible environment) of releases from the geologic repository.
Period of performance	10,000 years after permanent closure of the geologic repository.
Permanent closure[2]	Final back-filling of the main access drifts of the underground facility, if appropriate, and the sealing of shafts, ramps, and boreholes.

Probabilistic[1]	(1) Based on or subject to probability. (2) Involving a variate, such as temperature or porosity. At each instance of time, the variate may take on any of the values of a specified set with a certain probability. Data from a probabilistic process are an ordered set of observations, each of which is one item from a probability distribution.
Probability[1]	The chance that an outcome will occur from the set of possible outcomes. Statistical probability examines actual events and can be verified by observation or sampling. Knowledge of the exact probability of an event is usually limited by the inability to know, or compile, the complete set of possible outcomes over time or space, a degree of belief.
Probability distribution[1]	The set of outcomes (values) and their corresponding probabilities for a random variable.
Processes[1]	Phenomena and activities that have gradual, continuous interactions with the system being modeled. For purposes of screening features, events, and processes for total system performance assessment, a process is defined as a natural or human-caused phenomenon that has a potential to affect disposal system performance and that operates during all or a significant part of the period of performance.
Pyroclastic	Of or relating to individual particles or fragments of clastic rock material of any size formed by volcanic explosion or ejected from a volcanic vent.
Safety analysis, preclosure[2]	A systematic examination of the site; the design; and the potential hazards, initiating events, and event sequences and their consequences (e.g., radiological exposures to workers and the public). The analysis identifies structures, systems, and components important to safety.
Saturated zone[2]	That part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric. See also *unsaturated zone*.
Scenario[1]	A well-defined, connected sequence of features, events, and processes that can be thought of as an outline of a future condition of the repository system. Scenarios can be undisturbed, in which case the performance would be expected, or nominal, behavior for the system. Scenarios can also be disturbed, if altered by disruptive events such as human intrusion or natural phenomena such as volcanism or nuclear criticality.
Scenario class[1]	A set of related scenarios that share sufficient similarities that they can usefully be aggregated for the purposes of screening or analysis. The number and breadth of scenario classes depends on the resolution at which scenarios have been defined. Coarsely defined scenarios result in fewer, broad scenario classes, whereas narrowly defined scenarios result in many narrow scenario classes. Scenario classes (and scenarios) should be aggregated at the coarsest level at which a technically sound argument can be made, while still retaining adequate detail for the purposes of analysis.

Seepage[1]	The inflow of groundwater moving in fractures or pore spaces of permeable rock to an open space in the rock such as a drift. Seepage rate is the percolation flux that enters the drift. Seepage is an important factor in waste package degradation and mobilization and migration of radionuclides out of the repository.
Seismic[1]	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
Spent nuclear fuel[1]	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. Spent fuel that has been burned (irradiated) in a reactor to the extent that it no longer makes an efficient contribution to a nuclear chain reaction. This fuel is more radioactive than it was before irradiation, and releases significant amounts of heat from the decay of its fission product radionuclides. See *burnup*.
Uncertainty[1]	A measure of how much a calculated or estimated value varies from the unknown true value.
Unsaturated zone[2]	The zone between the land surface and the regional water table. Generally, fluid pressure in this zone is less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the fluid pressure locally may be greater than atmospheric.
Variability (statistical)[1]	A measure of how a quantity varies over time or space.
Waste form[2]	The radioactive waste materials and any encapsulating or stabilizing matrix.
Water table[2]	That surface in a groundwater body, separating the unsaturated zone from the saturated zone, at which the water pressure is atmospheric.

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[1] Definition cited from glossary of *Yucca Mountain Review Plan* (NRC 2003 [DIRS 163274]).
[2] Definition cited from 10 CFR 63.2 (10 CFR 63 [DIRS 156605]).

APPENDIX B

SAPHIRE ANALYSIS USED FOR CRITICALITY FEPS SCREENING ANALYSIS

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APPENDIX B - SAPHIRE ANALYSIS USED FOR CRITICALTY FEPS SCREENING ANALYSIS

The SAPHIRE analysis used for the evaluation of the criticality FEPs screening analysis is based on the configuration generator (BSC 2004 [DIRS 168552]). The event trees used in the SAPHIRE criticality FEPs analysis are presented and discussed in Section B.1. The logic rules used to assign the basic event probabilities and direct the evaluation of the event trees are presented in Sections B.2 through B.22 The basic event values used in this analysis are presented in Section B.23 and the SAPHIRE-calculated end-state results are presented in Section B.24.

B.1 SAPHIRE EVENT TREES

Figures B-1 through B-27, taken from Attachment I of *Configuration Generator Model* (BSC 2004 [DIRS 168552]), present the event trees used in the criticality FEPs screening analysis. Figure B-1 presents the “WP–WF” event tree used for determining the waste form and waste package type inventory fraction. Figure B-2 presents the “WP01-21-PWR-AP” event tree used to initiate the criticality FEPs screening analysis of the 21-PWR Absorber Plate waste package type. This event tree is an example of the 22 waste package type event trees defined in Table 6.2-2. Figure B-3 presents the “YMP–INIT–EVENTS” event tree for directing the SAPHIRE evaluation of the criticality FEPs cases – base case, seismic disruptive event, rock fall disruptive event, and the igneous disruptive event. Figures B-4 and B-5 presents the “MSL–ET” and “MSL–ET2” event trees for initiating the evaluation of the configuration classes of the master scenario list (YMP 2003 [DIRS 165505], Section 3.3). The event trees of Figures B-6 through B-13 detail the events and processes necessary for the formation and evaluation of in-package configuration classes. The event trees of Figures B-14 through B-20 detail the events and processes necessary for the formation and evaluation of near-field configuration classes. The event trees of Figures B-21 through B-23 detail the events and processes necessary for the formation and evaluation of far-field configuration classes. Finally, Figures B-24 through B-27 present the event trees required for the formation and evaluation of configuration classes resulting from an igneous disruptive event.

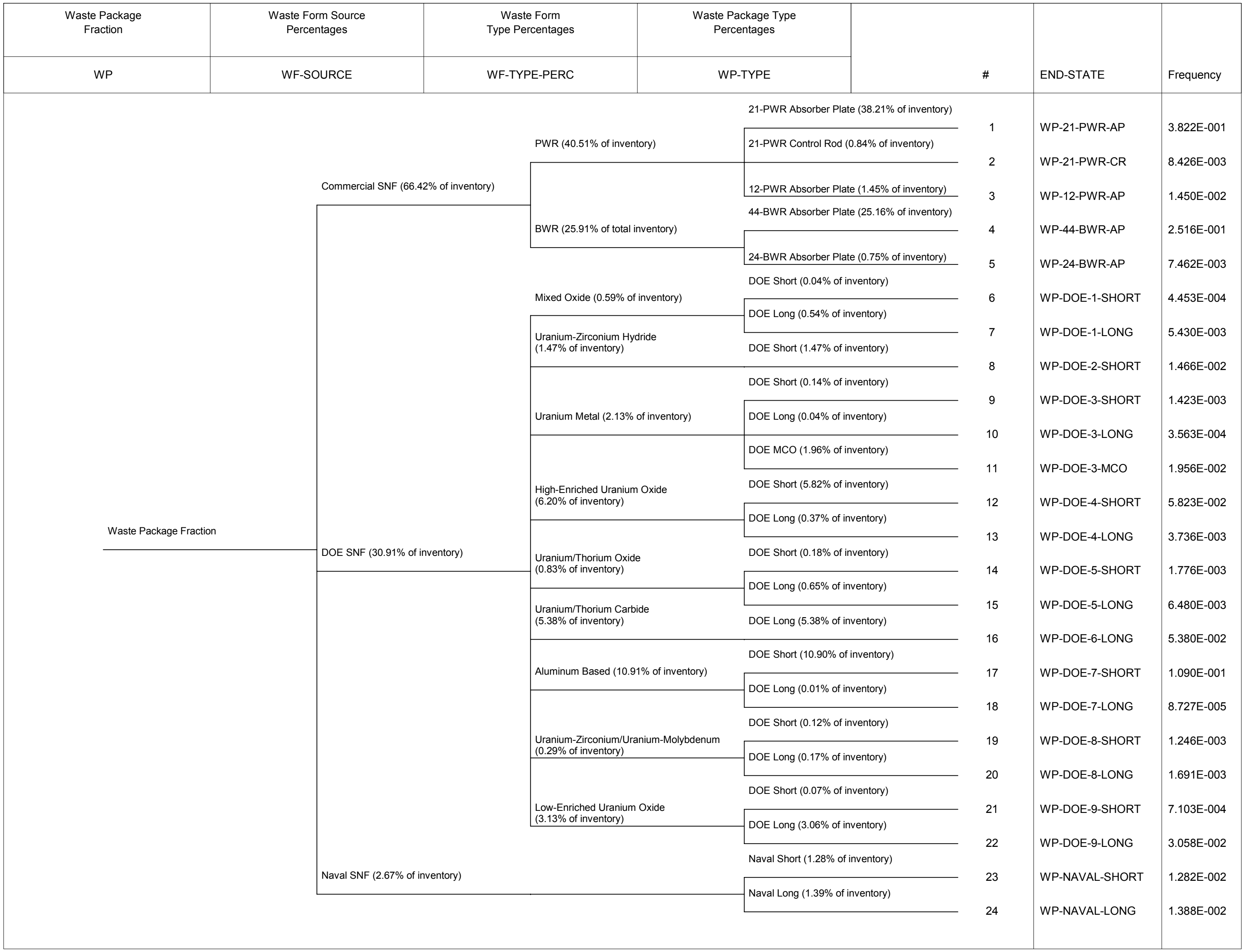

Figure B-1. Waste Form and Waste Package Type Inventory Fraction Event Tree — “WP-WF”

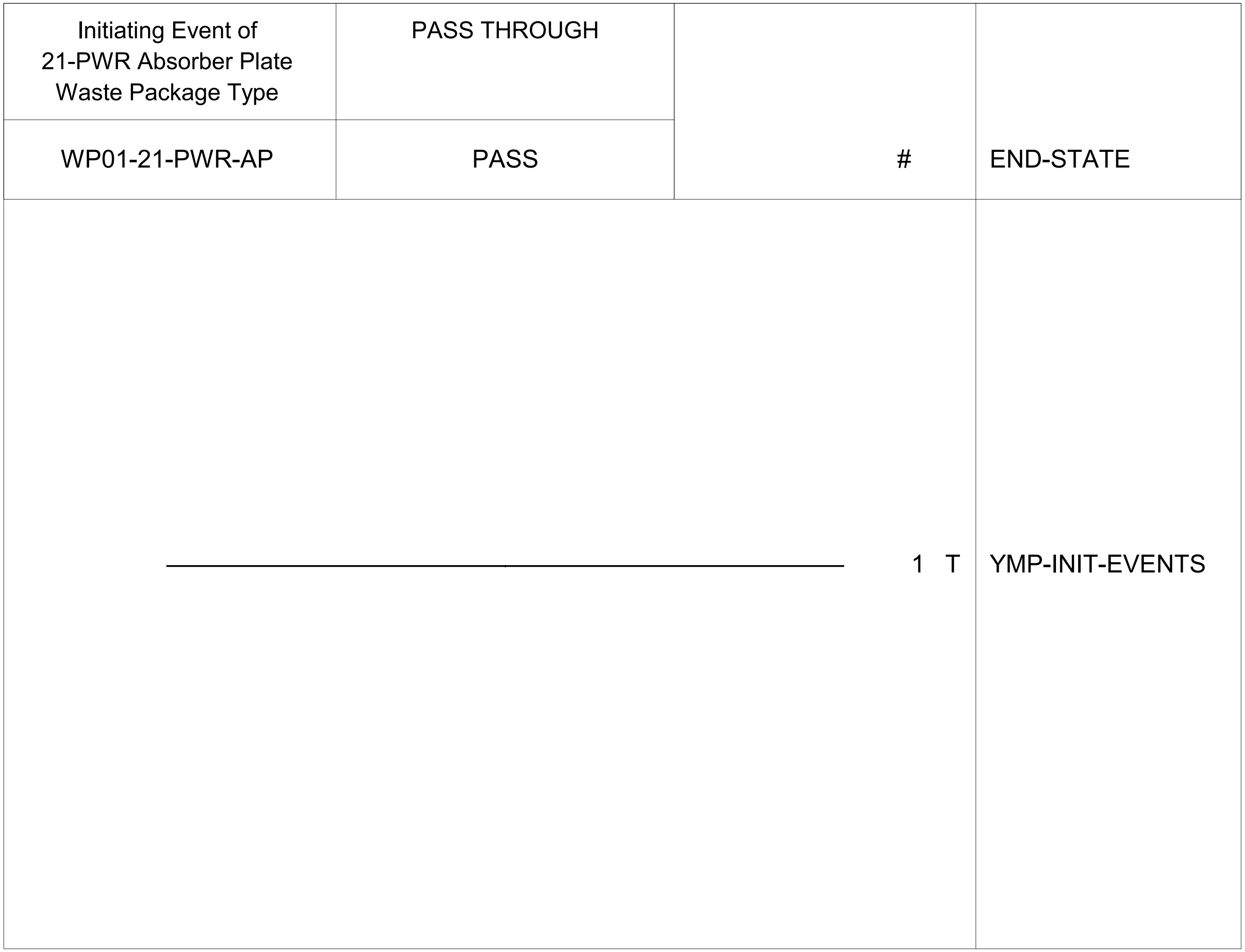

Figure B-2. Example of Waste Package Type Event Tree — “WP01-21-PWR-AP”

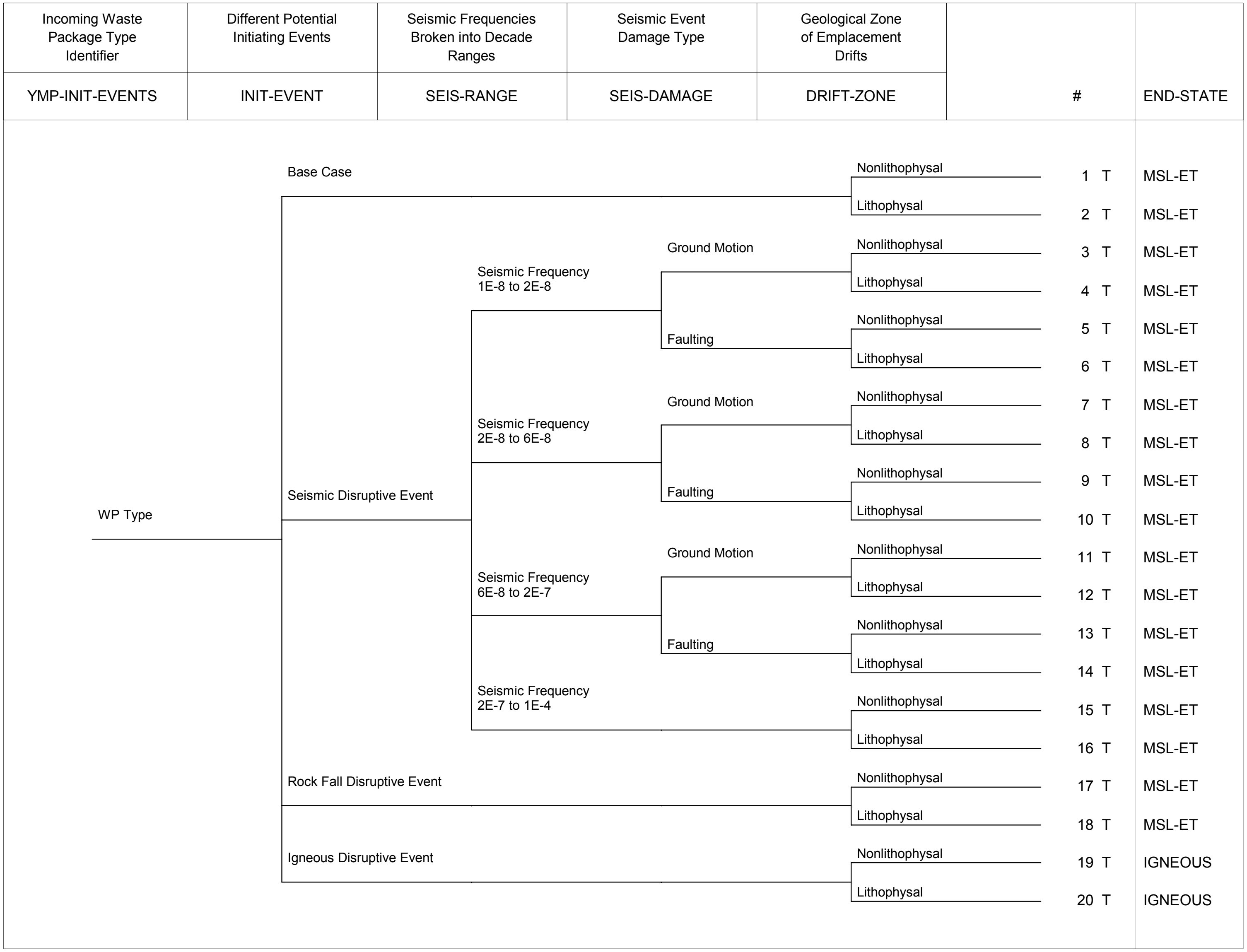

Figure B-3. Criticality FEPs Case Assignment Event Tree — ”YMP-INIT-EVENTS”

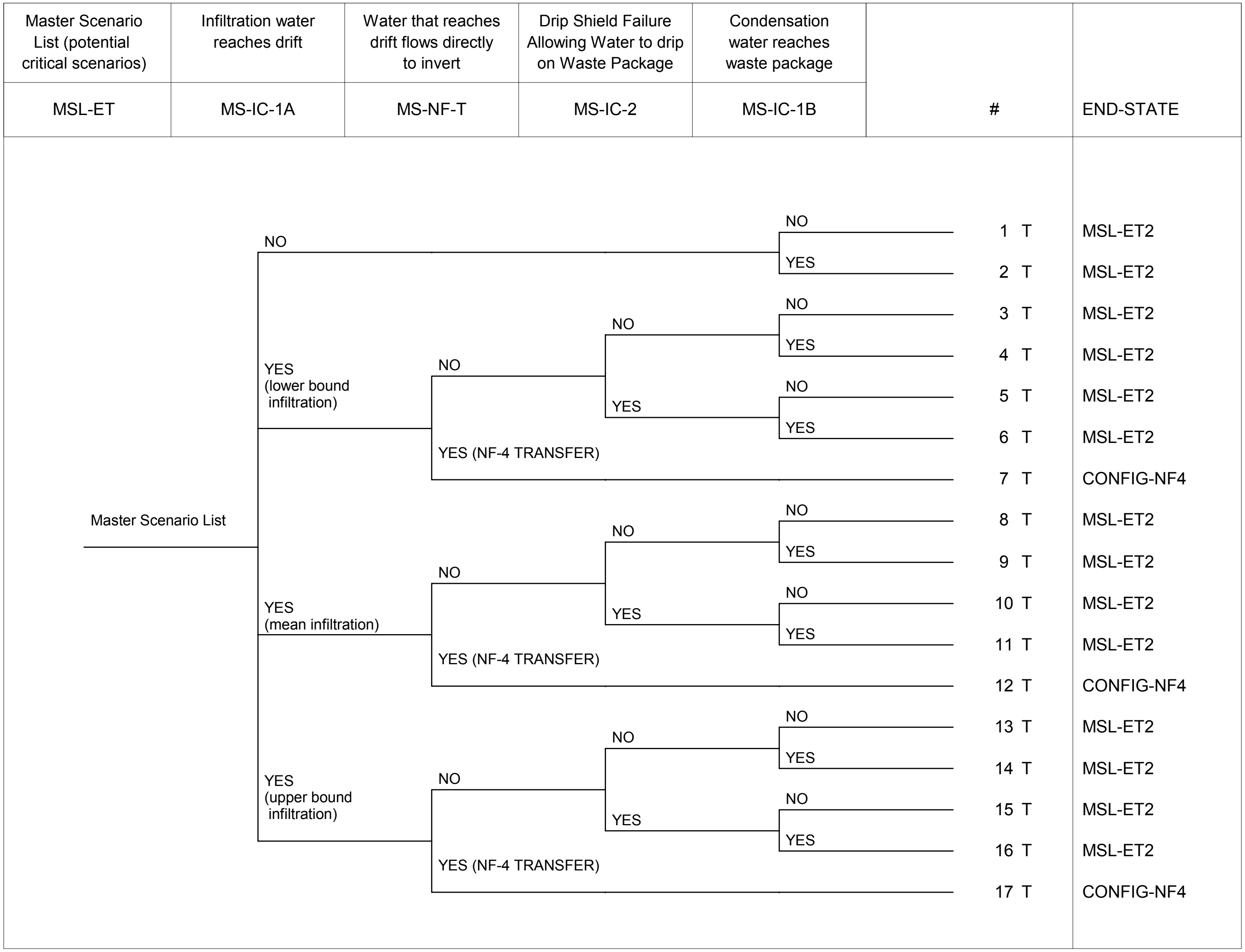

Figure B-4. Master Scenario List Event Tree — ”MSL-ET”

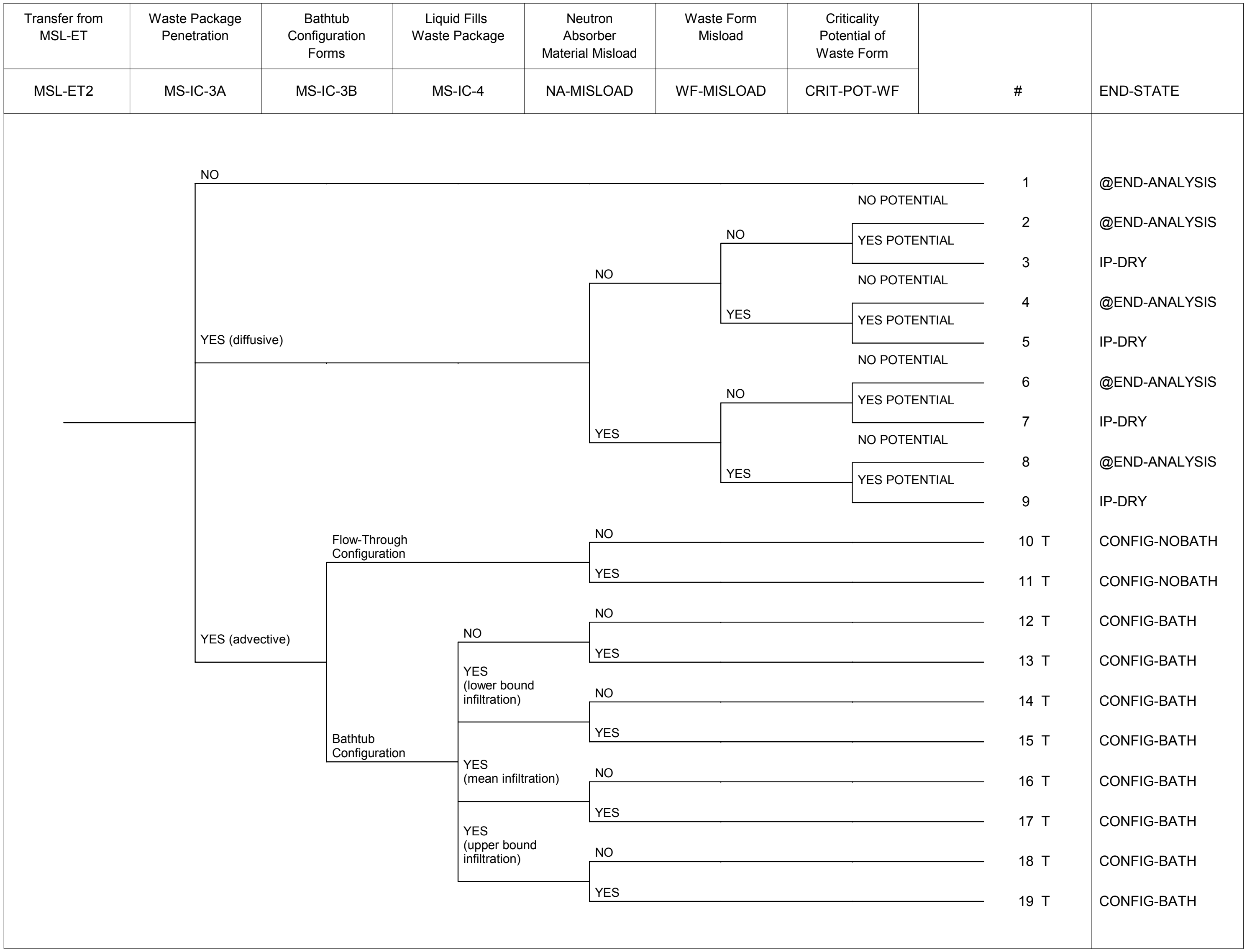

Figure B-5. Master Scenario List Event Tree – Continued — ”MSL-ET2”

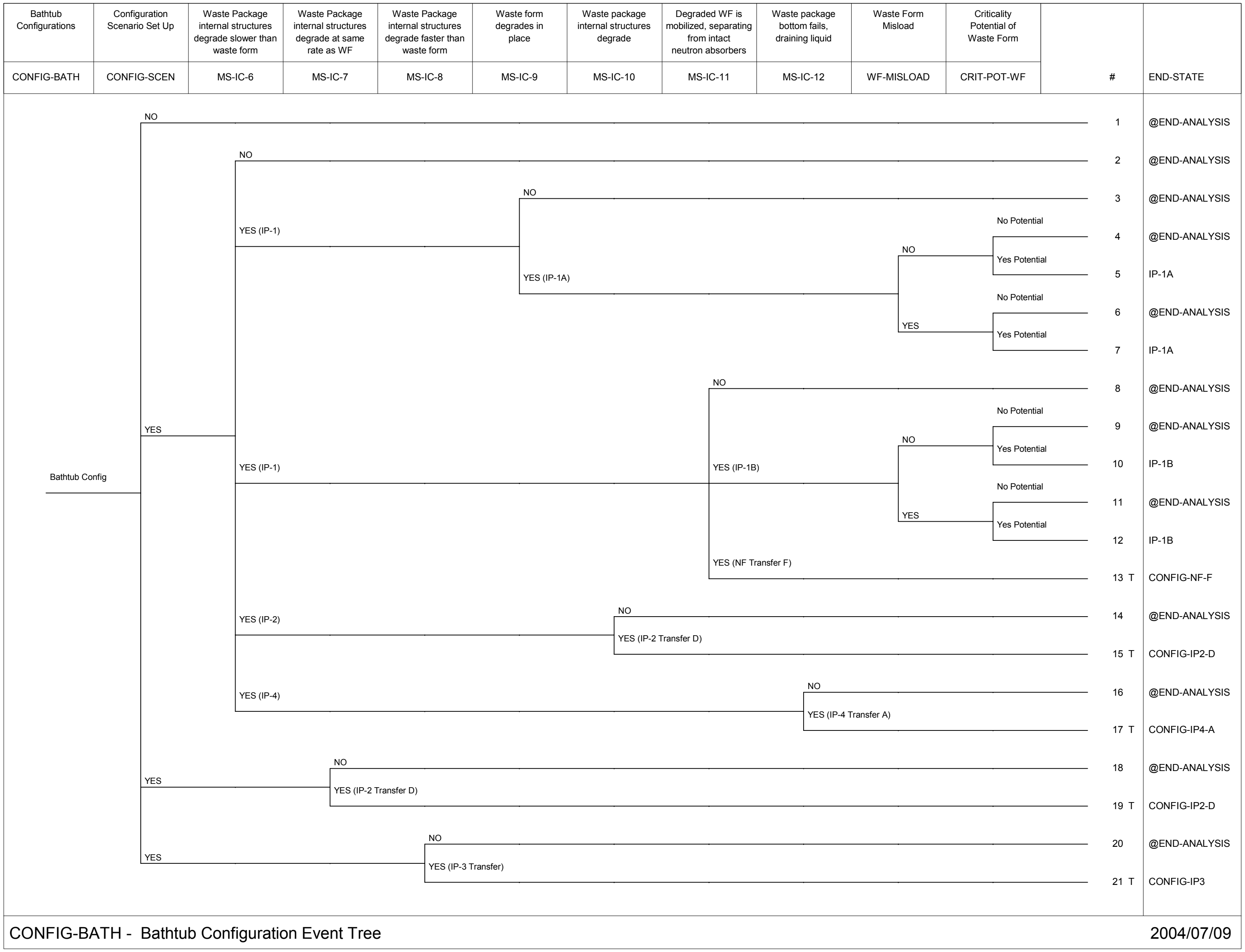

Figure B-6. Bathtub Configuration Event Tree — “CONFIG-BATH”

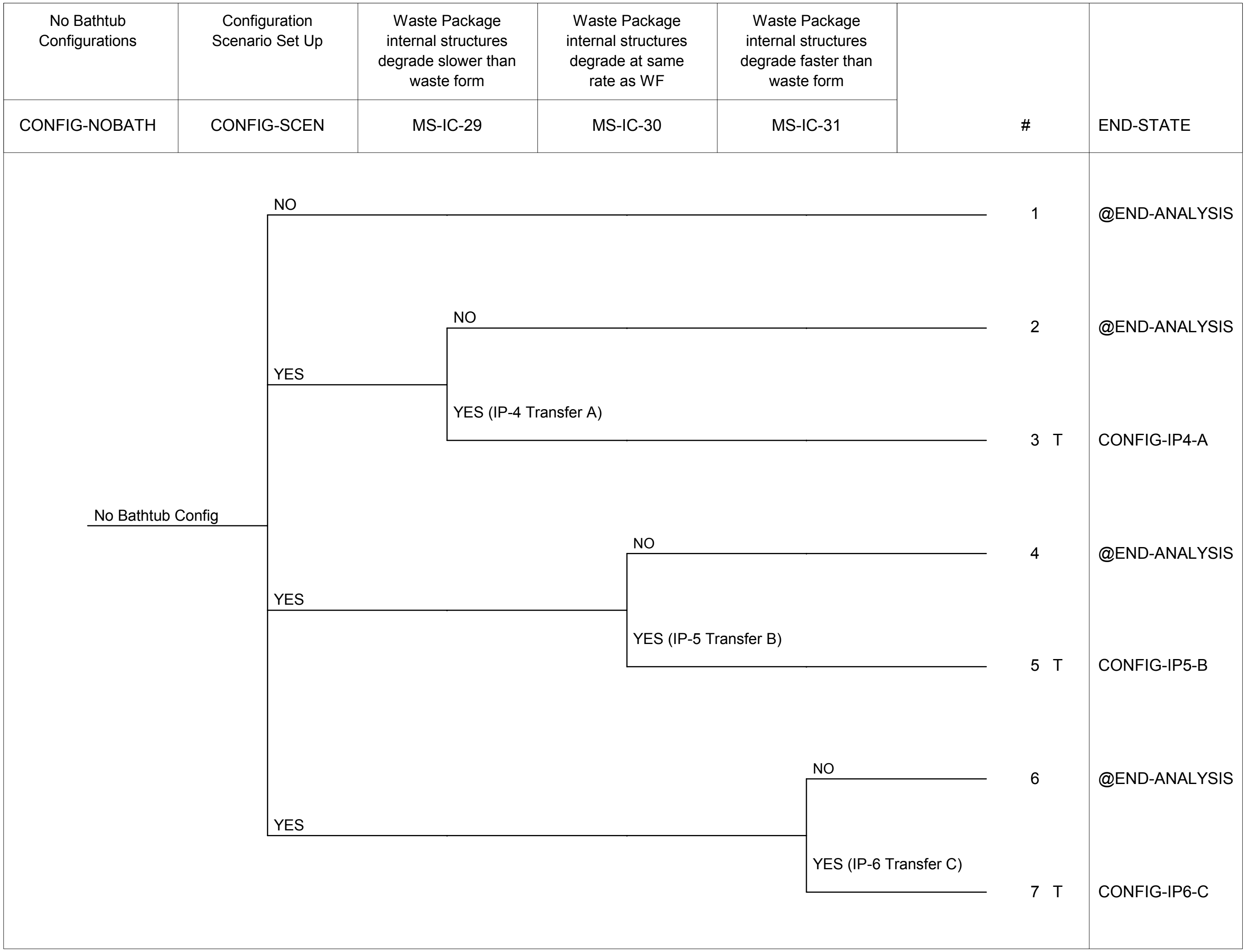

Figure B-7. Flow-Through Configuration Event Tree — “CONFIG-NOBATH”

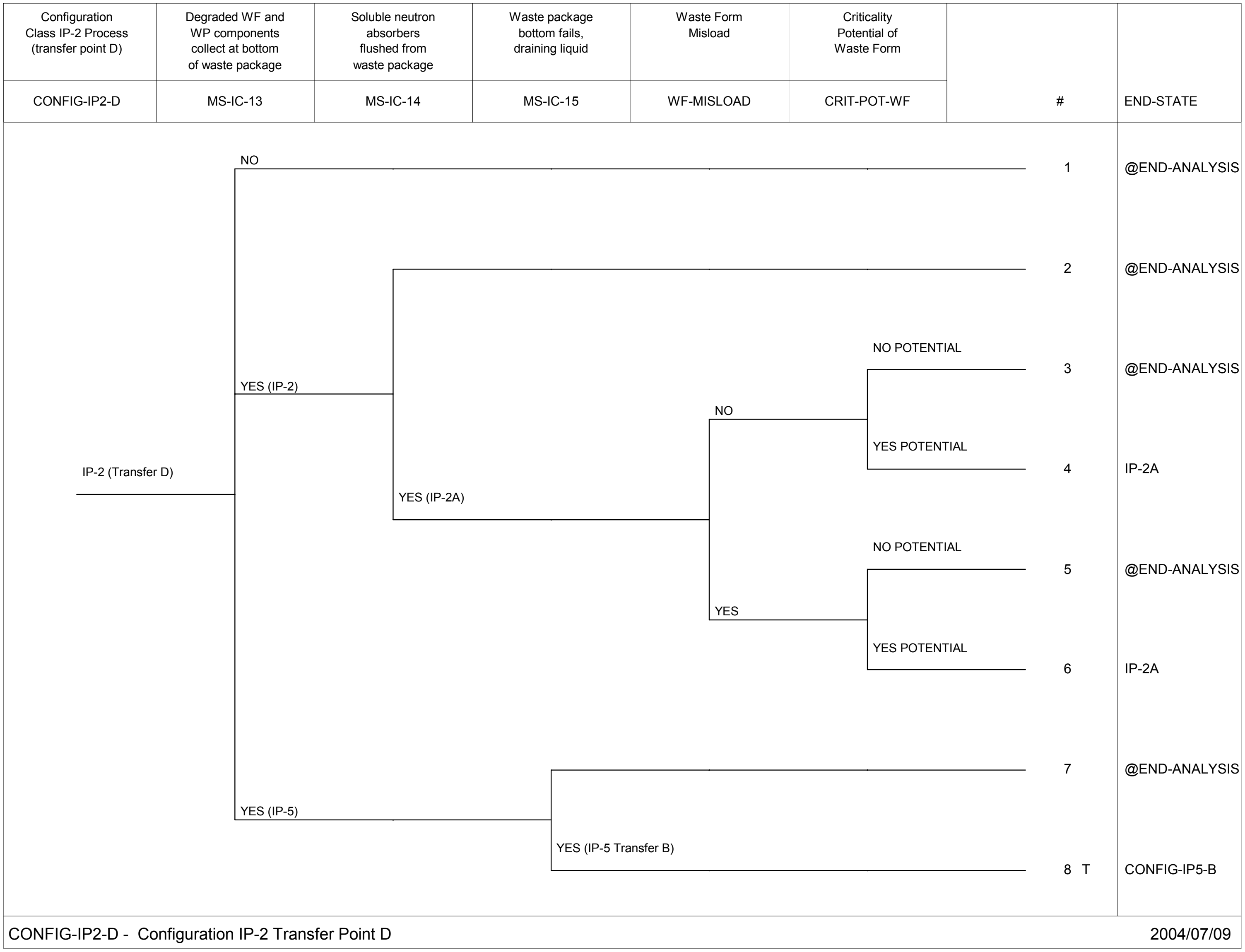

Figure B-8. Configuration Class IP-2 Event Tree — “CONFIG-IP2-D”

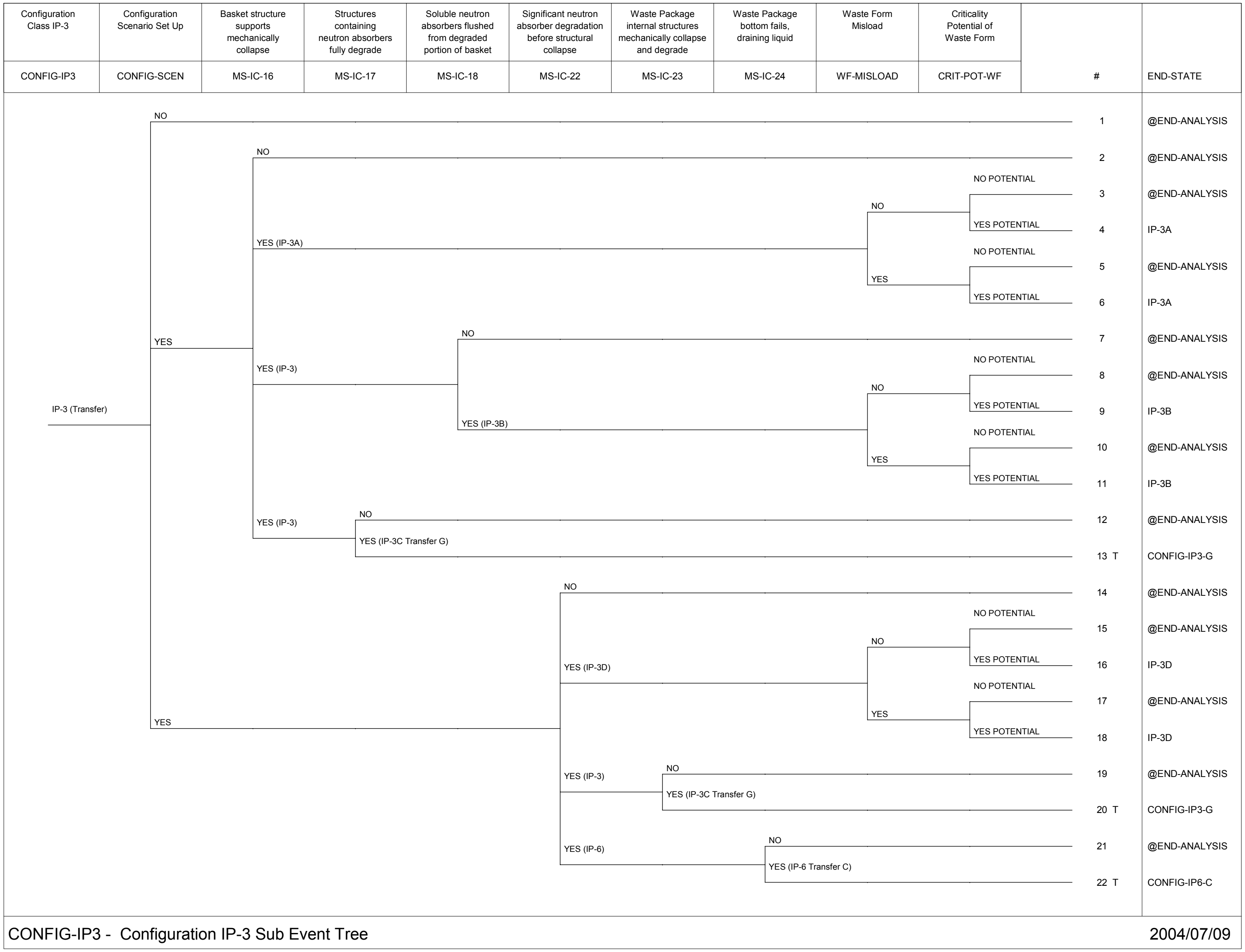

Figure B-9. Configuration Class IP-3 Event Tree — “CONFIG-IP3”

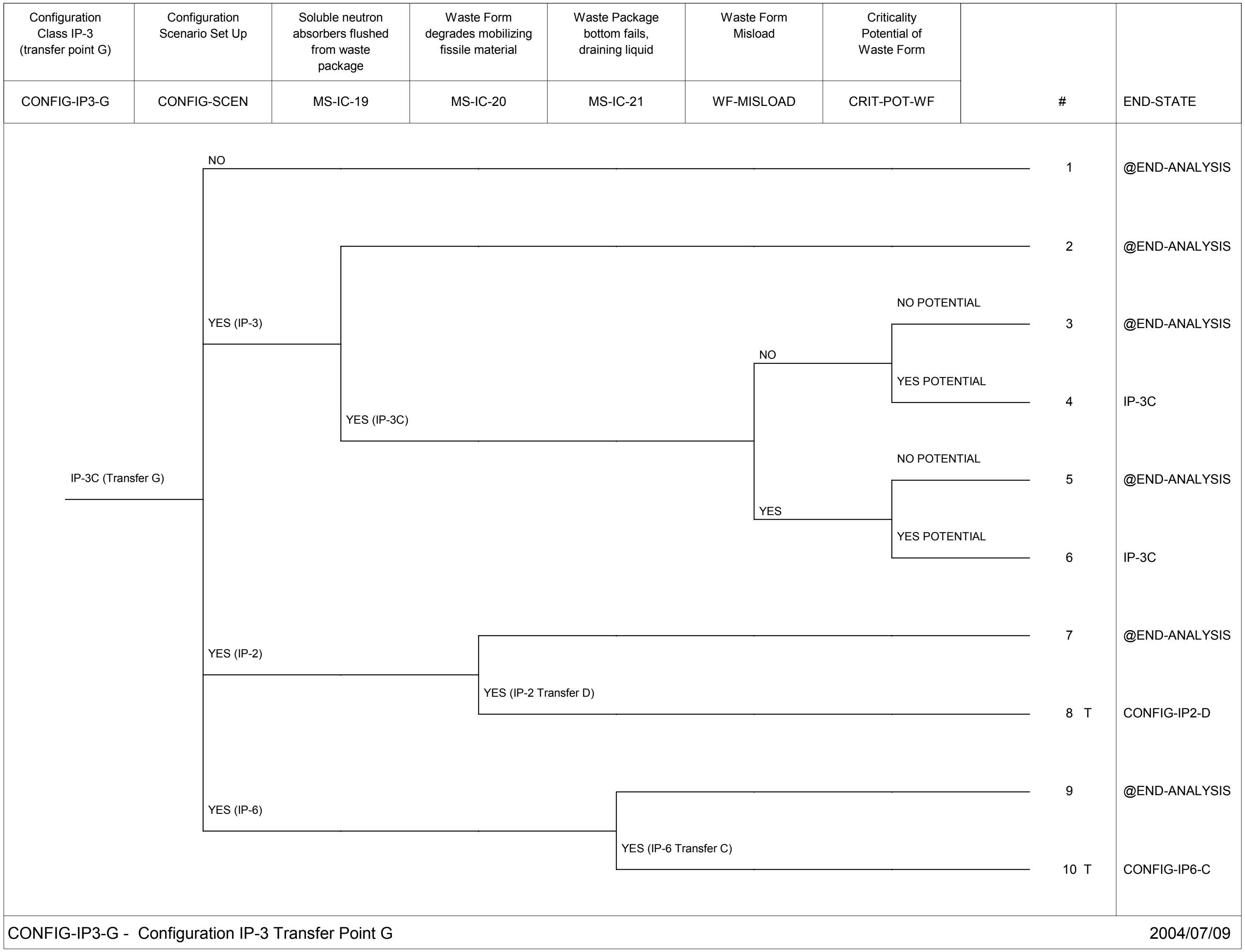

Figure B-10. Continuation of Configuration Class IP-3 Event Tree — “CONFIG-IP3-G”

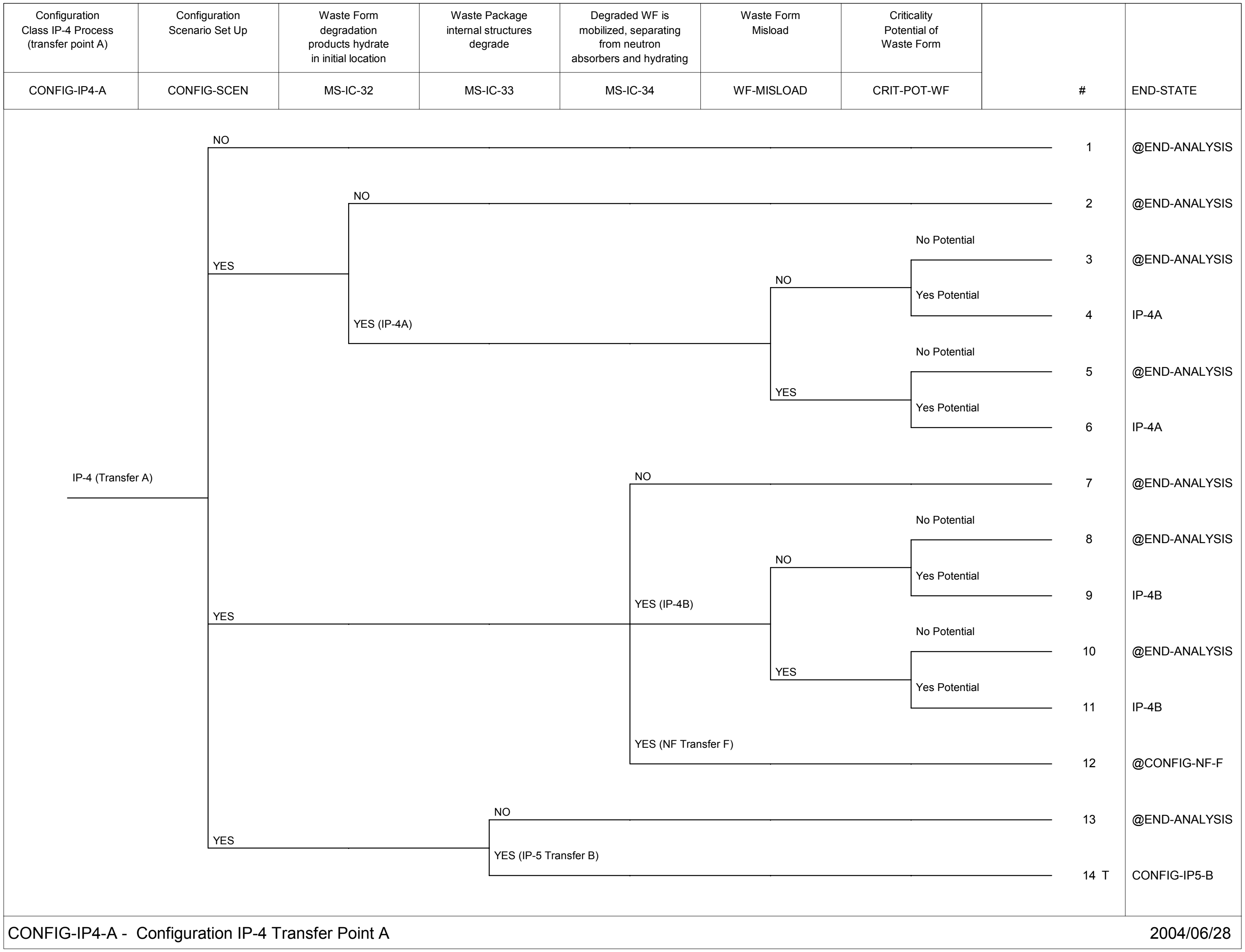

Figure B-11. Configuration Class IP-4 Event Tree — “CONFIG-IP4-A”

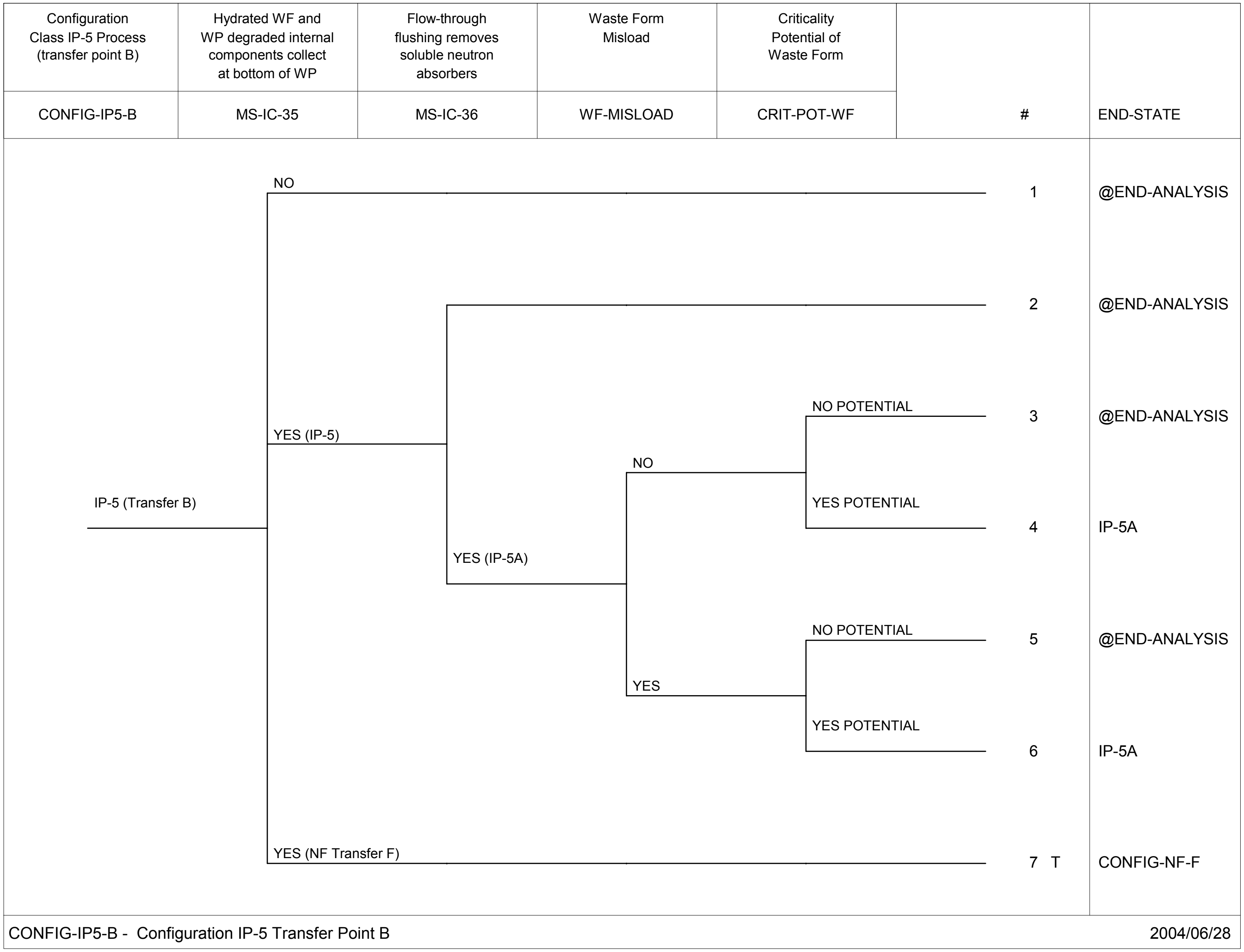

Figure B-12. Configuration Class IP-5 Event Tree — “CONFIG-IP5-B”

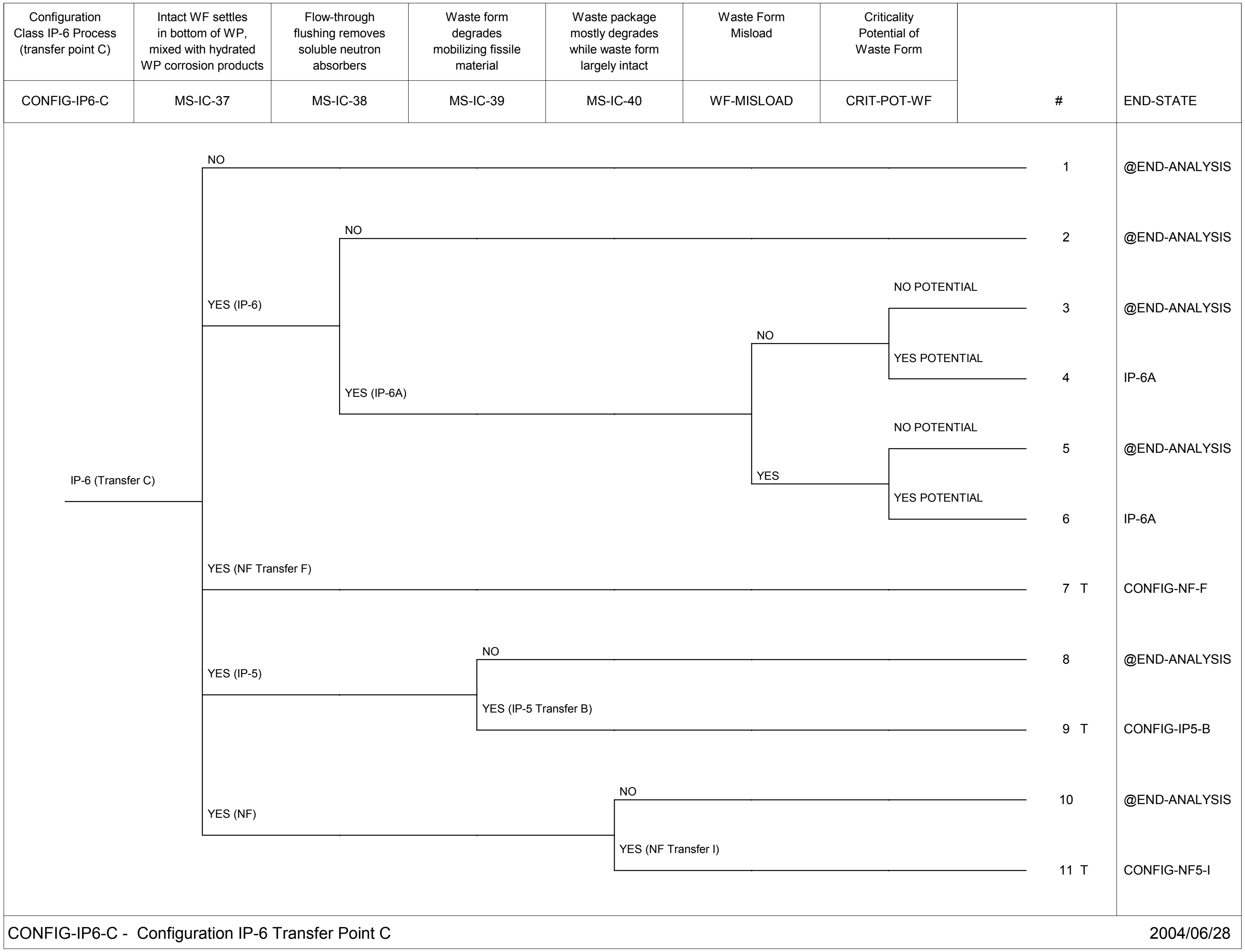

Figure B-13. Configuration Class IP-6 Event Tree — “CONFIG-IP6-C”

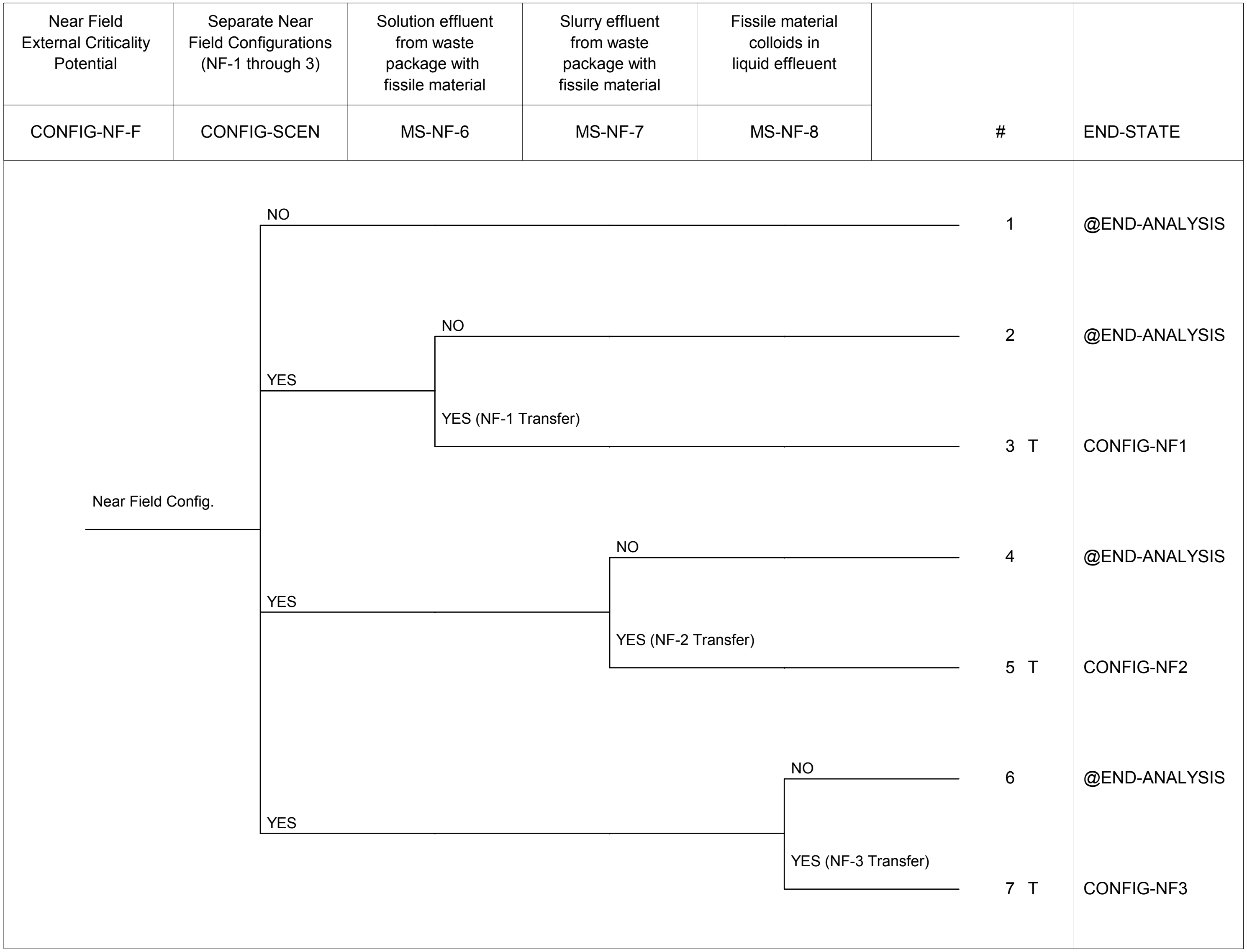

Figure B-14. Initial Near-Field Configuration Class Event Tree — “CONFIG-NF-F”

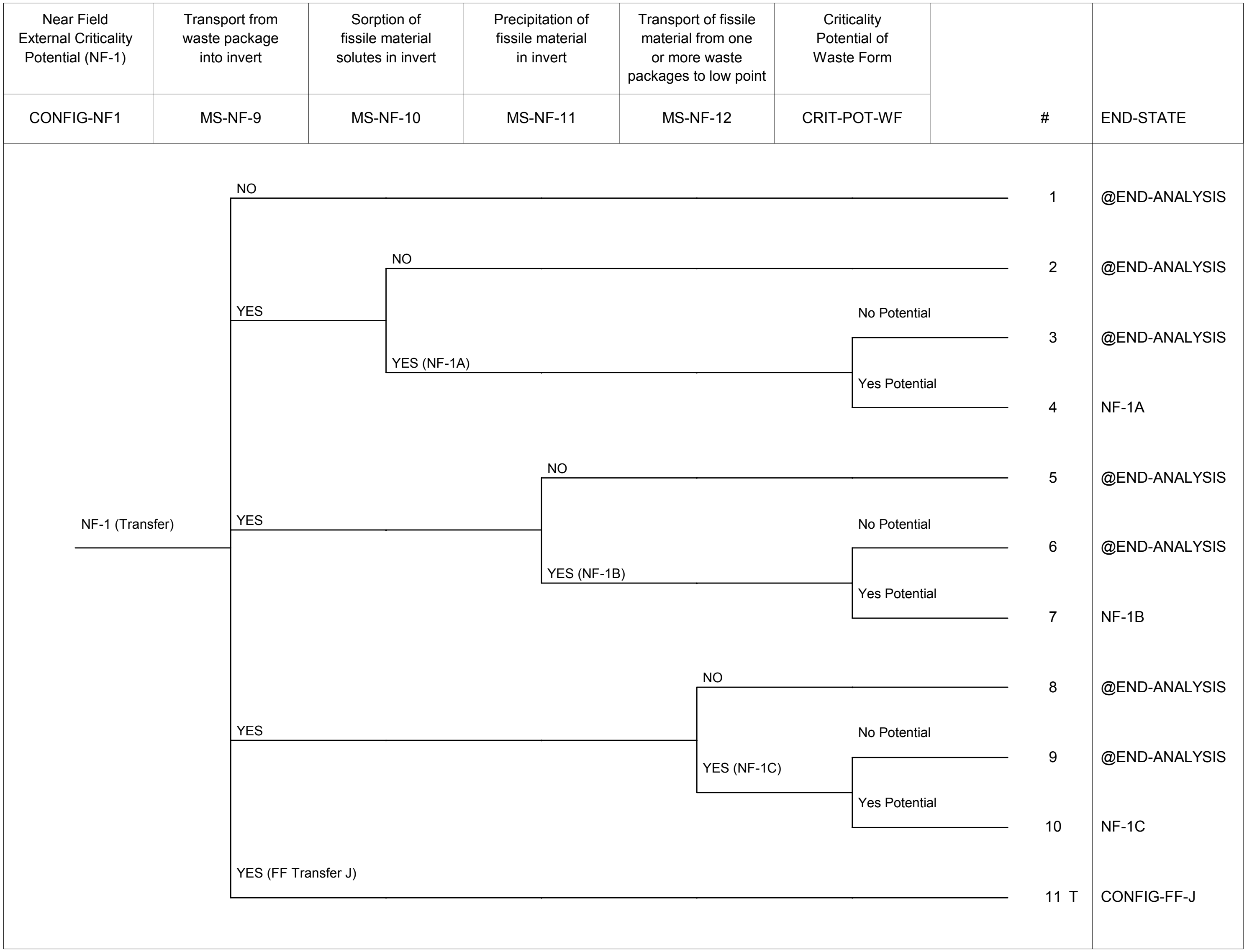

Figure B-15. Near-Field Configuration Class NF-1 Event Tree — "CONFIG-NF1"

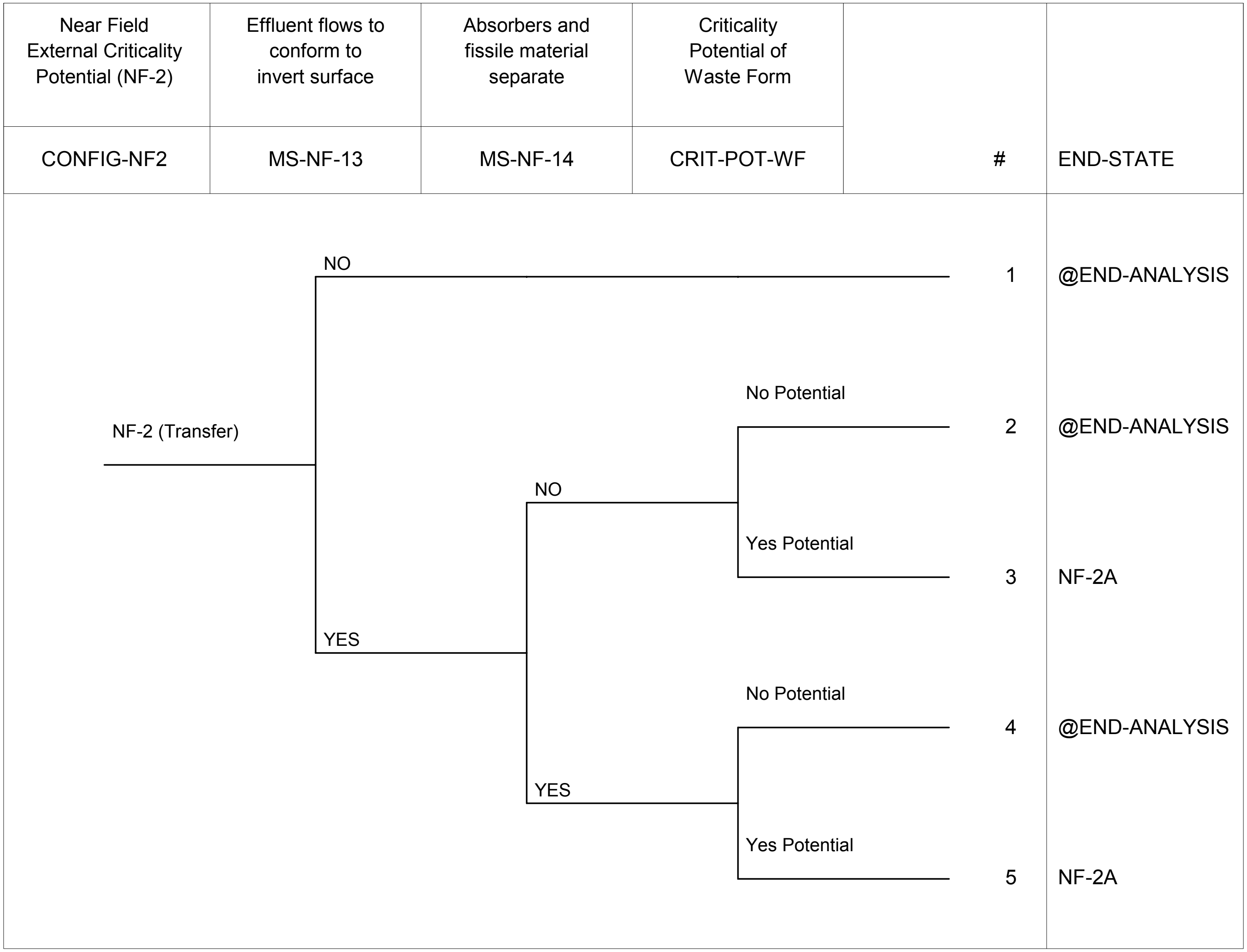

Figure B-16. Near-Field Configuration Class NF-2 Event Tree — “CONFIG-NF2”

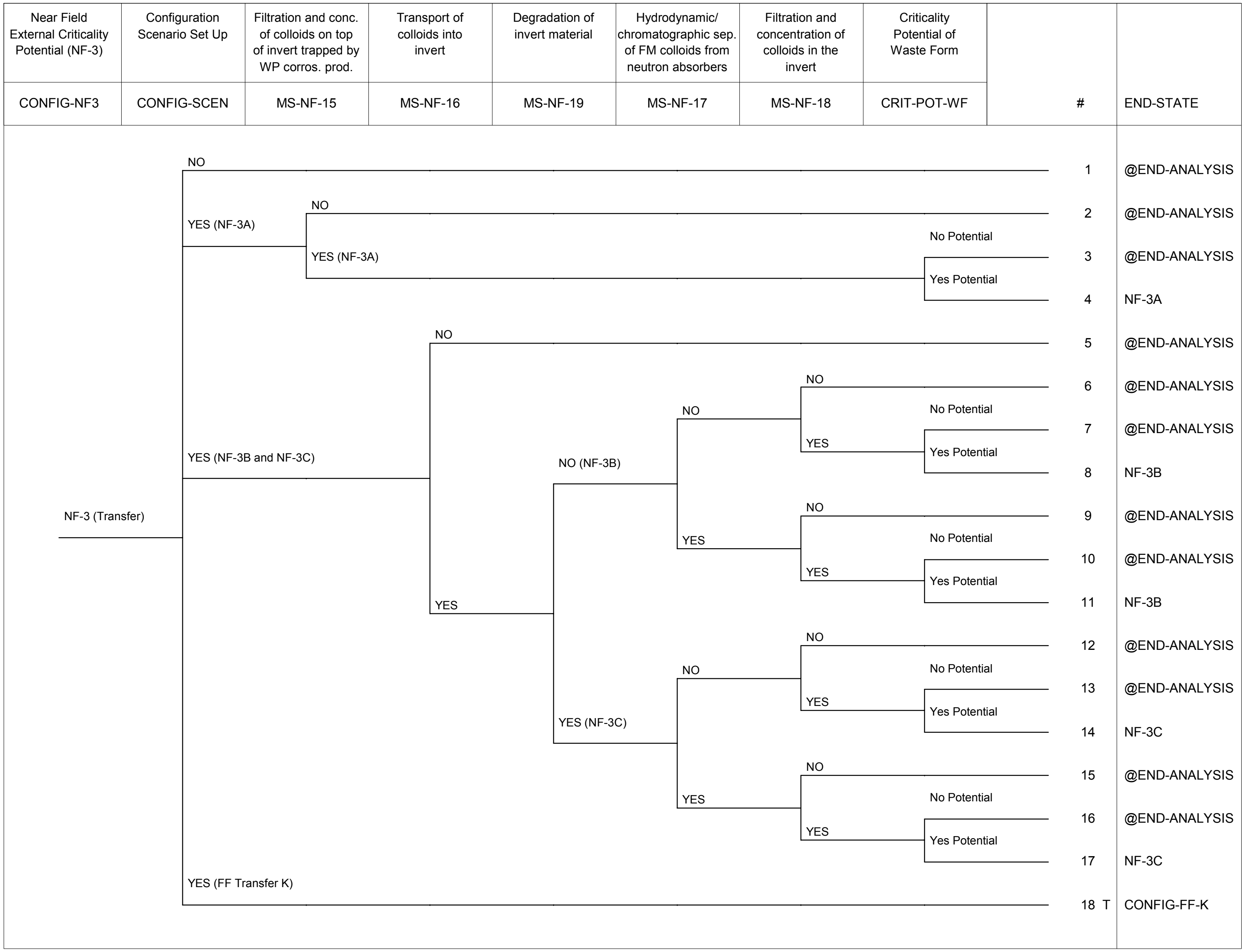

Figure B-17. Near-Field Configuration Class NF-3 Event Tree — “CONFIG-NF3”

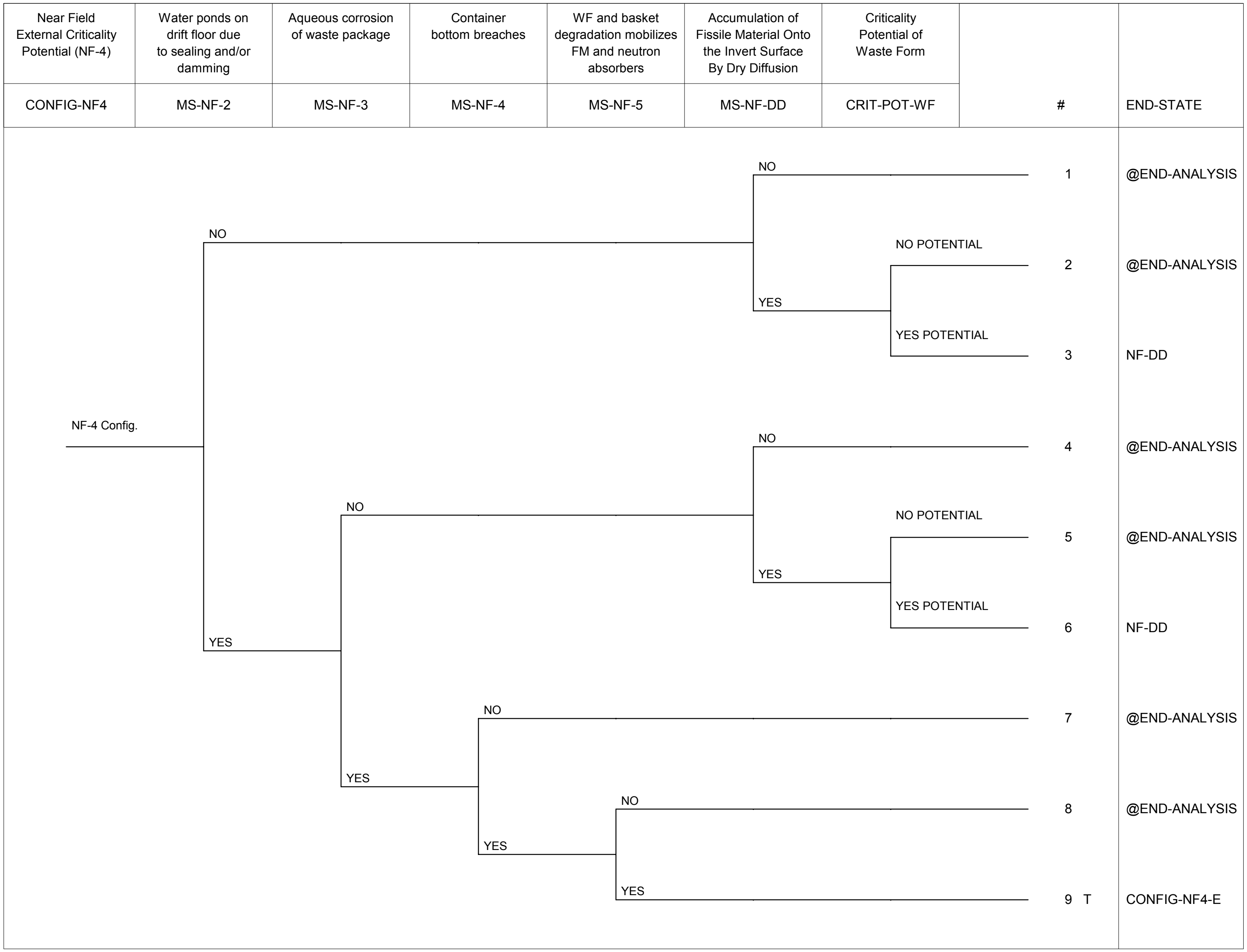

Figure B-18. Near-Field Configuration Class NF-4 Event Tree — “CONFIG-NF4”

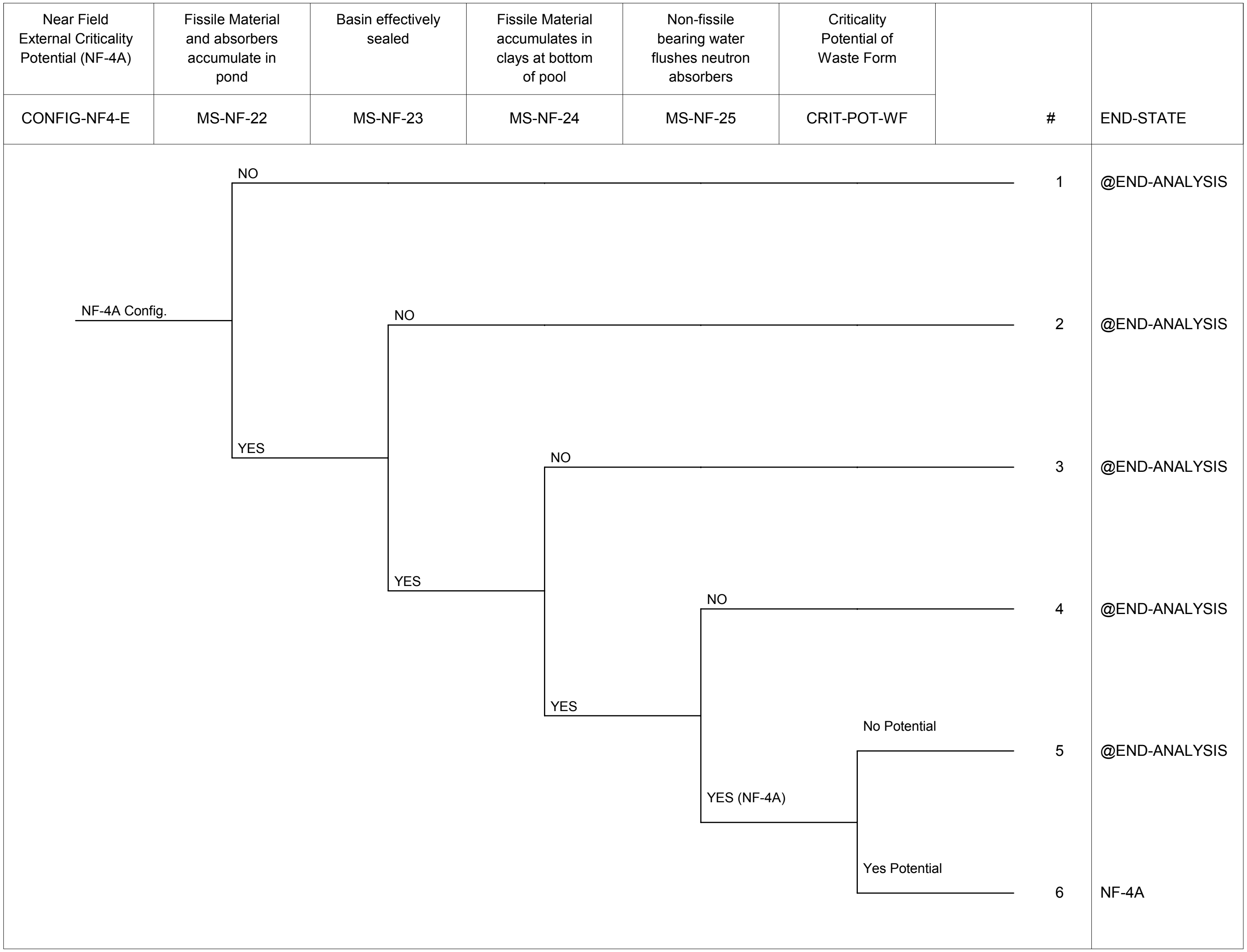

Figure B-19. Near-Field Configuration Class NF-4 Event Tree – Continued — “CONFIG-NF4-E”

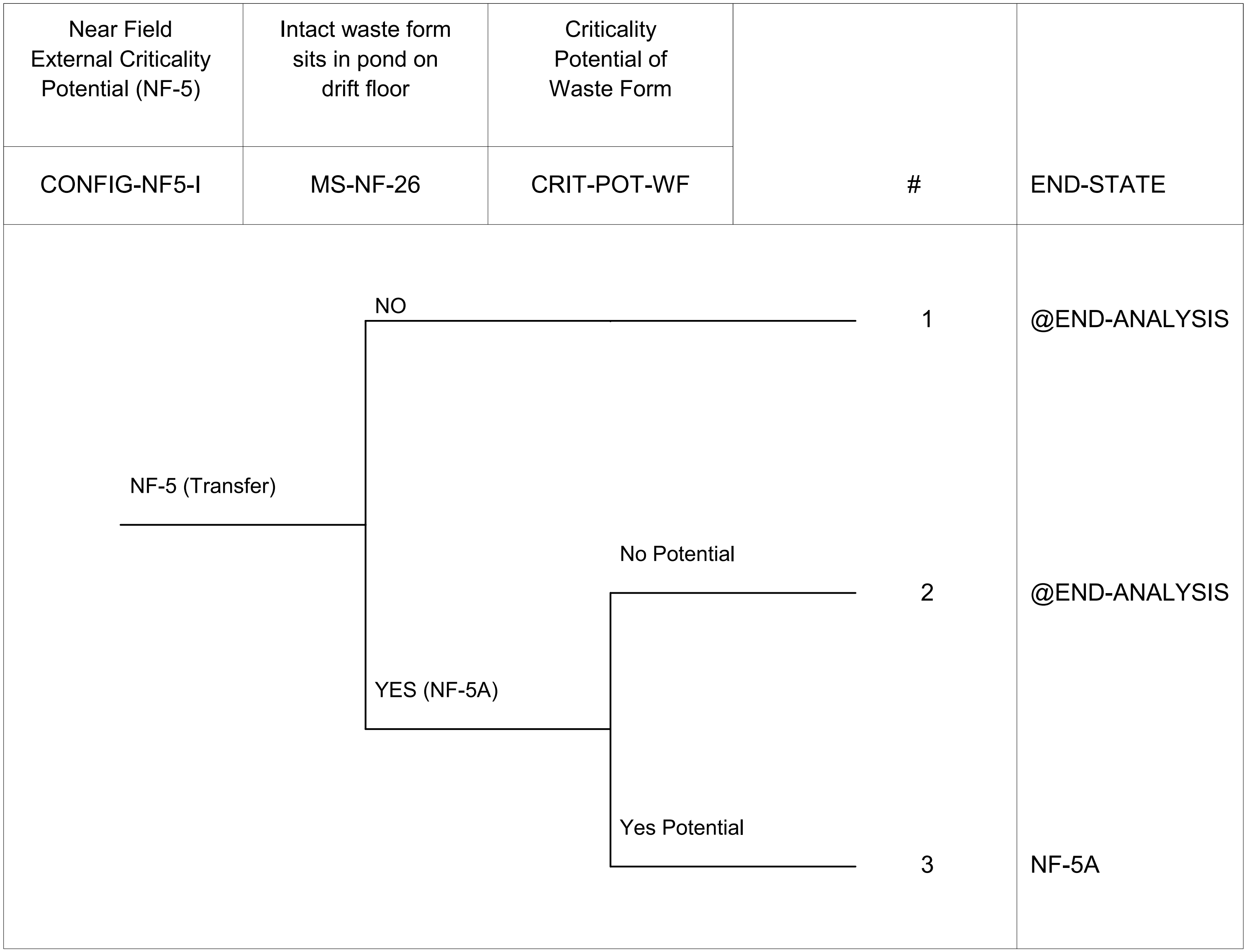

Figure B-20. Near-Field Configuration Class NF-5 Event Tree — “CONFIG-NF5-I”

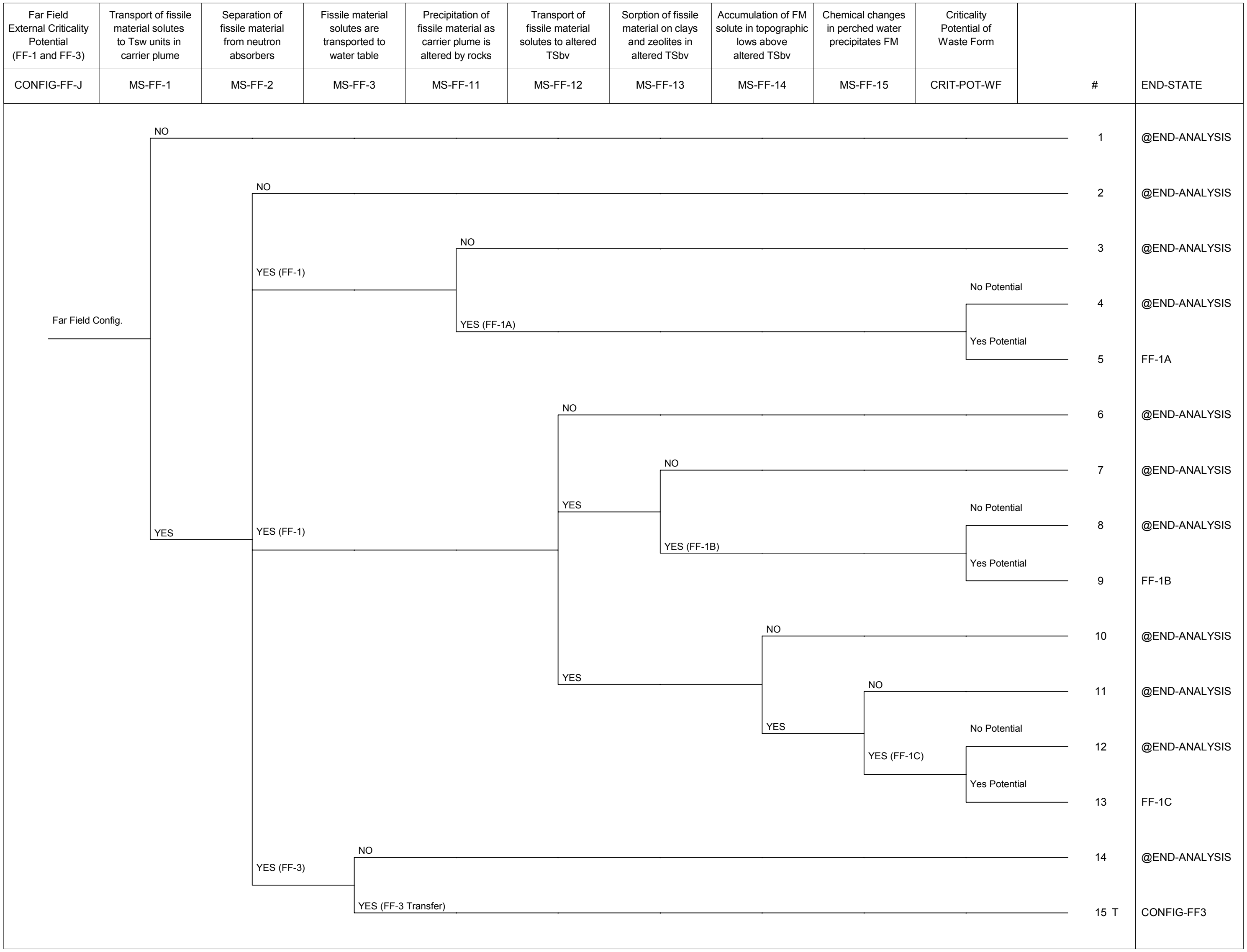

Figure B-21. Far-Field Configuration Class FF-1 Event Tree — “CONFIG-FF-J”

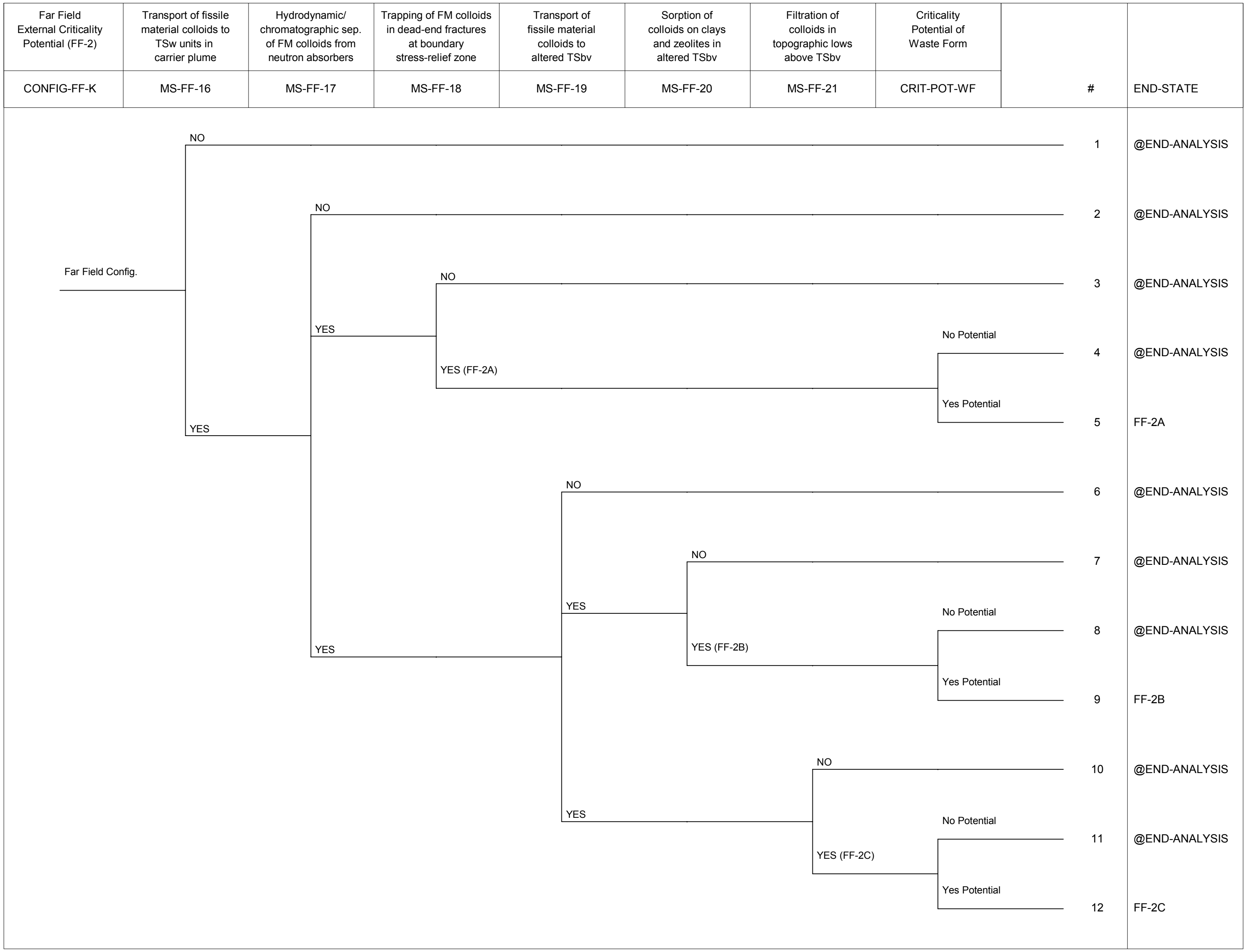

Figure B-22. Far-Field Configuration Class FF-2 Event Tree — “CONFIG-FF-K”

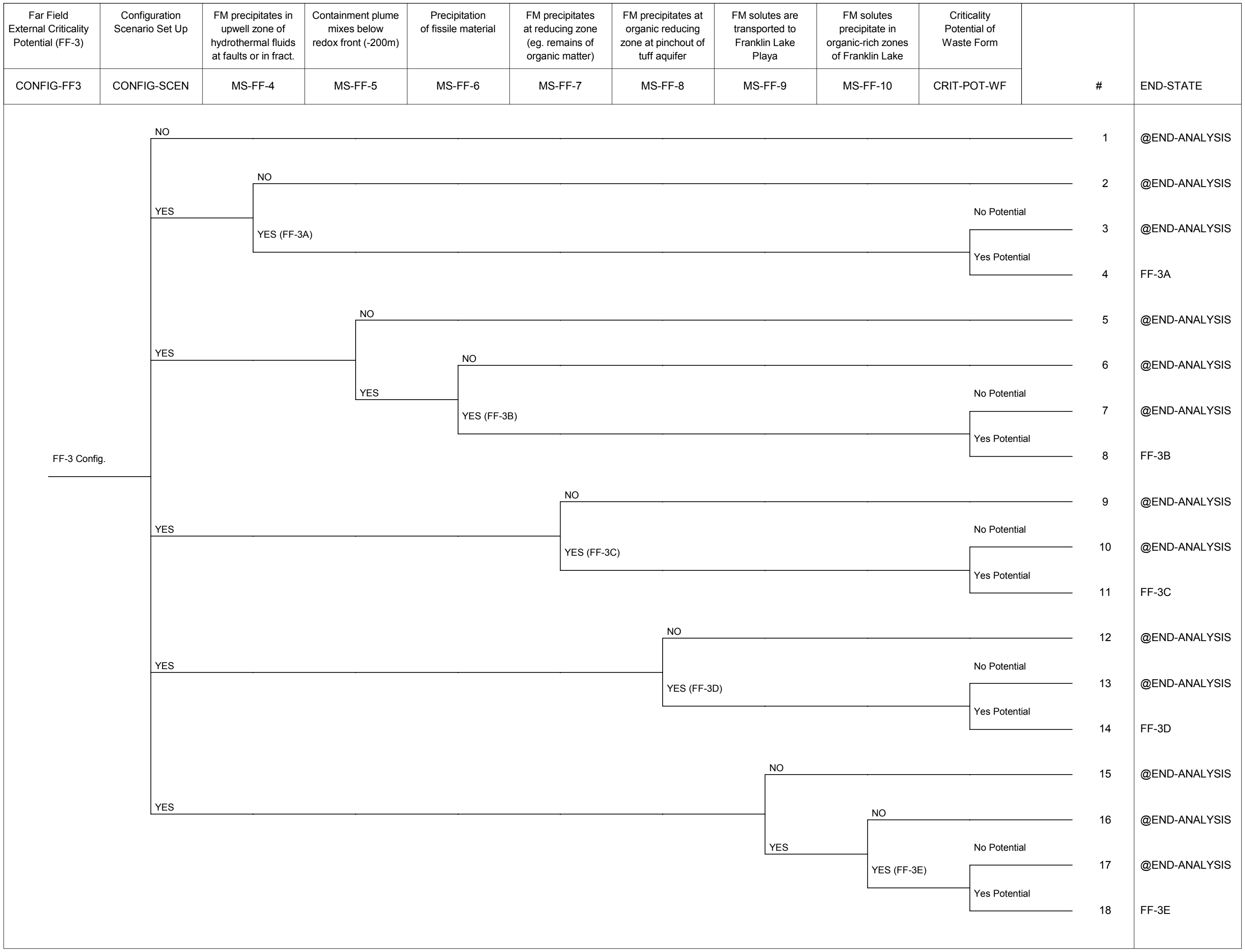

Figure B-23. Far-Field Configuration Class FF-3 Event Tree — “CONFIG-FF3”

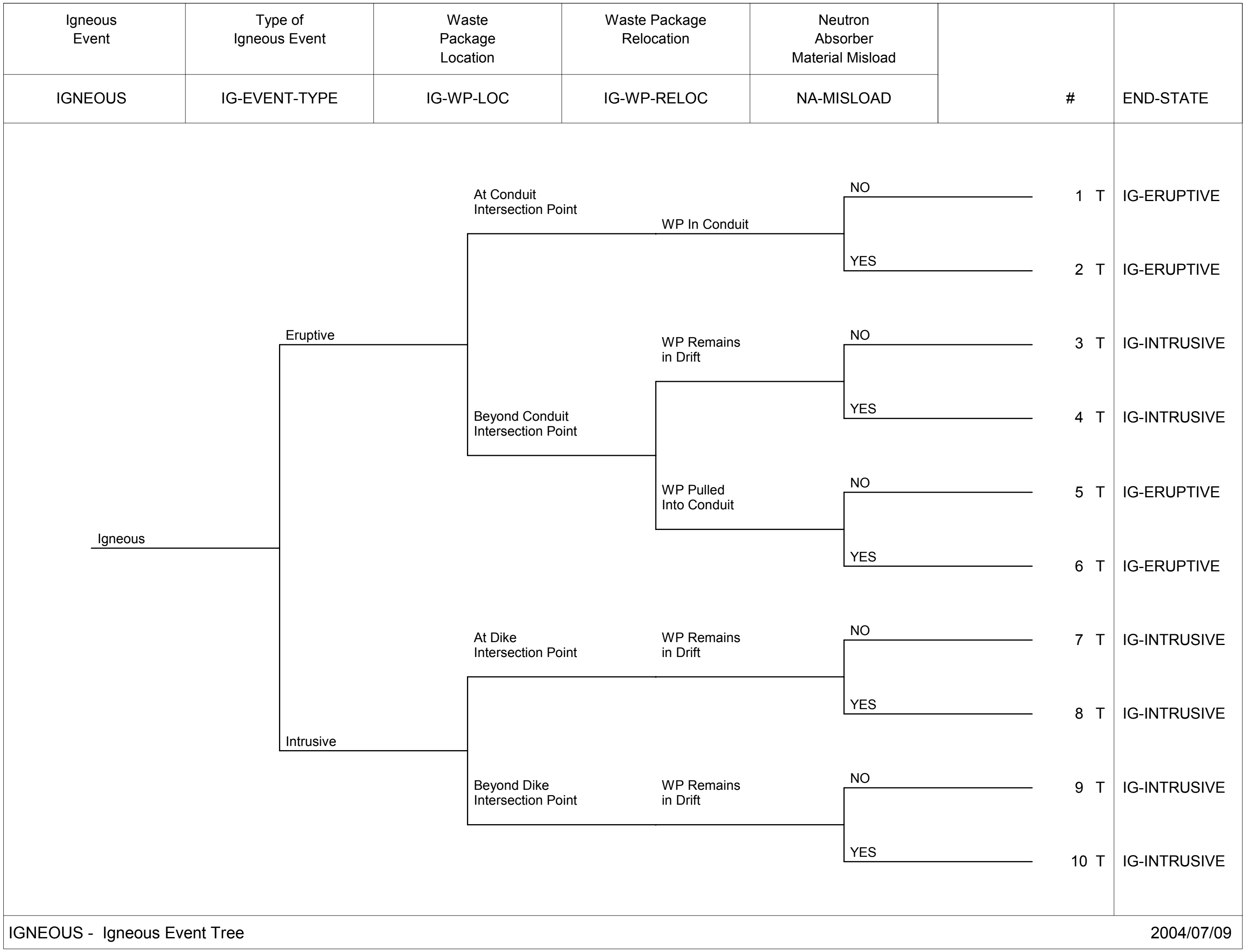

Figure B-24. Initial Igneous Event Tree — “IGNEOUS”

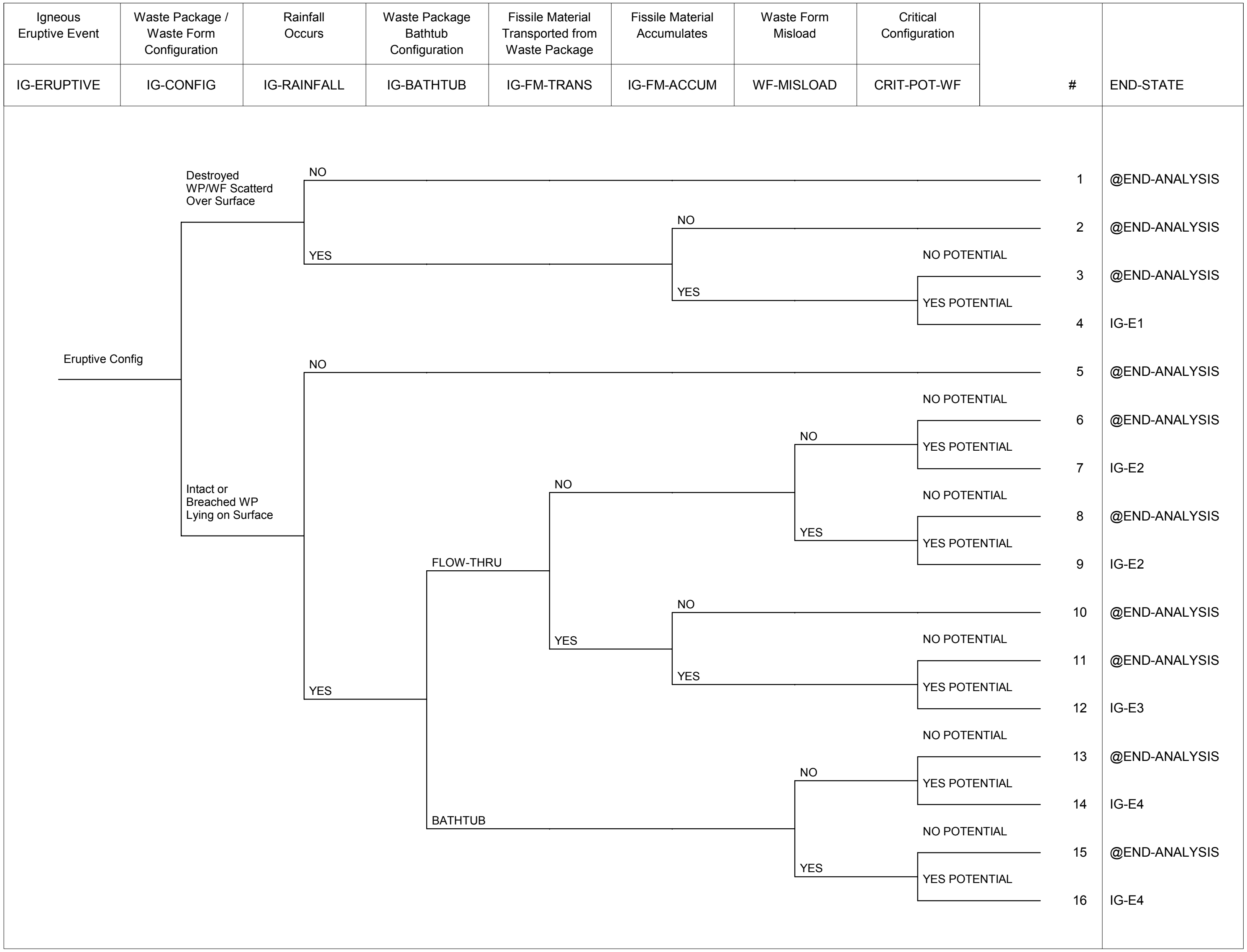

Figure B-25. Eruptive Scenario Igneous Event Tree — “IG-ERUPTIVE”

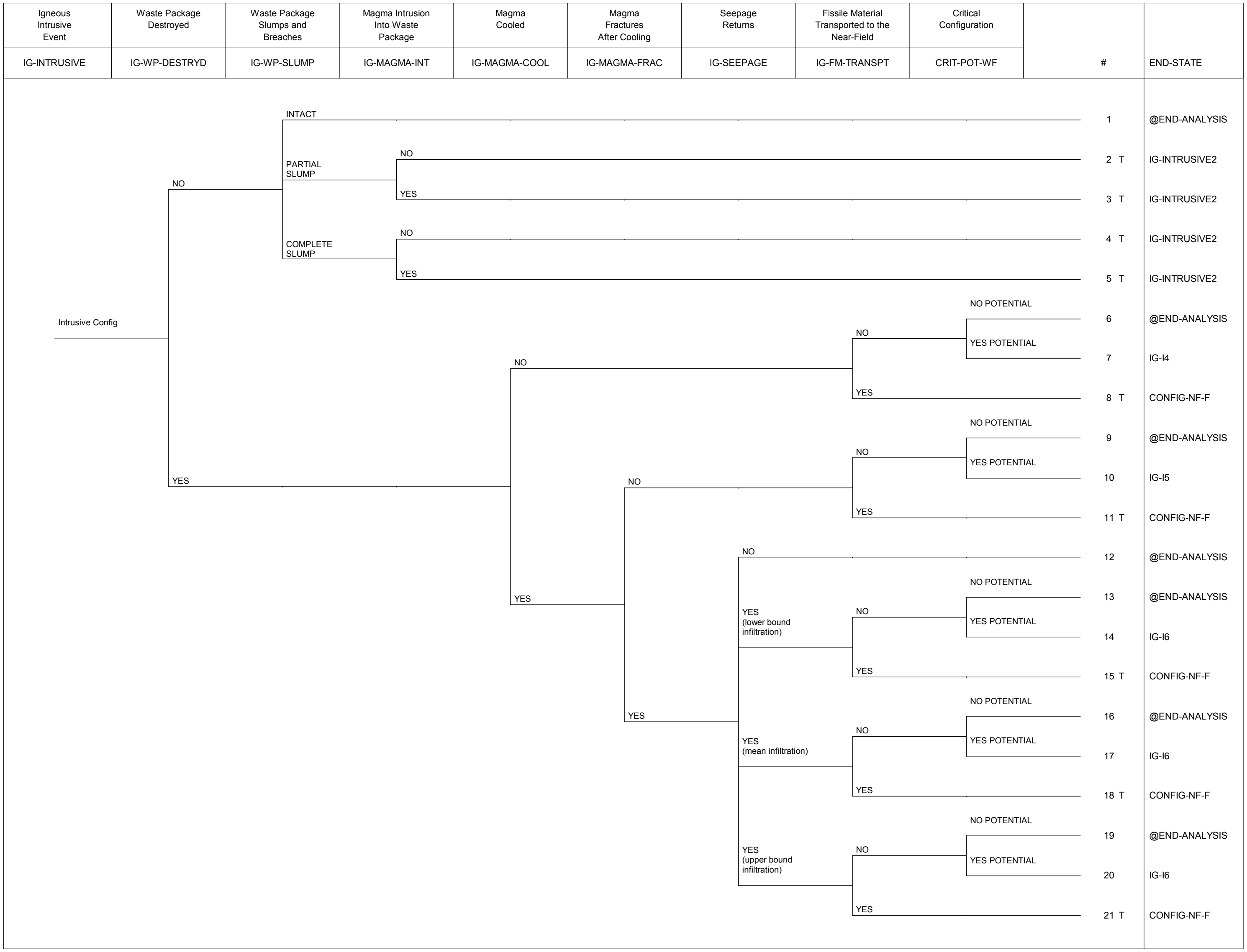

Figure B-26. Intrusive Scenario Igneous Event Tree — “IG-INTRUSIVE”

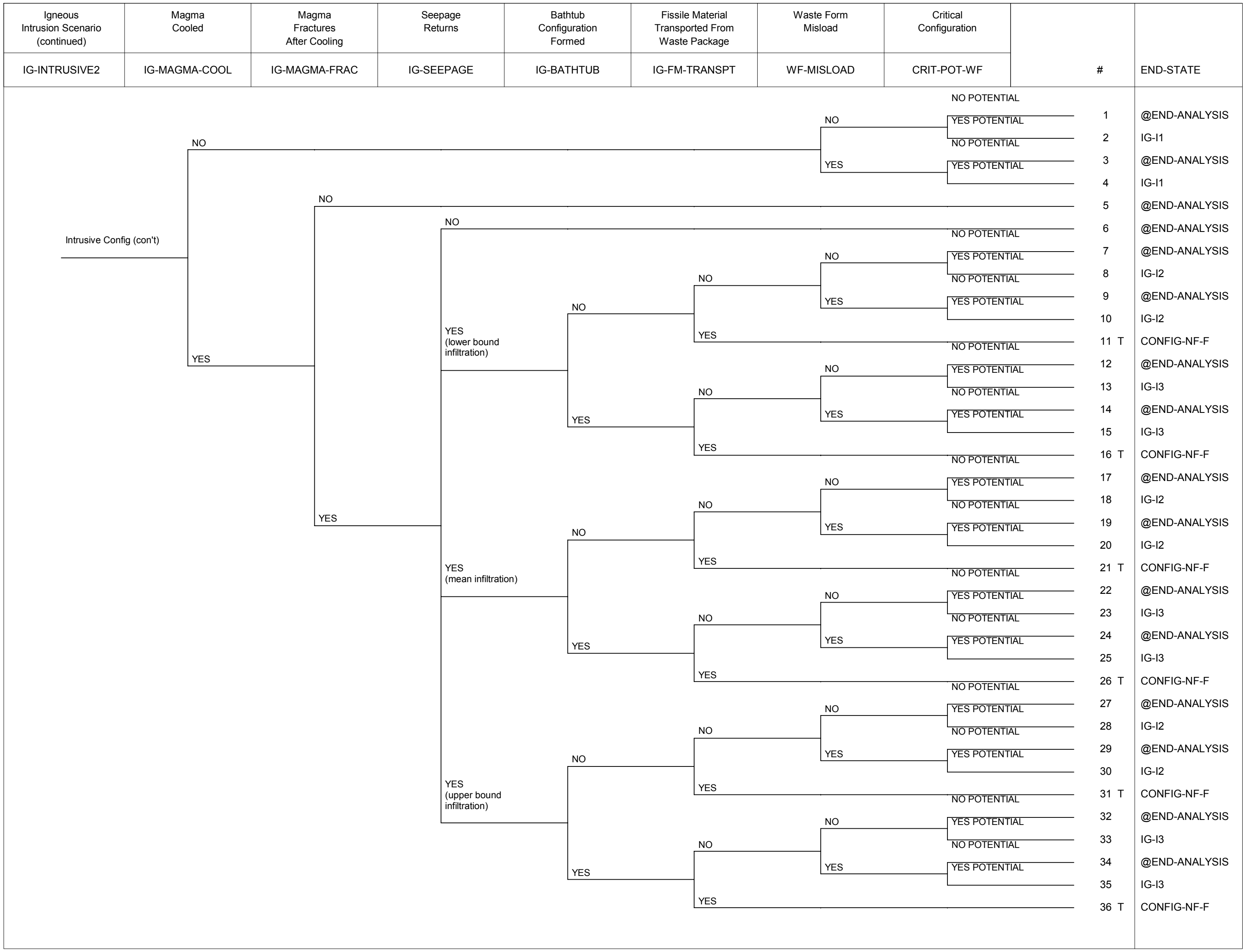

Figure B-27. Intrusive Scenario Igneous Event Tree - Continued — “IG-INTRUSIVE2”

B.2 LINKAGE RULES FOR THE “WP-WF” EVENT TREE (FIGURE B-1)

The following linkage rules are used to assign the event values representing the percentage of total waste package inventory for the various waste form types, waste form subtypes, and waste package types.

```
|
| Top Event WF-SOURCE
| waste form source fractions
|
if always then
|
| assign CSNF, DOE SNF, and NAVAL waste form fractions
|
 /WF-SOURCE    = WF-SOURCE-CSNF;
  WF-SOURCE[1] = WF-SOURCE-DSNF;
  WF-SOURCE[2] = WF-SOURCE-NSNF;
|
endif;
|
|
| Top Event WF-TYPE-PERC
| waste form type fractions
|
if /WF-SOURCE then
|
| individual CSNF type assignment
|
 /WF-TYPE-PERC = WF-TYPE-PWR;
  WF-TYPE-PERC = WF-TYPE-BWR;
elsif WF-SOURCE[1] then
|
| individual DOE waste form type assignment
|
 /WF-TYPE-PERC    = WF-TYPE-FFTF;
  WF-TYPE-PERC[1] = WF-TYPE-TRIGA;
  WF-TYPE-PERC[2] = WF-TYPE-NREACT;
  WF-TYPE-PERC[3] = WF-TYPE-SHPWR;
  WF-TYPE-PERC[4] = WF-TYPE-SHLWBR;
  WF-TYPE-PERC[5] = WF-TYPE-FSV;
  WF-TYPE-PERC[6] = WF-TYPE-MD;
  WF-TYPE-PERC[7] = WF-TYPE-FERMI;
  WF-TYPE-PERC[8] = WF-TYPE-TMI;
|
endif;
|
|
| Top Event WP-TYPE
| waste package type fractions
|
if /WF-SOURCE-CSNF * /WF-TYPE-PWR then
|
| 21-PWR AP, 21-PWR CR, and 12-PWR assignment
```

```
|
 /WP-TYPE = WP-TYPE-21PWRAP;
  WP-TYPE[1] = WP-TYPE-21PWRCR;
  WP-TYPE[2] = WP-TYPE-12PWRAP;
|
endif;
|
if /WF-SOURCE-CSNF * WF-TYPE-BWR then
|
| 44-BWR and 24-BWR assignment
|
 /WP-TYPE = WP-TYPE-44BWR;
  WP-TYPE = WP-TYPE-24BWR;
|
endif;
|
if WF-SOURCE-DSNF * /WF-TYPE-FFTF then
|
| FFTF short and long assignment
|
 /WP-TYPE = WP-TYPE-FFTFSH;
  WP-TYPE = WP-TYPE-FFTFL;
|
endif;
|
if WF-SOURCE-DSNF * WF-TYPE-NREACT then
|
| N Reactor short, long, and mco assignment
|
 /WP-TYPE = WP-TYPE-NREACTSH;
  WP-TYPE[1] = WP-TYPE-NREACTL;
  WP-TYPE[2] = WP-TYPE-NREACTMCO;
|
endif;
|
if WF-SOURCE-DSNF * WF-TYPE-SHPWR then
|
| Shippingport LWR short and long assignment
|
 /WP-TYPE = WP-TYPE-SHPWRSH;
  WP-TYPE = WP-TYPE-SHPWRL;
|
endif;
|
if WF-SOURCE-DSNF * WF-TYPE-SHLWBR then
|
| Shippingport LWBR short and long assignment
|
 /WP-TYPE = WP-TYPE-SHLWBRSH;
  WP-TYPE = WP-TYPE-SHLWBRL;
|
endif;
|
if WF-SOURCE-DSNF * WF-TYPE-MD then
|
| Aluminum Based melt & dilute short and long assignment
|
```

```
 /WP-TYPE = WP-TYPE-MDSH;
  WP-TYPE = WP-TYPE-MDL;
|
endif;
|
if WF-SOURCE-DSNF * WF-TYPE-FERMI then
|
| Enrico Fermi short and long assignment
|
 /WP-TYPE = WP-TYPE-FERMISH;
  WP-TYPE = WP-TYPE-FERMIL;
|
endif;
|
if WF-SOURCE-DSNF * WF-TYPE-TMI then
|
| Three Mile Island II Short and Long assignment
|
 /WP-TYPE = WP-TYPE-TMISH;
  WP-TYPE = WP-TYPE-TMIL;
|
endif;
|
if WF-SOURCE-NSNF then
|
| Naval short and long assignment
|
 /WP-TYPE = WP-TYPE-NAVALSH;
  WP-TYPE = WP-TYPE-NAVALL;
|
endif;
```

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B.3 LINKAGE RULES FOR THE "YMP-INIT-EVENT" EVENT TREE (FIGURE B-3)

The following linkage rules are used to substitute the event values for the four criticality FEPs cases considered in the SAPHIRE analysis – (1) Base Case, (2) Seismic Disruptive Event; (3) Rock Fall Disruptive Event, and (4) Igneous Disruptive Event. This event tree also assigns values for the fraction of lithophsysal and nonlithophysal geologic zones of the repository.

```
|
if always then
|
| Top Event INIT-EVENT
| initiate process of criticality FEPs cases
|
 /INIT-EVENT    = BASE-CASE;
  INIT-EVENT[1] = SEISMIC-EVENT;
  INIT-EVENT[2] = ROCKFALL-EVENT;
  INIT-EVENT[3] = IGNEOUS-EVENT;
|
| Top Event SEIS-RANGE
| probability of seismic exceedance frequency ranges
|
 /SEIS-RANGE    = SEIS-2E-8TO1E-8;
  SEIS-RANGE[1] = SEIS-6E-8TO2E-8;
  SEIS-RANGE[2] = SEIS-2E-7TO6E-8;
  SEIS-RANGE[3] = SEIS-1E-4TO2E-7;
|
| Top Event SEIS-DAMAGE
| seismic damage due to ground motion
|
 /SEIS-DAMAGE = SEIS-GROUND;
|
| Top Event DRIFT-ZONE
| fraction of repository in lithophysal and nonlithophysal
|
 /DRIFT-ZONE = DRIFT-ZONE-NONL;
  DRIFT-ZONE = DRIFT-ZONE-LITH;
|
endif;
|
| Top Event SEIS-DAMAGE
| seismic damage due to faulting
|
if (/SEIS-RANGE + SEIS-RANGE[1] + (SEIS-RANGE[2] *
    (~init(WP01-21-PWR-AP) + ~init(WP02-21-PWR-CR) +
     ~init(WP03-12-PWR-AP) + ~init(WP04-24-BWR-AP) +
     ~init(WP05-44-BWR-AP))))then
|
| potential faulting damage for all waste package types
| in these seismic ranges (exceptions follow)
|
  SEIS-DAMAGE = SEIS-FAULT-1;
|
```

```
elsif (SEIS-RANGE[2] * (init(WP01-21-PWR-AP) + init(WP02-21-PWR-CR) +
                        init(WP03-12-PWR-AP) + init(WP04-24-BWR-AP) +
                        init(WP05-44-BWR-AP))) then
|
| no faulting damage for 21-PWR AP, 21-PWR CR, 12-PWR CR,44-BWR AP,
| and 24-BWR AP waste package types in this seismic range
|
  SEIS-DAMAGE = SEIS-FAULT-0;
|
endif;
```

B.4 LINKAGE RULES FOR THE "MSL-ET" EVENT TREE (FIGURE B-4)

The following linkage rules are used to substitute the values for the events and processes that initiate the formation of potentially critical configurations. The events and processes defined by this event tree include seepage infiltration, condensation and drip shield failure.

```
|
|
|
|
| Top Event MS-IC-1A
| probability of no, lower-bound, mean, and upper-bound seepage scenarios
|
if (/BASE-CASE + ROCKFALL-EVENT) * DRIFT-ZONE then
|
| seepage probability for base case and rock fall events, lithophysal
|
 /MS-IC-1A    = MS-IC-1A-NOM-NWL;
  MS-IC-1A[1] = MS-IC-1A-NOM-LL;
  MS-IC-1A[2] = MS-IC-1A-NOM-ML;
  MS-IC-1A[3] = MS-IC-1A-NOM-UL;
|
elsif (/BASE-CASE + ROCKFALL-EVENT)* /DRIFT-ZONE then
|
| seepage probability for base case and rock fall events, nonlithophysal
|
 /MS-IC-1A    = MS-IC-1A-NOM-NWNL;
  MS-IC-1A[1] = MS-IC-1A-NOM-LNL;
  MS-IC-1A[2] = MS-IC-1A-NOM-MNL;
  MS-IC-1A[3] = MS-IC-1A-NOM-UNL;
|
elsif SEISMIC-EVENT * DRIFT-ZONE then
|
| seepage probability for seismic event, lithophysal
|
 /MS-IC-1A    = MS-IC-1A-SEIS-NWL;
  MS-IC-1A[1] = MS-IC-1A-SEIS-LL;
  MS-IC-1A[2] = MS-IC-1A-SEIS-ML;
  MS-IC-1A[3] = MS-IC-1A-SEIS-UL;
|
elsif SEISMIC-EVENT * /DRIFT-ZONE then
|
| seepage probability for seismic event, nonlithophysal
|
 /MS-IC-1A    = MS-IC-1A-SEIS-NWNL;
  MS-IC-1A[1] = MS-IC-1A-SEIS-LNL;
  MS-IC-1A[2] = MS-IC-1A-SEIS-MNL;
  MS-IC-1A[3] = MS-IC-1A-SEIS-UNL;
|
endif;
|
|
| Top Event MS-NF-T
| transfer to near-field event tree
|
```

```
if always then
|
 /MS-NF-T = MS-NF-T-0;
  MS-NF-T = MS-NF-T-1;
|
endif;
|
|
| Top Event MS-IC-2
| probability of drip shield failure
|
if /BASE-CASE + ROCKFALL-EVENT + /SEIS-GROUND + ~SEIS-DAMAGE then
|
| for base case, rock fall, and seismic ground motion events
|
 /MS-IC-2 = MS-IC-2-BC;
  MS-IC-2 = MS-IC-2-BC;
|
elsif SEIS-FAULT-1 then
|
| for seismic faulting events
|
 /MS-IC-2 = MS-IC-2-DE;
  MS-IC-2 = MS-IC-2-DE;
|
endif;
|
|
| Top Event MS-IC-1B
| probability of condensation
|
if always then
|
| no condensation
|
 /MS-IC-1B = MS-IC-1B-0;
  MS-IC-1B = MS-IC-1B-0;
|
endif;
```

B.5 LINKAGE RULES FOR THE "MSL-ET2" EVENT TREE (FIGURE B-5)

This event tree is a continuation of the "MSL-ET" event tree. The following linkage rules are used to substitute the values for additional events and processes that initiate the formation of potentially critical configurations. The events and processes defined by this event tree include waste package failure, bathtub configuration formation, waste package overfill, as well as events necessary to define and evaluate the criticality potential of a dry waste package configuration.

```
|
||
| SET VARIABLES
|
DOE-SHORT = (init(WP06-DOE1-SHORT) + init(WP08-DOE2-SHORT) +
             init(WP09-DOE3-SHORT) + init(WP12-DOE4-SHORT) +
             init(WP14-DOE5-SHORT) + init(WP17-DOE7-SHORT) +
             init(WP19-DOE8-SHORT) + init(WP21-DOE9-SHORT));
|
DOE-LONG = (init(WP07-DOE1-LONG) + init(WP10-DOE3-LONG) +
            init(WP13-DOE4-LONG) + init(WP15-DOE5-LONG) +
            init(WP16-DOE6-LONG) + init(WP18-DOE7-LONG) +
            init(WP20-DOE8-LONG) + init(WP22-DOE9-LONG));
|
DOE-MCO  = init(WP11-DOE3-MCO);
|
DOE-NAM1 = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG)  +
            init(WP08-DOE2-SHORT) + init(WP17-DOE7-SHORT) +
            init(WP18-DOE7-LONG));
|
DOE-NAM2 = (init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG));
|
DOE-NAM3 = (init(WP19-DOE8-SHORT) + init(WP20-DOE8-LONG));
|
DOE-NONAM = (init(WP09-DOE3-SHORT) + init(WP10-DOE3-LONG)  +
             init(WP11-DOE3-MCO)   + init(WP12-DOE4-SHORT) +
             init(WP13-DOE4-LONG)  + init(WP16-DOE6-LONG)  +
             init(WP21-DOE9-SHORT) + init(WP22-DOE9-LONG));
|
DOE-MISLOAD = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG));
|
DOE-NOMIS = (init(WP08-DOE2-SHORT) + init(WP09-DOE3-SHORT) +
             init(WP10-DOE3-LONG)  + init(WP11-DOE3-MCO)   +
             init(WP12-DOE4-SHORT) + init(WP13-DOE4-LONG)  +
             init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG)  +
             init(WP16-DOE6-LONG)  + init(WP17-DOE7-SHORT) +
             init(WP18-DOE7-LONG)  + init(WP19-DOE8-SHORT) +
             init(WP20-DOE8-LONG)  + init(WP21-DOE9-SHORT) +
             init(WP22-DOE9-LONG));
|
|
| Top Event MS-IC-3A
| probability of waste package failure
|
if (/BASE-CASE * (/MS-IC-1A + /MS-IC-2)) then
|
| for base case with no seepage or no drip shield failure scenarios
```

```
| 10% waste packages have diffusive flowpath due to deliquesence
| induced localized corrosion
|
 /MS-IC-3A    = MS-IC-3A-D1;
  MS-IC-3A[1] = MS-IC-3A-D1;
  MS-IC-3A[2] = MS-IC-3A-0;
|
elsif ((/SEIS-GROUND + ~SEIS-DAMAGE) * (/MS-IC-1A + /MS-IC-2)) then
|
| for seismic event with no seepage or no drip shield failure
| 100% diffusive flowpath due to ground motion induced damage
|
 /MS-IC-3A    = MS-IC-3A-D3;
  MS-IC-3A[1] = MS-IC-3A-D3;
  MS-IC-3A[2] = MS-IC-3A-0;
|
elsif (SEIS-FAULT-1 * ~/MS-IC-1A) then
|
| for seismic faulting with seepage scenarios
| 100% of impacted waste packages have advective flowpath
|
 /MS-IC-3A    = MS-IC-3A-A1;
  MS-IC-3A[1] = MS-IC-3A-0;
  MS-IC-3A[2] = MS-IC-3A-A1;
|
endif;
|
| Top Event MS-IC-3B
| probability of bathtub formation
|
if SEISMIC-EVENT then
|
| for all seismic events resulting in waste package advective flow path
|
 /MS-IC-3B = MS-IC-3B-1;
  MS-IC-3B = MS-IC-3B-1;
|
else
|
| all other cases
|
 /MS-IC-3B = MS-IC-3B-0;
  MS-IC-3B = MS-IC-3B-0;
|
endif;
|
| Top Event MS-IC-4
| probability of overfilling waste package
|
| for 21-PWR Absorber Plate Waste Package
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * init(WP01-21-PWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-21AP;
```

```
  MS-IC-4[1] = MS-IC-4-SE-LL-21AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1  * DRIFT-ZONE * MS-IC-1A[2] * init(WP01-21-PWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-ML-21AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-21AP;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * init(WP01-21-PWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-21AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UL-21AP;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * init(WP01-21-PWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LNL-21AP;
  MS-IC-4[1] = MS-IC-4-SE-LNL-21AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * init(WP01-21-PWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-21AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-21AP;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * init(WP01-21-PWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-21AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-21AP;
|
endif;
|
| for 21-PWR Control Rod Waste Package Type
```

```
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * init(WP02-21-PWR-CR)) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-21CR;
  MS-IC-4[1] = MS-IC-4-SE-LL-21CR;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[2] * init(WP02-21-PWR-CR)) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-ML-21CR;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-21CR;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * init(WP02-21-PWR-CR)) then
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-21CR;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UL-21CR;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * init(WP02-21-PWR-CR)) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LNL-21CR;
  MS-IC-4[1] = MS-IC-4-SE-LNL-21CR;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * init(WP02-21-PWR-CR)) then
|
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-21CR;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-21CR;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * init(WP02-21-PWR-CR)) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-21CR;
```

```
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-21CR;
|
endif;
|
| for 12-PWR Absorber Plate Waste Package Type
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * init(WP03-12-PWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-12AP;
  MS-IC-4[1] = MS-IC-4-SE-LL-12AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[2] * init(WP03-12-PWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-ML-12AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-12AP;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * init(WP03-12-PWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-12AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UL-12AP;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * init(WP03-12-PWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LNL-12AP;
  MS-IC-4[1] = MS-IC-4-SE-LNL-12AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * init(WP03-12-PWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-12AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-12AP;
  MS-IC-4[3] = MS-IC-4-0;
```

```
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * init(WP03-12-PWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-12AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-12AP;
|
endif;
|
| for 24-BWR Absorber Plate Waste Package Type
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * init(WP04-24-BWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-24AP;
  MS-IC-4[1] = MS-IC-4-SE-LL-24AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[2] * init(WP04-24-BWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-ML-24AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-24AP;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * init(WP04-24-BWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-24AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UL-24AP;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * init(WP04-24-BWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LNL-24AP;
  MS-IC-4[1] = MS-IC-4-SE-LNL-24AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * init(WP04-24-BWR-AP)) then
|
```

```
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-24AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-24AP;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * init(WP04-24-BWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-24AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-24AP;
|
endif;
|
| for 44-BWR Absorber Plate Waste Package Type
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * init(WP05-44-BWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-44AP;
  MS-IC-4[1] = MS-IC-4-SE-LL-44AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[2] * init(WP05-44-BWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-ML-44AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-44AP;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * init(WP05-44-BWR-AP)) then
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-44AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UL-44AP;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * init(WP05-44-BWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
```

```
 /MS-IC-4    = MS-IC-4-SE-LNL-44AP;
  MS-IC-4[1] = MS-IC-4-SE-LNL-44AP;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * init(WP05-44-BWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-44AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-44AP;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * init(WP05-44-BWR-AP)) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-44AP;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-44AP;
|
endif;
|
| for DOE SNF Short Waste Package Type
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * DOE-SHORT) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-DOES;
  MS-IC-4[1] = MS-IC-4-SE-LL-DOES;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[2] * DOE-SHORT) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-ML-DOES;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-DOES;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * DOE-SHORT) then
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-DOES;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
```

```
  MS-IC-4[3] = MS-IC-4-SE-UL-DOES;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * DOE-SHORT) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LNL-DOES;
  MS-IC-4[1] = MS-IC-4-SE-LNL-DOES;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * DOE-SHORT) then
|
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-DOES;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-DOES;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * DOE-SHORT) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-DOES;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-DOES;
|
endif;
|
| for DOE SNF LONG Waste Package Type
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * DOE-LONG) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-DOEL;
  MS-IC-4[1] = MS-IC-4-SE-LL-DOEL;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[2] * DOE-LONG) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-ML-DOEL;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-DOEL;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * DOE-LONG) then
```

```
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-DOEL;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UL-DOEL;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * DOE-LONG) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LNL-DOEL;
  MS-IC-4[1] = MS-IC-4-SE-LNL-DOEL;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * DOE-LONG) then
|
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-DOEL;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-DOEL;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * DOE-LONG) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-DOEL;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-DOEL;
|
endif;
|
| for DOE SNF MCO Waste Package Type
|
if (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[1] * DOE-MCO) then
|
| for seismic faulting event, lithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LL-DOEM;
  MS-IC-4[1] = MS-IC-4-SE-LL-DOEM;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[2] * DOE-MCO) then
|
| for seismic faulting event, lithophysal zone,
| mean seepage scenario
```

```
|
 /MS-IC-4    = MS-IC-4-SE-ML-DOEM;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-ML-DOEM;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * DRIFT-ZONE * MS-IC-1A[3] * DOE-MCO) then
|
| for seismic faulting event, lithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UL-DOEM;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UL-DOEM;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[1] * DOE-MCO) then
|
| for seismic faulting event, nonlithophysal zone,
| lower-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-LNL-DOEM;
  MS-IC-4[1] = MS-IC-4-SE-LNL-DOEM;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[2] * DOE-MCO) then
|
| for seismic faulting event, nonlithophysal zone,
| mean seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-MNL-DOEM;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-SE-MNL-DOEM;
  MS-IC-4[3] = MS-IC-4-0;
|
elsif (SEIS-FAULT-1 * /DRIFT-ZONE * MS-IC-1A[3] * DOE-MCO) then
|
| for seismic faulting event, nonlithophysal zone,
| upper-bound seepage scenario
|
 /MS-IC-4    = MS-IC-4-SE-UNL-DOEM;
  MS-IC-4[1] = MS-IC-4-0;
  MS-IC-4[2] = MS-IC-4-0;
  MS-IC-4[3] = MS-IC-4-SE-UNL-DOEM;
|
endif;
|
|
| Top Event NA-MISLOAD
| probability of neutron absorber misload
|
if init(WP01-21-PWR-AP) then
|
| for the 21-PWR Absorber Plate Waste Package
|
 /NA-MISLOAD = NA-MISLOAD-21AP;
```

```
  NA-MISLOAD = NA-MISLOAD-21AP;
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
 /NA-MISLOAD = NA-MISLOAD-21CR;
  NA-MISLOAD = NA-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP04-24-BWR-AP) +
       init(WP05-44-BWR-AP) + DOE-NAM1)then
|
| for the 12-PWR, 24-BWR, and 44-BWR Absorber Plate Waste Packages
| and FFTF, TRIGA, and Aluminum Based DOE SNF waste forms
|
 /NA-MISLOAD = NA-MISLOAD-12AP;
  NA-MISLOAD = NA-MISLOAD-12AP;
|
elsif DOE-NAM2 then
|
| for Shippingport LWBR DOE SNF waste form
|
 /NA-MISLOAD = NA-MISLOAD-DOE-NAM2;
  NA-MISLOAD = NA-MISLOAD-DOE-NAM2;
|
elsif DOE-NAM3 then
|
| for Enrico Fermi DOE SNF waste form
|
 /NA-MISLOAD = NA-MISLOAD-DOE-NAM3;
  NA-MISLOAD = NA-MISLOAD-DOE-NAM3;
|
elsif DOE-NONAM then
|
| for the Fort St. Vrain, N Reactor, Shippingport PWR, and TMI II
| DOE SNF waste forms
|
 /NA-MISLOAD = NA-MISLOAD-DOE-NONAM;
  NA-MISLOAD = NA-MISLOAD-DOE-NONAM;
|
endif;
|
|
| Top Event WF-MISLOAD
| probability of misloading waste form into waste package / canister
|
if init(WP01-21-PWR-AP) then
|
| for the 21-PWR Absorber Plate Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21AP;
  WF-MISLOAD = WF-MISLOAD-21AP;
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
```

```
 /WF-MISLOAD = WF-MISLOAD-21CR;
  WF-MISLOAD = WF-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP05-44-BWR-AP) +
       init(WP04-24-BWR-AP) + DOE-NOMIS) then
|
| misload probability for 12-PWR and 24-BWR Absorber Plate and the
| Aluminum Based, Enrico Fermi, Fort St. Vrain, N Reactor, Shippingport PWR,
| Shippingport LWBR, TMI II and TRIGA DOE SNF waste forms
|
 /WF-MISLOAD = WF-MISLOAD-12AP;
  WF-MISLOAD = WF-MISLOAD-12AP;
|
elsif DOE-MISLOAD then
|
| misload probability for the FFTF DOE SNF waste form
|
 /WF-MISLOAD = WF-MISLOAD-DOE;
  WF-MISLOAD = WF-MISLOAD-DOE;
|
endif;
|
|
| Top Event CRIT-POT-WF
| criticality potential of configuration
|
if (MS-IC-3A[1]) then
|
| if diffusive waste package failures (dry configurations)
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
endif;
```

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B.6 LINKAGE RULES FOR THE "CONFIG-BATH" EVENT TREE (FIGURE B-6)

The following linkage rules are used to substitute the values for the events and processes that define the formation of potentially critical configurations for a waste package bathtub configuration of the "CONFIG-BATH" event tree.

```
|
| SET VARIABLES
|
|
DOE-MISLOAD = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG));
|
DOE-NOMIS = (init(WP08-DOE2-SHORT) + init(WP09-DOE3-SHORT) +
             init(WP10-DOE3-LONG)  + init(WP11-DOE3-MCO)   +
             init(WP12-DOE4-SHORT) + init(WP13-DOE4-LONG)  +
             init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG)  +
             init(WP16-DOE6-LONG)  + init(WP17-DOE7-SHORT) +
             init(WP18-DOE7-LONG)  + init(WP19-DOE8-SHORT) +
             init(WP20-DOE8-LONG)  + init(WP21-DOE9-SHORT) +
             init(WP22-DOE9-LONG));
|
|
if always then
|
| Top Event CONFIG-SCEN
| evaluate all success branches
|
 /CONFIG-SCEN    = MS-IC-TOP-NO-0;
  CONFIG-SCEN[1] = MS-IC-TOP-YES-1;
  CONFIG-SCEN[2] = MS-IC-TOP-YES-1;
  CONFIG-SCEN[3] = MS-IC-TOP-YES-1;
|
|
| Top Event MS-IC-6
| evaluate all success branches
|
 /MS-IC-6    = MS-IC-TOP-NO-0;
  MS-IC-6[1] = MS-IC-TOP-YES-1;
  MS-IC-6[2] = MS-IC-TOP-YES-1;
  MS-IC-6[3] = MS-IC-TOP-YES-1;
  MS-IC-6[4] = MS-IC-TOP-YES-1;
|
|
| Top Event MS-IC-7
| waste package internals do not degrade at same rate as waste form
|
 /MS-IC-7 = MS-IC-TOP-NO-1;
  MS-IC-7 = MS-IC-TOP-YES-0;
|
|
| Top Event MS-IC-8
| waste package internals do not degrade faster than waste form
|
 /MS-IC-8 = MS-IC-TOP-NO-1;
  MS-IC-8 = MS-IC-TOP-YES-0;
|
```

```
|
| Top Event MS-IC-9
| waste form does degrade in place
|
 /MS-IC-9 = MS-IC-9-1;
  MS-IC-9 = MS-IC-9-1;
|
| Top Event MS-IC-10
| waste package internals do not degrade during performance period
|
 /MS-IC-10 = MS-IC-TOP-NO-1;
  MS-IC-10 = MS-IC-TOP-YES-0;
|
endif;
|
| Top Event MS-IC-11
| degraded waste form is mobilized, neutron absorber separation
|
if /MS-IC-4 then
|
| if waste package does not fill
|
  /MS-IC-11    = MS-IC-11-0;
   MS-IC-11[1] = MS-IC-11-1;
   MS-IC-11[2] = MS-IC-11-2A;
|
 elsif ( MS-IC-4[1] +  MS-IC-4[2] +  MS-IC-4[3]) then
|
| if waste package overfills - MS-IC-4[1] or MS-IC-4[2] or MS-IC-4[3]
|
  /MS-IC-11    = MS-IC-11-0;
   MS-IC-11[1] = MS-IC-11-1;
   MS-IC-11[2] = MS-IC-11-2B;
|
endif;
|
|
| Top Event MS-IC-12
| waste package bottom does not fail during performace period
|
if always then
|
 /MS-IC-12 = MS-IC-TOP-NO-0;
  MS-IC-12 = MS-IC-TOP-YES-1;
|
endif;
|
|
| Top Event WF-MISLOAD
| probability of misloading waste form into waste package / canister
|
if init(WP01-21-PWR-AP) then
|
| for the 21-PWR Absorber Plate Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21AP;
  WF-MISLOAD = WF-MISLOAD-21AP;
```

```
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21CR;
  WF-MISLOAD = WF-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP05-44-BWR-AP) +
       init(WP04-24-BWR-AP) + DOE-NOMIS) then
|
| misload probability for 12-PWR and 24-BWR Absorber Plate and the
| Aluminum Based, Enrico Fermi, Fort St. Vrain, N Reactor, Shippingport PWR,
| Shippingport LWBR, TMI II and TRIGA DOE SNF waste forms
|
 /WF-MISLOAD = WF-MISLOAD-12AP;
  WF-MISLOAD = WF-MISLOAD-12AP;
|
elsif DOE-MISLOAD then
|
| misload probability for the FFTF DOE SNF waste form
|
 /WF-MISLOAD = WF-MISLOAD-DOE;
  WF-MISLOAD = WF-MISLOAD-DOE;
|
endif;
|
|
| Top Event CRIT-POT-WF
| criticality potential of configuration
|
| for configuration classes IP-1A and IP-1B without any type of misload
|
if (/NA-MISLOAD * /WF-MISLOAD * (MS-IC-6[1] + MS-IC-6[2])) then
|
| for no waste package misload
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
elsif ((NA-MISLOAD + (WF-MISLOAD * DOE-MISLOAD)) *
       (MS-IC-6[1] + MS-IC-6[2])) then
|
| for waste package neutron absorber material or DOE SNF misloads
|
 /CRIT-POT-WF = CRIT-POT-WF-YES;
  CRIT-POT-WF = CRIT-POT-WF-YES;
|
elsif (WF-MISLOAD * /NA-MISLOAD * (MS-IC-6[1] + MS-IC-6[2]) *
       (init(WP01-21-PWR-AP) + init(WP02-21-PWR-CR))) then
|
| for waste package waste form 21-PWR misloads only
|
 /CRIT-POT-WF = CRIT-POT-WF-MISL;
  CRIT-POT-WF = CRIT-POT-WF-MISL;
|
endif;
```

B.7 LINKAGE RULES FOR THE "CONFIG-IP3" EVENT TREE (FIGURE B-9)

The following linkage rules are used to substitute the values for the events and processes that define the formation of configuration class IP-3 of the "CONFIG-IP3" event tree.

```
|
| SET VARIABLES
|
|
DOE-MISLOAD = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG));
|
DOE-NOMIS = (init(WP08-DOE2-SHORT) + init(WP09-DOE3-SHORT) +
             init(WP10-DOE3-LONG)  + init(WP11-DOE3-MCO)   +
             init(WP12-DOE4-SHORT) + init(WP13-DOE4-LONG)  +
             init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG)  +
             init(WP16-DOE6-LONG)  + init(WP17-DOE7-SHORT) +
             init(WP18-DOE7-LONG)  + init(WP19-DOE8-SHORT) +
             init(WP20-DOE8-LONG)  + init(WP21-DOE9-SHORT) +
             init(WP22-DOE9-LONG));
|
|
if always then
|
| Top Event CONFIG-SCEN
|
 /CONFIG-SCEN    = MS-IC-TOP-NO-0;
  CONFIG-SCEN[1] = MS-IC-TOP-YES-1;
  CONFIG-SCEN[2] = MS-IC-TOP-YES-1;
|
| Top Event MS-IC-16
|
 /MS-IC-16    = MS-IC-16-0;
  MS-IC-16[1] = MS-IC-16-1;
  MS-IC-16[2] = MS-IC-16-2;
  MS-IC-16[3] = MS-IC-16-3;
|
| Top Event MS-IC-17
|
 /MS-IC-17 = MS-IC-TOP-NO-0;
  MS-IC-17 = MS-IC-TOP-YES-1;
|
| Top Event MS-IC-18
|
 /MS-IC-18 = MS-IC-18-0;
  MS-IC-18 = MS-IC-18-1;
|
| Top Event MS-IC-22
|
 /MS-IC-22    = MS-IC-TOP-NO-0;
  MS-IC-22[1] = MS-IC-22-1;
  MS-IC-22[2] = MS-IC-22-2;
  MS-IC-22[3] = MS-IC-22-3;
|
| Top Event MS-IC-23
|
```

```
 /MS-IC-23 = MS-IC-TOP-NO-0;
  MS-IC-23 = MS-IC-TOP-YES-1;
|
| Top Event MS-IC-24
|
 /MS-IC-24 = MS-IC-TOP-NO-0;
  MS-IC-24 = MS-IC-TOP-YES-1;
|
endif;
|
|
| Top Event WF-MISLOAD
| probability of misloading waste form into waste package / canister
|
if init(WP01-21-PWR-AP) then
|
| for the 21-PWR Absorber Plate Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21AP;
  WF-MISLOAD = WF-MISLOAD-21AP;
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21CR;
  WF-MISLOAD = WF-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP05-44-BWR-AP) +
       init(WP04-24-BWR-AP) + DOE-NOMIS) then
|
| misload probability for 12-PWR and 24-BWR Absorber Plate and the
| Aluminum Based, Enrico Fermi, Fort St. Vrain, N Reactor, Shippingport PWR,
| Shippingport LWBR, TMI II and TRIGA DOE SNF waste forms
|
 /WF-MISLOAD = WF-MISLOAD-12AP;
  WF-MISLOAD = WF-MISLOAD-12AP;
|
elsif DOE-MISLOAD then
|
| misload probability for the FFTF DOE SNF waste form
|
 /WF-MISLOAD = WF-MISLOAD-DOE;
  WF-MISLOAD = WF-MISLOAD-DOE;
|
endif;
|
|
| Top Event CRIT-POT-WF
| criticality potential of configuration
|
| for configuration classes IP-3A, IP-3B, and IP-3C without any type of
misload
|
if (/NA-MISLOAD * /WF-MISLOAD * (MS-IC-16[1] + MS-IC-18 + MS-IC-22[1])) then
|
| for no waste package misload
```

```
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
elsif ((NA-MISLOAD + (WF-MISLOAD * DOE-MISLOAD)) *
       (MS-IC-16[1] + MS-IC-18 + MS-IC-22[1])) then
|
| for waste package neutron absorber material or DOE SNF misload
|
 /CRIT-POT-WF = CRIT-POT-WF-YES;
  CRIT-POT-WF = CRIT-POT-WF-YES;
|
elsif (WF-MISLOAD * /NA-MISLOAD * (MS-IC-16[1] + MS-IC-18 + MS-IC-22[1]) *
       (init(WP01-21-PWR-AP) + init(WP02-21-PWR-CR))) then
|
| for waste package waste form 21-PWR misloads only
|
 /CRIT-POT-WF = CRIT-POT-WF-MISL;
  CRIT-POT-WF = CRIT-POT-WF-MISL;
|
endif;
```

B.8 LINKAGE RULES FOR THE "CONFIG-IP4-A" EVENT TREE (FIGURE B-11)

The following linkage rules are used to substitute the values for the events and processes that define the formation of configuration class IP-4 of the "CONFIG-IP4-A" event tree.

```
|
| SET VARIABLES
|
|
DOE-MISLOAD = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG));
|
DOE-NOMIS = (init(WP08-DOE2-SHORT) + init(WP09-DOE3-SHORT) +
             init(WP10-DOE3-LONG)  + init(WP11-DOE3-MCO)   +
             init(WP12-DOE4-SHORT) + init(WP13-DOE4-LONG)  +
             init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG)  +
             init(WP16-DOE6-LONG)  + init(WP17-DOE7-SHORT) +
             init(WP18-DOE7-LONG)  + init(WP19-DOE8-SHORT) +
             init(WP20-DOE8-LONG)  + init(WP21-DOE9-SHORT) +
             init(WP22-DOE9-LONG));
|
if always then
|
|
| Top Event CONFIG-SCEN
|
 /CONFIG-SCEN    = MS-IC-TOP-NO-0;
  CONFIG-SCEN[1] = MS-IC-TOP-YES-1;
  CONFIG-SCEN[2] = MS-IC-TOP-YES-1;
  CONFIG-SCEN[3] = MS-IC-TOP-YES-1;
|
| Top Event MS-IC-32
|
 /MS-IC-32 = MS-IC-TOP-NO-0;
  MS-IC-32 = MS-IC-32-1;
|
|
| Top Event MS-IC-33
|
 /MS-IC-33 = MS-IC-TOP-NO-0;
  MS-IC-33 = MS-IC-TOP-YES-1;
|
|
| Top Event MS-IC-34
|
 /MS-IC-34    = MS-IC-TOP-NO-0;
  MS-IC-34[1] = MS-IC-TOP-YES-0;
  MS-IC-34[2] = MS-IC-TOP-YES-1;
endif
|
|
| Top Event WF-MISLOAD
| probability of misloading waste form into waste package / canister
|
if init(WP01-21-PWR-AP) then
|
```

```
| for the 21-PWR Absorber Plate Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21AP;
  WF-MISLOAD = WF-MISLOAD-21AP;
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21CR;
  WF-MISLOAD = WF-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP05-44-BWR-AP) +
       init(WP04-24-BWR-AP) + DOE-NOMIS) then
|
| misload probability for 12-PWR and 24-BWR Absorber Plate and the
| Aluminum Based, Enrico Fermi, Fort St. Vrain, N Reactor, Shippingport PWR,
| Shippingport LWBR, TMI II and TRIGA DOE SNF waste forms
|
 /WF-MISLOAD = WF-MISLOAD-12AP;
  WF-MISLOAD = WF-MISLOAD-12AP;
|
elsif DOE-MISLOAD then
|
| misload probability for the FFTF DOE SNF waste form
|
 /WF-MISLOAD = WF-MISLOAD-DOE;
  WF-MISLOAD = WF-MISLOAD-DOE;
|
endif;
|
|
| Top Event CRIT-POT-WF
| criticality potential of configuration
|
| for configuration classes IP-4A and IP-4B without any type of misload
|
if (/NA-MISLOAD * /WF-MISLOAD * (MS-IC-32 + MS-IC-34[1])) then
|
| for no waste package misload
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
elsif ((NA-MISLOAD + (WF-MISLOAD * DOE-MISLOAD)) *
       (MS-IC-32 + MS-IC-34[1])) then
|
| for waste package neutron absorber material or DOE SNF misload
|
 /CRIT-POT-WF = CRIT-POT-WF-YES;
  CRIT-POT-WF = CRIT-POT-WF-YES;
|
elsif (WF-MISLOAD * /NA-MISLOAD * (MS-IC-32 + MS-IC-34[1]) *
       (init(WP01-21-PWR-AP) + init(WP02-21-PWR-CR))) then
|
| for waste package waste form 21-PWR misloads only
|
```

```
 /CRIT-POT-WF = CRIT-POT-WF-MISL;
  CRIT-POT-WF = CRIT-POT-WF-MISL;
|
endif;
```

B.9 LINKAGE RULES FOR THE “CONFIG-IP5-B” EVENT TREE (FIGURE B-12)

The following linkage rules are used to substitute the values for the events and processes that define the formation of configuration class IP-5 of the “CONFIG-IP5-B” event tree.

```
|
if always then
|
| Top Event MS-IC-35
|
 /MS-IC-35    = MS-IC-TOP-NO-0;
  MS-IC-35[1] = MS-IC-TOP-YES-0;
  MS-IC-35[2] = MS-IC-TOP-YES-1;
|
endif;
```

B.10 LINKAGE RULES FOR THE “CONFIG-NF-F” EVENT TREE (FIGURE B-14)

The following linkage rules are used to substitute the values for the events and processes that initiate the formation of near-field configuration classes of the “CONFIG-NF-F” event tree.

```
|
| for seismic and igneous disruptive events
|
if (SEISMIC-EVENT + IGNEOUS-EVENT) then
|
| Top Event CONFIG-SCEN
| direct processing of near-field configuration classes NF-1, NF-2, & NF-3
|
 /CONFIG-SCEN    = MS-IC-TOP-NO-0;
  CONFIG-SCEN[1] = MS-IC-TOP-YES-1;
  CONFIG-SCEN[1] = MS-IC-TOP-YES-1;
  CONFIG-SCEN[1] = MS-IC-TOP-YES-1;
|
| Top Event MS-NF-6
| initiate processing of near-field configuration class NF-1
|
 /MS-NF-6 = MS-IC-TOP-NO-0;
  MS-NF-6 = MS-IC-TOP-YES-1;
|
| Top Event MS-NF-8
| initiate processing of near-field configuration class NF-3
|
 /MS-NF-8 = MS-IC-TOP-NO-0;
  MS-NF-8 = MS-IC-TOP-YES-1;
|
endif;
|
|
| Top Event MS-NF-7
|
if MS-IC-12 + IG-FM-TRANSPT then
|
| initiate processing of near-field configuration class NF-2 only
| if bottom waste package failure or igneous event occurs
|
 /MS-NF-7 = MS-IC-TOP-NO-0;
  MS-NF-7 = MS-IC-TOP-YES-1;
|
else
|
 /MS-NF-7 = MS-IC-TOP-NO-1;
  MS-NF-7 = MS-IC-TOP-YES-0;
|
endif;
```

B.11 LINKAGE RULES FOR THE “CONFIG-NF1” EVENT TREE (FIGURE B-15)

The following linkage rules are used to substitute the values for the events and processes that define the formation of near-field configuration class NF-1 of the “CONFIG-NF1” event tree.

```
|
| Top Event CONFIG-SCEN
| direct processing of near-field configuration subclasses NF-1A,
| NF-1B and NF-1C
|
if (SEISMIC-EVENT + IGNEOUS-EVENT) then
|
| for seismic and igneous disruptive events
|
 /MS-NF-9    = MS-NF-TOP-NO-0;
  MS-NF-9[1] = MS-NF-TOP-YES-1;
  MS-NF-9[2] = MS-NF-TOP-YES-1;
  MS-NF-9[3] = MS-NF-TOP-YES-1;
  MS-NF-9[4] = MS-NF-TOP-YES-1;
|
endif;
|
| for seismic disruptive events only
|
if SEISMIC-EVENT then
|
| Top Event MS-NF-10
| initiate processing of near-field configuration subclass NF-1A
|
 /MS-NF-10 = MS-NF-TOP-NO-0;
  MS-NF-10 = MS-NF-10-1;
|
| Top Event MS-NF-11
| initiate processing of near-field configuration subclass NF-1B
|
 /MS-NF-11 = MS-NF-TOP-NO-0;
  MS-NF-11 = MS-NF-11-1;
|
| Top Event MS-NF-10
| initiate processing of near-field configuration subclass NF-1C
|
 /MS-NF-12 = MS-NF-TOP-NO-0;
  MS-NF-12 = MS-NF-12-1;
|
endif;
|
| Top Event CRIT-POT-WF
| criticality potential of near-field configurations
|
if (MS-NF-10 + MS-NF-11 + MS-NF-12) then
|
| for near-field configuration subclasses NF-1A, NF-1B, & NF-1C
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
```

```
|
endif;
|
| for igneous disruptive events only
|
if IGNEOUS-EVENT then
|
| Top Event MS-NF-10
| initiate processing of near-field configuration subclass NF-1A
|
 /MS-NF-10 = MS-NF-TOP-NO-1;
  MS-NF-10 = MS-NF-TOP-YES-0;
|
| Top Event MS-NF-11
| initiate processing of near-field configuration subclass NF-1B
|
 /MS-NF-11 = MS-NF-TOP-NO-1;
  MS-NF-11 = MS-NF-TOP-YES-0;
|
| Top Event MS-NF-10
| initiate processing of near-field configuration subclass NF-1C
|
 /MS-NF-12 = MS-NF-TOP-NO-1;
  MS-NF-12 = MS-NF-TOP-YES-0;
|
endif;
```

B.12 LINKAGE RULES FOR THE "CONFIG-NF2" EVENT TREE (FIGURE B-16)

The following linkage rules are used to substitute the values for the events and processes that define the formation of near-field configuration class NF-2 of the "CONFIG-NF2" event tree.

```
|
| for seismic disruptive events
|
if SEISMIC-EVENT then
|
| Top Event MS-NF-13
| initiate evaluation of near-field configuration subclass NF-2A
|
 /MS-NF-13 = MS-NF-TOP-NO-0;
  MS-NF-13 = MS-NF-13-1;
|
| Top Event MS-NF-14
| neutron absorber and fissile materials separate
|
 /MS-NF-14 = MS-NF-TOP-NO-1;
  MS-NF-14 = MS-NF-TOP-YES-1;
|
endif;
|
| Top Event CRIT-POT-WF
| criticality potential of near-field configuration subclass NF-2A
|
if MS-NF-13 then
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
endif;
|
| for igneous disruptive events
|
if IGNEOUS-EVENT then
|
| Top Event MS-NF-13
| initiate evaluation of near-field configuration subclass NF-2A
|
 /MS-NF-13 = MS-IC-TOP-NO-1;
  MS-NF-13 = MS-IC-TOP-YES-0;
|
endif;
```

B.13 LINKAGE RULES FOR THE "CONFIG-NF3" EVENT TREE (FIGURE B-17)

The following linkage rules are used to substitute the values for the events and processes that define the formation of near-field configuration class NF-3 of the "CONFIG-NF3" event tree.

```
|
| Top Event MS-NF-16
| directs the evaluation of near-field configuration subclases NF-3A,
| NF-3B, and NF-3C
|
if SEISMIC-EVENT + IGNEOUS-EVENT then
|
| for seismic and igneous disruptive events
|
 /CONFIG-SCEN = MS-NF-TOP-NO-0;
  CONFIG-SCEN[1] = MS-NF-TOP-YES-1;
  CONFIG-SCEN[2] = MS-NF-TOP-YES-1;
|
endif;
|
| for seismic disruptive events
|
if SEISMIC-EVENT then
|
| Top Event MS-NF-15
| initiate evaluation of near-field configuration subclass NF-3A
|
 /MS-NF-15 = MS-NF-TOP-NO-0;
  MS-NF-15 = MS-NF-15-1;
|
| Top Event MS-NF-16
| initiate evaluation of near-field configuration subclasses
| NF-3B and NF-3C
|
 /MS-NF-16 = MS-NF-TOP-NO-0;
  MS-NF-16[1] = MS-NF-TOP-YES-1;
  MS-NF-16[2] = MS-NF-TOP-YES-1;
|
| Top Event MS-NF-19
| degradation of invert material
|
 /MS-NF-19 = MS-NF-19-90;
  MS-NF-19 = MS-NF-19-90;
|
| Top Event MS-NF-17
| separation of neutron absorber and fissile material containing colloids
|
 /MS-NF-17 = MS-NF-TOP-NO-1;
  MS-NF-17 = MS-NF-TOP-YES-1;
|
| Top Event MS-IC-18
| filtration and concentration of colloids
|
 /MS-NF-18 = MS-NF-TOP-NO-0;
  MS-NF-18 = MS-NF-TOP-YES-1;
```

```
|
endif;
|
| Top Event CRIT-POT-WF
| criticality potential of near-field configuration
| subclasses NF-3A, NF-3B, and NF-3C
|
if (MS-NF-15 + MS-NF-16[1]) then
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
endif;
|
| for igneous disuptive events
|
if IGNEOUS-EVENT then
|
| Top Event MS-NF-15
| initiate evaluation of near-field configuration subclass NF-3A
|
 /MS-NF-15 = MS-NF-TOP-NO-1;
  MS-NF-15 = MS-NF-TOP-YES-0;
|
| Top Event MS-NF-16
| initiate evaluation of near-field configuration subclasses
| NF-3B and NF-3C
|
 /MS-NF-16 = MS-NF-TOP-NO-0;
  MS-NF-16[1] = MS-NF-TOP-YES-1;
  MS-NF-16[2] = MS-NF-TOP-YES-1;
|
| Top Event MS-NF-19
| degradation of invert material
|
 /MS-NF-19 = MS-NF-19-90;
  MS-NF-19 = MS-NF-19-90;
|
| Top Event MS-NF-17
| separation of neutron absorber and fissile material containing colloids
|
 /MS-NF-17 = MS-NF-TOP-NO-1;
  MS-NF-17 = MS-NF-TOP-YES-0;
|
| Top Event MS-IC-18
| filtration and concentration of colloids
|
 /MS-NF-18 = MS-NF-TOP-NO-1;
  MS-NF-18 = MS-NF-TOP-YES-0;
|
endif;
```

B.14 LINKAGE RULES FOR THE “CONFIG-NF4” EVENT TREE (FIGURE B-18)

The following linkage rules are used to substitute the values for the events and processes that define the formation of near-field configuration class NF-4 of the “CONFIG-NF4” event tree.

```
|
| event tree accessed for base case, seismic and rock-fall disruptive events
|
| Top Event MS-NF-2
| initiation near-field configuration class NF-4
|
if always then
|
 /MS-NF-2 = MS-NF-TOP-NO-1;
  MS-NF-2 = MS-NF-TOP-YES-0;
|
endif;
|
| Top Event MS-NF-DD
| probability of dry diffusion accumulation in the invert
|
if always then
|
 /MS-NF-DD = MS-NF-TOP-NO-1;
  MS-NF-DD = MS-NF-TOP-YES-0;
|
endif;
```

B.15 LINKAGE RULES FOR THE "CONFIG-FF-J" EVENT TREE (FIGURE B-21)

The following linkage rules are used to substitute the values for the events and processes that define the formation of far-field configuration class FF-1 of the "CONFIG-FF-J" event tree.

```
|
| for seismic and igneous disrupt events
|
if (SEISMIC-EVENT + IGNEOUS-EVENT) then
|
| Top Event MS-FF-1
| transport of fissile material to the far-field - initiates the
| evaluation of far-field configuration class FF-1
|
 /MS-FF-1 = MS-FF-TOP-NO-0;
  MS-FF-1 = MS-FF-TOP-YES-1;
|
| Top Event MS-FF-2
| directs the evaluation of far-field configuration subclasses
| FF-1A, FF-1B, and FF-1C
|
 /MS-FF-2 = MS-IC-TOP-NO-0;
  MS-FF-2[1] = MS-IC-TOP-YES-1;
  MS-FF-2[2] = MS-IC-TOP-YES-1;
  MS-FF-2[3] = MS-IC-TOP-YES-1;
|
| Top Event MS-FF-3
| transport of fissile material to the water table - transfer to
| CONFIG-FF3 event tree for evaluation of far-field configuration
| class FF-3
|
 /MS-FF-3 = MS-IC-TOP-NO-0;
  MS-FF-3 = MS-IC-TOP-YES-1;
|
| Top Event MS-FF-11
| precipitation of fissile material in the unsaturated zone -
| far-field configuration subclass FF-1A
|
 /MS-FF-11 = MS-IC-TOP-NO-1;
  MS-FF-11 = MS-IC-TOP-YES-0;
|
| Top Event MS-FF-12
| transport of fissile materials to altered TSbv - initiates
| evaluation of far-field configuration subclasses FF-1B and FF-1C
|
 /MS-FF-12 = MS-IC-TOP-NO-0;
  MS-FF-12[1] = MS-IC-TOP-YES-1;
  MS-FF-12[2] = MS-IC-TOP-YES-1;
|
| Top Event MS-FF-13
| sorption of fissile material in clays and zeolites in the altered TSbv -
| far-field configuration subclass FF-1B
|
 /MS-FF-13 = MS-FF-TOP-NO-1;
  MS-FF-13 = MS-FF-TOP-YES-0;
```

```
|
| Top Event MS-FF-14
| accumulation of fissile material in topographical low above altered TSbv -
| far-field configuration subclass FF-1C
|
 /MS-FF-14 = MS-FF-TOP-NO-1;
  MS-FF-14 = MS-FF-TOP-YES-0;
|
endif;
```

B.16 LINKAGE RULES FOR THE "CONFIG-FF-K" EVENT TREE (FIGURE B-22)

The following linkage rules are used to substitute the values for the events and processes that define the formation of far-field configuration class FF-2 of the "CONFIG-FF-K" event tree.

```
|
| for seismic and igneous disruptive events
|
if SEISMIC-EVENT + IGNEOUS-EVENT then
|
| Top Event MS-FF-16
| transport of colloids to TSw - directs evaluation of far-field
| configuratin class FF-2
|
 /MS-FF-16 = MS-FF-TOP-NO-0;
  MS-FF-16 = MS-FF-TOP-YES-1;
|
| Top Event MS-FF-17
| separation of neutron absober and fissile materials - directs
| evaluation of far-field configuration subclasses FF-2A, FF-2B and FF-2C
|
 /MS-FF-17    = MS-FF-TOP-NO-0;
  MS-FF-17[1] = MS-FF-TOP-YES-1;
  MS-FF-17[2] = MS-FF-TOP-YES-1;
|
| Top Event MS-FF-18
| colloids trapped in dead-end fractures - far-field configuration
| subclass FF-2A
|
 /MS-FF-18 = MS-FF-TOP-NO-1;
  MS-FF-18 = MS-FF-TOP-YES-0;
|
| Top Event MS-FF-19
| transport of colloids to altered TSbv - initiates evaluation
| of far-field configuration subclasses FF-2B and FF-2C
|
 /MS-FF-19    = MS-FF-TOP-NO-0;
  MS-FF-19[1] = MS-FF-TOP-YES-1;
  MS-FF-19[2] = MS-FF-TOP-YES-1;
|
| Top Event MS-FF-20
| sorption of colloids on clays and zeolites in altered TSbv -
| far-field configuration subclass FF-2B
|
 /MS-FF-20 = MS-FF-TOP-NO-1;
  MS-FF-20 = MS-FF-TOP-YES-0;
|
| Top Event MS-FF-21
| filtration of colloids in topographic lows above altered TSbv -
| far-field configuration subclass FF-2C
|
 /MS-FF-21 = MS-FF-TOP-NO-1;
  MS-FF-21 = MS-FF-TOP-YES-0;
endif;
```

B.17 LINKAGE RULES FOR THE "CONFIG-FF3" EVENT TREE (FIGURE B-23)

The following linkage rules are used to substitute the values for the events and processes that define the formation of near-field configuration class FF-3 of the "CONFIG-FF3" event tree.

```
|
| for seismic and igneous disruptive events
|
if (SEISMIC-EVENT + IGNEOUS-EVENT) then
|
| Top Event CONFIG-SCEN
| directs the evaluation of far-field configuration class FF-3
|
 /CONFIG-SCEN    = MS-FF-TOP-NO-0;
  CONFIG-SCEN[1] = MS-FF-TOP-YES-1;
  CONFIG-SCEN[2] = MS-FF-TOP-YES-1;
  CONFIG-SCEN[3] = MS-FF-TOP-YES-1;
  CONFIG-SCEN[4] = MS-FF-TOP-YES-1;
  CONFIG-SCEN[5] = MS-FF-TOP-YES-1;
|
| Top Event MS-FF-4
| fissile material precipitates in upwell zone - far-field
| configuration subclass FF-3A
|
 /MS-FF-4 = MS-FF-TOP-NO-1;
  MS-FF-4 = MS-FF-TOP-YES-0;
|
| Top Event MS-FF-5
| containment plume mixes below redox front
|
 /MS-FF-5 = MS-FF-TOP-NO-0;
  MS-FF-5 = MS-FF-TOP-YES-1;
|
| Top Event MS-FF-6
| fissile material precipitiate below redox front - far-field
| configuration subclass FF-3B
|
 /MS-FF-6 = MS-FF-TOP-NO-1;
  MS-FF-6 = MS-FF-TOP-YES-0;
|
| Top Event MS-FF-7
| fissile material precipitates at reducing zone - far-field
| configuration subclass FF-3C
|
 /MS-FF-7 = MS-FF-TOP-NO-1;
  MS-FF-7 = MS-FF-TOP-YES-0;
|
| Top Event MS-FF-8
| fissile materials precipitate at pinchout of tuff aquifer -
| far-field configuration subclass FF-3D
|
 /MS-FF-8 = MS-FF-TOP-NO-1;
  MS-FF-8 = MS-FF-TOP-YES-0;
|
| Top Event MS-FF-9
```

```
| fissile materials transported to Franklin Lake
|
 /MS-FF-9 = MS-FF-TOP-NO-0;
  MS-FF-9 = MS-FF-TOP-YES-1;
|
| Top Event MS-FF-10
| fissile material precipitate in Franklin Lake - far-field
| configuration subclass FF-3E
|
 /MS-FF-10 = MS-FF-TOP-NO-0;
  MS-FF-10 = MS-FF-10-1;
|
endif;
|
| Top Event CRIT-POT-WF
| criticality potential of far-field configuration subclasses
| FF-3A, FF-3B, FF-3C, FF-3D, and FF-3E
|
if (MS-FF-4 + MS-FF-6 + MS-FF-7 + MS-FF-8 + MS-FF-10) then
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
endif;
```

B.18 LINKAGE RULES FOR THE “IGNEOUS” EVENT TREE (FIGURE B-24)

The following linkage rules are used to substitute the values for the events and processes that initiate the formation of igneous configurations of the “IGNEOUS” event tree.

```
|
| SET VARIABLES
|
DOE-NAM1 = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG)  +
            init(WP08-DOE2-SHORT) + init(WP17-DOE7-SHORT) +
            init(WP18-DOE7-LONG));
|
DOE-NAM2 = (init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG));
|
DOE-NAM3 = (init(WP19-DOE8-SHORT) + init(WP20-DOE8-LONG));
|
DOE-NONAM = (init(WP09-DOE3-SHORT) + init(WP10-DOE3-LONG)  +
             init(WP11-DOE3-MCO)   + init(WP12-DOE4-SHORT) +
             init(WP13-DOE4-LONG)  + init(WP16-DOE6-LONG)  +
             init(WP21-DOE9-SHORT) + init(WP22-DOE9-LONG));
|
|
| for igneous disruptive events only
|
if IGNEOUS-EVENT then
|
| Top Event IG-EVENT-TYPE
| type of igneous event
|
 /IG-EVENT-TYPE = IG-EVENT-TYPE-ERUP;
  IG-EVENT-TYPE = IG-EVENT-TYPE-INT;
|
| Top Event IG-WP-LOC
| initial waste package location
|
 /IG-WP-LOC = IG-TOP-NO-1;
  IG-WP-LOC = IG-TOP-YES-1;
|
endif;
|
|
| Top Event IG-WP-RELOC
| final waste package location - for eruptive scenario only for
| waste package beyond the conduit intersection point
|
if (/IG-EVENT-TYPE * IG-WP-LOC) then
|
 /IG-WP-RELOC = IG-TOP-NO-1;
  IG-WP-RELOC = IG-TOP-YES-0;
|
endif;
|
|
| Top Event NA-MISLOAD
| probability of neutron absorber misload
```

```
|
if init(WP01-21-PWR-AP) then
|
| for the 21-PWR Absorber Plate Waste Package
|
 /NA-MISLOAD = NA-MISLOAD-21AP;
  NA-MISLOAD = NA-MISLOAD-21AP;
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
 /NA-MISLOAD = NA-MISLOAD-21CR;
  NA-MISLOAD = NA-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP04-24-BWR-AP) +
       init(WP05-44-BWR-AP) + DOE-NAM1)then
|
| for the 12-PWR, 24-BWR, and 44-BWR Absorber Plate Waste Packages
| and FFTF, TRIGA, and Aluminum Based DOE SNF waste forms
|
 /NA-MISLOAD = NA-MISLOAD-12AP;
  NA-MISLOAD = NA-MISLOAD-12AP;
|
elsif DOE-NAM2 then
|
| for Shippingport LWBR DOE SNF waste form
|
 /NA-MISLOAD = NA-MISLOAD-DOE-NAM2;
  NA-MISLOAD = NA-MISLOAD-DOE-NAM2;
|
elsif DOE-NAM3 then
|
| for Enrico Fermi DOE SNF waste form
|
 /NA-MISLOAD = NA-MISLOAD-DOE-NAM3;
  NA-MISLOAD = NA-MISLOAD-DOE-NAM3;
|
elsif DOE-NONAM then
|
| for the Fort St. Vrain, N Reactor, Shippingport PWR, and TMI II
| DOE SNF waste forms
|
 /NA-MISLOAD = NA-MISLOAD-DOE-NONAM;
  NA-MISLOAD = NA-MISLOAD-DOE-NONAM;
|
endif;
```

B.19 LINKAGE RULES FOR THE “IG-ERUPTIVE” EVENT TREE (FIGURE B-25)

The following linkage rules are used to substitute the values for the events and processes that define the formation of igneous eruptive configuration classes IG-E1 through IG-E4 of the “IG-ERUPTIVE” event tree.

```
|
| SET VARIABLES
|
|
DOE-MISLOAD = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG));
|
DOE-NOMIS = (init(WP08-DOE2-SHORT) + init(WP09-DOE3-SHORT) +
             init(WP10-DOE3-LONG)  + init(WP11-DOE3-MCO)   +
             init(WP12-DOE4-SHORT) + init(WP13-DOE4-LONG)  +
             init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG)  +
             init(WP16-DOE6-LONG)  + init(WP17-DOE7-SHORT) +
             init(WP18-DOE7-LONG)  + init(WP19-DOE8-SHORT) +
             init(WP20-DOE8-LONG)  + init(WP21-DOE9-SHORT) +
             init(WP22-DOE9-LONG));
|
| for igneous disruptive events only - eruptive scenario for waste
| packages initially in the conduit or that are later sucked into conduit
|
if (IGNEOUS-EVENT * /IG-EVENT-TYPE * (/IG-WP-LOC + IG-WP-RELOC))  then
|
| Top Event IG-CONFIG
| waste package configuration on surface
|
 /IG-CONFIG = IG-CONFIG-0;
  IG-CONFIG = IG-TOP-YES-0;
|
|
| Top Event IG-RAINFALL
| probability of rainfall
|
 /IG-RAINFALL = IG-TOP-NO-0;
  IG-RAINFALL = IG-TOP-YES-1;
|
endif;
|
|
| TOP EVENT IG-FM-ACCUM
| fissile material accumulates after rainfall
|
if (IGNEOUS-EVENT * /IG-CONFIG * IG-RAINFALL) then
|
 /IG-FM-ACCUM = IG-FM-ACCUM-0;
  IG-FM-ACCUM = IG-TOP-YES-0;
|
endif;
|
|
| Top Event WF-MISLOAD
| probability of misloading waste form into waste package / canister
|
```

```
if init(WP01-21-PWR-AP) then
|
| for the 21-PWR Absorber Plate Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21AP;
  WF-MISLOAD = WF-MISLOAD-21AP;
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21CR;
  WF-MISLOAD = WF-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP05-44-BWR-AP) +
       init(WP04-24-BWR-AP) + DOE-NOMIS) then
|
| misload probability for 12-PWR and 24-BWR Absorber Plate and the
| Aluminum Based, Enrico Fermi, Fort St. Vrain, N Reactor, Shippingport PWR,
| Shippingport LWBR, TMI II and TRIGA DOE SNF waste forms
|
 /WF-MISLOAD = WF-MISLOAD-12AP;
  WF-MISLOAD = WF-MISLOAD-12AP;
|
elsif DOE-MISLOAD then
|
| misload probability for the FFTF DOE SNF waste form
|
 /WF-MISLOAD = WF-MISLOAD-DOE;
  WF-MISLOAD = WF-MISLOAD-DOE;
|
endif;
|
|
| Top Event CRIT-POT-WF
| criticality potential of igneous configuration
|
if (IG-FM-ACCUM + /WF-MISLOAD) then
|
| if fissile material accumulation and no misload, no criticality potential
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
elsif WF-MISLOAD then
|
| if waste package misloaded, criticality potential yes
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
endif;
|
|
| Top Event CRIT-POT-WF
|
if IG-FM-ACCUM then
```

```
|
| criticality potential of igneous configurations IG-E1 and IG-E3
| fissile material accumulation external to waste package,
| no criticality potential
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
elsif (IG-CONFIG * (NA-MISLOAD + (WF-MISLOAD * DOE-MISLOAD))) then
|
| criticality potential of igneous configurations IG-E2 and IG-E4
| igneous event, waste package not destroyed, neutron absorber material
| of DOE SNF misload
|
 /CRIT-POT-WF = CRIT-POT-WF-YES;
  CRIT-POT-WF = CRIT-POT-WF-YES;
|
elsif (IGNEOUS-EVENT * /IG-WP-DESTRYD * WF-MISLOAD * /NA-MISLOAD *
       (init(WP01-21-PWR-AP) + init(WP02-21-PWR-CR))*
       (init(WP01-21-PWR-AP) + init(WP02-21-PWR-CR))) then
|
| criticality potential of igneous configurations IG-E2 and IG-E4
| igneous event, waste package not destroyed, waste form 21-PWR misload only
|
 /CRIT-POT-WF = CRIT-POT-WF-MISL;
  CRIT-POT-WF = CRIT-POT-WF-MISL;
|
endif;
```

B.20 LINKAGE RULES FOR THE “IG-INTRUSIVE” EVENT TREE (FIGURE B-26)

The following linkage rules are used to substitute the values for the events and processes that define the formation of igneous intrusive configuration classes IG-I4, IG-I5, and IG-I6 of the “IG-INTRUSIVE” event tree.

```
|
| for igneous disruptive events only - intrusive scenario and
| eruptive scenario for waste packages beyond conduit that remain in drift
|
if (IGNEOUS-EVENT * (IG-EVENT-TYPE + /IG-WP-RELOC)) then
|
| Top Event IG-WP-DESTRYD
| probability that intrusive event will destroy waste package
|
 /IG-WP-DESTRYD = IG-WP-DESTRYD-0;
  IG-WP-DESTRYD = IG-TOP-YES-0;
|
| Top Event IG-WP-SLUMP
| probability of waste package slump
|
 /IG-WP-SLUMP    = IG-TOP-NO-0;
  IG-WP-SLUMP[1] = IG-TOP-YES-0;
  IG-WP-SLUMP[2] = IG-TOP-YES-1;
|
| Top Event IG-MAGMA-INT
| probability of magma intrusion into waste package
|
 /IG-MAGMA-INT = IG-TOP-NO-1;
  IG-MAGMA-INT = IG-TOP-YES-0;
|
endif;
|
|
| Top Event CRIT-POT-WF
| criticality potential of igneous configurations IG-I4, IG-I5, and
| IG-I6
|
if (IGNEOUS-EVENT * IG-WP-DESTRYD * /IG-FM-TRANSPT) then
|
| igneous event, waste package destroyed, fissile material not
| relocated to the near-field
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
endif;
```

B.21 LINKAGE RULES FOR THE “IG-INTRUSIVE2” EVENT TREE (FIGURE B-27)

The following linkage rules are used to substitute the values for the events and processes that define the formation of igneous intrusive configuration classes IG-I1, IG-I2, and IG-I3 of the “IG-INTRUSIVE2” event tree.

```
|
| SET VARIABLES
|
|
DOE-MISLOAD = (init(WP06-DOE1-SHORT) + init(WP07-DOE1-LONG));
|
DOE-NOMIS = (init(WP08-DOE2-SHORT) + init(WP09-DOE3-SHORT) +
             init(WP10-DOE3-LONG)  + init(WP11-DOE3-MCO)   +
             init(WP12-DOE4-SHORT) + init(WP13-DOE4-LONG)  +
             init(WP14-DOE5-SHORT) + init(WP15-DOE5-LONG)  +
             init(WP16-DOE6-LONG)  + init(WP17-DOE7-SHORT) +
             init(WP18-DOE7-LONG)  + init(WP19-DOE8-SHORT) +
             init(WP20-DOE8-LONG)  + init(WP21-DOE9-SHORT) +
             init(WP22-DOE9-LONG));
|
|
| for igneous disruptive events only - intrusive scenario, waste packages
| in drift, not destroyed, but slumped partially or completely
|
if always then
|
| Top Event IG-MAGMA-COOL
| evaluation before and after magma cooling
|
 /IG-MAGMA-COOL = IG-MAGMA-COOL-0;
  IG-MAGMA-COOL = IG-MAGMA-COOL-1;
|
| Top Event IG-MAGMA-FRAC
| probability that magma fractures after cooling
|
 /IG-MAGMA-FRAC = IG-TOP-NO-0;
  IG-MAGMA-FRAC = IG-MAGMA-FRAC-1;
|
| Top Event IG-BATHTUB
| probability of formation of bathtub configuration given seepage
| after magma cooling
|
 /IG-BATHTUB = IG-BATHTUB-0;
  IG-BATHTUB = IG-TOP-YES-0;
|
| Top Event IG-FM-TRANSPT
| probability of fissile material transport to the invert
|
 /IG-FM-TRANSPT = IG-FM-TRANSPT-0;
  IG-FM-TRANSPT = IG-FM-TRANSPT-1;
endif
|
|
| Top Event IG-SEEPAGE
| probability of no, lower-bound, mean, and upper-bound
```

```
| seepage scenarios
|
if (IGNEOUS-EVENT * IG-MAGMA-COOL * IG-MAGMA-FRAC * DRIFT-ZONE) then
|
| igneous event, magma cooled, lithophysal zone
|
 /IG-SEEPAGE    = IG-SEEPAGE-NWL;
  IG-SEEPAGE[1] = IG-SEEPAGE-LL;
  IG-SEEPAGE[2] = IG-SEEPAGE-ML;
  IG-SEEPAGE[3] = IG-SEEPAGE-UL;
|
elsif (IGNEOUS-EVENT * IG-MAGMA-COOL * IG-MAGMA-FRAC * /DRIFT-ZONE) then
|
| igneous event, magma cooled and fractured, nonlithophysal
|
 /IG-SEEPAGE    = IG-SEEPAGE-NWNL;
  IG-SEEPAGE[1] = IG-SEEPAGE-LNL;
  IG-SEEPAGE[2] = IG-SEEPAGE-MNL;
  IG-SEEPAGE[3] = IG-SEEPAGE-UNL;
|
endif;
|
|
| Top Event WF-MISLOAD
| probability of misloading waste form into waste package / canister
|
if init(WP01-21-PWR-AP) then
|
| for the 21-PWR Absorber Plate Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21AP;
  WF-MISLOAD = WF-MISLOAD-21AP;
|
elsif init(WP02-21-PWR-CR) then
|
| for the 21-PWR Control Rod Waste Package
|
 /WF-MISLOAD = WF-MISLOAD-21CR;
  WF-MISLOAD = WF-MISLOAD-21CR;
|
elsif (init(WP03-12-PWR-AP) + init(WP05-44-BWR-AP) +
       init(WP04-24-BWR-AP) + DOE-NOMIS) then
|
| misload probability for 12-PWR and 24-BWR Absorber Plate and the
| Aluminum Based, Enrico Fermi, Fort St. Vrain, N Reactor, Shippingport PWR,
| Shippingport LWBR, TMI II and TRIGA DOE SNF waste forms
|
 /WF-MISLOAD = WF-MISLOAD-12AP;
  WF-MISLOAD = WF-MISLOAD-12AP;
|
elsif DOE-MISLOAD then
|
| misload probability for the FFTF DOE SNF waste form
|
 /WF-MISLOAD = WF-MISLOAD-DOE;
  WF-MISLOAD = WF-MISLOAD-DOE;
|
```

```
endif;
|
|
| Top Event CRIT-POT-WF
| criticality potential of igneous configurations IG-I1, IG-I2, and
| IG-I3
|
if (IGNEOUS-EVENT * /IG-WP-DESTRYD * /NA-MISLOAD * /WF-MISLOAD) then
|
| igneous event, waste package not destroyed, no misload of any type
|
 /CRIT-POT-WF = CRIT-POT-WF-NONE;
  CRIT-POT-WF = CRIT-POT-WF-NONE;
|
elsif (IGNEOUS-EVENT * /IG-WP-DESTRYD *
       (NA-MISLOAD + (WF-MISLOAD * DOE-MISLOAD))) then
|
| igneous event, waste package not destroyed, neutron absorber material
| or DOE SNF misload
|
 /CRIT-POT-WF = CRIT-POT-WF-YES;
  CRIT-POT-WF = CRIT-POT-WF-YES;
|
elsif (IGNEOUS-EVENT * /IG-WP-DESTRYD * WF-MISLOAD * /NA-MISLOAD *
       (init(WP01-21-PWR-AP) + init(WP02-21-PWR-CR))) then
|
| igneous event, waste package not destroyed, waste form 21-PWR misloads only
|
 /CRIT-POT-WF = CRIT-POT-WF-MISL;
  CRIT-POT-WF = CRIT-POT-WF-MISL;
|
endif;
```

B.22 PROJECT PARTITION RULES

The following partition rules are used to create encoded end states for the FEPS event tree sequences that result in either a bathtub or flow-through configuration. These encoded end states represent sequences for the three SAPHIRE evaluated criticality FEPs cases (igneous disruptive event not evaluated in SAPHIRE), eight of the ten waste package types (naval waste package types are not considered in this evaluation), and the two geological zones (lithophysal and nonlithophysal) considered in this analysis.

```
|
|
| Set Criticality FEPs Case
|
if /BASE-CASE then
 GlobalPartition = "BC";
|
elsif (SEISMIC-EVENT * SEIS-FAULT-1) then
 GlobalPartition = "SF";
|
elsif (SEISMIC-EVENT * (/SEIS-GROUND + ~SEIS-DAMAGE)) then
 GlobalPartition = "SG";
|
elsif ROCKFALL-EVENT then
 GlobalPartition = "RF";
|
elsif (IGNEOUS-EVENT * /IG-EVENT-TYPE-ERUP) then
 GlobalPartition = "IE";
|
elsif (IGNEOUS-EVENT * IG-EVENT-TYPE-INT) then
 GlobalPartition = "II";
|
endif;
|
| Set Waste Package / Waste Form Type
|
if init(WP01-21-PWR-AP) then
 GlobalPartition = "??-WP01";
|
elsif init(WP02-21-PWR-CR) then
 GlobalPartition = "??-WP02";
|
elsif init(WP03-12-PWR-AP) then
 GlobalPartition = "??-WP03";
|
elsif init(WP04-24-BWR-AP) then
 GlobalPartition = "??-WP04";
|
elsif init(WP05-44-BWR-AP) then
 GlobalPartition = "??-WP05";
|
elsif init(WP06-DOE1-SHORT) then
 GlobalPartition = "??-WP06";
|
elsif init(WP07-DOE1-LONG) then
 GlobalPartition = "??-WP07";
|
elsif init(WP08-DOE2-SHORT) then
 GlobalPartition = "??-WP08";
|
```

```
elsif init(WP09-DOE3-SHORT) then
 GlobalPartition = "??-WP09";
|
elsif init(WP10-DOE3-LONG) then
 GlobalPartition = "??-WP10";
|
elsif init(WP11-DOE3-MCO) then
 GlobalPartition = "??-WP11";
|
elsif init(WP12-DOE4-SHORT) then
 GlobalPartition = "??-WP12";
|
elsif init(WP13-DOE4-LONG) then
 GlobalPartition = "??-WP13";
|
elsif init(WP14-DOE5-SHORT) then
 GlobalPartition = "??-WP14";
|
elsif init(WP15-DOE5-LONG) then
 GlobalPartition = "??-WP15";
|
elsif init(WP16-DOE6-LONG) then
 GlobalPartition = "??-WP16";
|
elsif init(WP17-DOE7-SHORT) then
 GlobalPartition = "??-WP17";
|
elsif init(WP18-DOE7-LONG) then
 GlobalPartition = "??-WP18";
|
elsif init(WP19-DOE8-SHORT) then
 GlobalPartition = "??-WP19";
|
elsif init(WP20-DOE8-LONG) then
 GlobalPartition = "??-WP20";
|
elsif init(WP21-DOE9-SHORT) then
 GlobalPartition = "??-WP21";
|
elsif init(WP22-DOE9-LONG) then
 GlobalPartition = "??-WP22";
|
endif;
|
|  Set Configuration Class
|
if (MS-IC-3A-D1 + MS-IC-3A-D2 + MS-IC-3A-D3) then
 GlobalPartition = "???????-IPDRY";
|
elsif MS-IC-9-1 then
 GlobalPartition = "???????-IP1A";
|
elsif MS-IC-11-1 then
 GlobalPartition = "???????-IP1B";
|
elsif MS-IC-14-1 then
 GlobalPartition = "???????-IP2A";
|
elsif MS-IC-16-1 then
 GlobalPartition = "???????-IP3A";
|
elsif MS-IC-18-1 then
 GlobalPartition = "???????-IP3B";
|
```

```
elsif MS-IC-19-1 then
 GlobalPartition = "???????-IP3C";
|
elsif MS-IC-22-1 then
 GlobalPartition = "???????-IP3D";
|
elsif MS-IC-32-1 then
 GlobalPartition = "???????-IP4A";
|
elsif MS-IC-34-1 then
 GlobalPartition = "???????-IP4B";
|
elsif MS-IC-36-1 then
 GlobalPartition = "???????-IP5A";
|
elsif MS-IC-38-1 then
 GlobalPartition = "???????-IP6A";
|
elsif MS-NF-10-1 then
 GlobalPartition = "???????-NF1A";
|
elsif MS-NF-11-1 then
 GlobalPartition = "???????-NF1B";
|
elsif MS-NF-12-1 then
 GlobalPartition = "???????-NF1C";
|
elsif MS-NF-13-1 then
 GlobalPartition = "???????-NF2A";
|
elsif MS-NF-15-1 then
 GlobalPartition = "???????-NF3A";
|
elsif (/MS-NF-19-1 + /MS-NF-19-90) then
 GlobalPartition = "???????-NF3B";
|
elsif (MS-NF-19-1 + MS-NF-19-90) then
 GlobalPartition = "???????-NF3C";
|
elsif MS-NF-DD-1 then
 GlobalPartition = "???????-NFDD";
|
elsif MS-NF-25-1 then
 GlobalPartition = "???????-NF4A";
|
elsif MS-NF-26-1 then
 GlobalPartition = "???????-NF5A";
|
elsif MS-FF-11-1 then
 GlobalPartition = "???????-FF1A";
|
elsif MS-FF-13-1 then
 GlobalPartition = "???????-FF1B";
|
elsif MS-FF-15-1 then
 GlobalPartition = "???????-FF1C";
|
elsif MS-FF-18-1 then
 GlobalPartition = "???????-FF2A";
|
elsif MS-FF-20-1 then
 GlobalPartition = "???????-FF2B";
|
elsif MS-FF-21-1 then
```

```
 GlobalPartition = "???????-FF2C";
|
elsif MS-FF-4-1 then
 GlobalPartition = "???????-FF3A";
|
elsif MS-FF-6-1 then
 GlobalPartition = "???????-FF3B";
|
elsif MS-FF-7-1 then
 GlobalPartition = "???????-FF3C";
|
elsif MS-FF-8-1 then
 GlobalPartition = "???????-FF3D";
|
elsif MS-FF-10-1 then
 GlobalPartition = "???????-FF3E";
|
elsif (/IG-CONFIG-0 * IG-FM-ACCUM-1) then
 GlobalPartition = "???????-IGE1";
|
elsif (IG-CONFIG-1 * /IG-FM-TRANSPT-0)then
 GlobalPartition = "???????-IGE2";
|
elsif (IG-CONFIG-1 * IG-FM-TRANSPT-1) then
 GlobalPartition = "???????-IGE3";
|
elsif (IG-CONFIG-1 * IG-BATHTUB-1) then
 GlobalPartition = "???????-IGE4";
|
elsif (IG-WP-DESTRYD-1 * /IG-MAGMA-COOL-0 * /IG-FM-TRANSPT-0) then
 GlobalPartition = "???????-IGI4";
|
elsif (IG-WP-DESTRYD-0 * /IG-MAGMA-COOL-0 * /IG-MAGMA-FRAC-0 *
       /IG-FM-TRANSPT-0) then
 GlobalPartition = "???????-IGI5";
|
elsif (IG-WP-DESTRYD-1 * IG-MAGMA-COOL-1 * IG-MAGMA-FRAC-1 *
       /IG-FM-TRANSPT-0) then
 GlobalPartition = "???????-IGI6";
|
elsif (/IG-WP-DESTRYD-0 * /IG-MAGMA-COOL-0) then
 GlobalPartition = "???????-IGI1";
|
elsif (/IG-WP-DESTRYD-0 * IG-MAGMA-COOL-1 * /IG-BATHTUB-0) then
 GlobalPartition = "???????-IGI2";
|
elsif (/IG-WP-DESTRYD-0 * IG-MAGMA-COOL-1 * IG-BATHTUB-1) then
 GlobalPartition = "???????-IGI3";
|
endif;
```

B.23 BASIC EVENTS FOR SAPHIRE ANALYSIS

Table B-1 lists the basic event values used in the Criticality FEPs evaluations.

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
BASIC EVENTS FOR CRITICALITY POTENTIAL TOP EVENT – *CRIT-POT-WF*		
CRIT-POT-WF	CRITICALITY POTENTIAL OF WASTE FORM	1.000E+000
CRIT-POT-WF-MISL	WASTE FORM MISLOAD CONFIGURATION HAS CRITICALITY POTENTIAL	2.480E-005
CRIT-POT-WF-NONE	CONFIGURATION HAS NO CRITICALITY POTENTIAL	0.000E+000
CRIT-POT-WF-YES	CONFIGURATION HAS CRITICALITY POTENTIAL	1.000E+000
BASIC EVENTS FOR DRIFT GEOLOGIC ZONE TOP EVENT – *DRIFT-ZONE*		
DRIFT-ZONE	REPOSITORY DRIFT ZONE	1.000E+000
DRIFT-ZONE-LITH	Developed Event (top event substitution for drift-zone)	8.500E-001
DRIFT-ZONE-NONL	Developed Event (top event substitution for drift-zone)	8.500E-001
BASIC EVENT LISTING FOR IGNEOUS CONFIGURATION EVENT TREES		
IG-BATHTUB	BATHTUB CONFIGURATION DURING IGNEOUS EVENT	0.000E+000
IG-BATHTUB-0	Developed Event (TOP EVENT SUBSTITUTION FOR IG-BATHTUB)	0.000E+000
IG-BATHTUB-1	Developed Event (TOP EVENT SUBSTITUTION FOR IG-BATHTUB)	1.000E+000
IG-CONFIG	WASTE PACKAGE/WASTE FORM CONFIGURATION	1.000E+000
IG-CONFIG-0	Developed Event (TOP EVENT SUBSTITUTION FOR IG-CONFIG)	0.000E+000
IG-CONFIG-1	Developed Event (TOP EVENT SUBSTITUTION FOR IG-CONFIG)	1.000E+000
IG-EVENT-TYPE	TYPE OF IGNEOUS EVENT	1.000E+000
IG-EVENT-TYPE-ERUP	Developed Event (TOP EVENT SUBSTITUTION FOR IG-EVENT-TYPE)	2.200E-001
IG-EVENT-TYPE-INT	Developed Event (TOP EVENT SUBSTITUTION FOR IG-EVENT-TYPE)	1.000E+000
IG-FM-ACCUM	FISSILE MATERIAL ACCUMULATES	1.000E+000
IG-FM-ACCUM-0	Developed Event (TOP EVENT SUBSTITUTION FOR IG-FM-ACCUM)	0.000E+000
IG-FM-ACCUM-1	Developed Event (TOP EVENT SUBSTITUTION FOR IG-FM-ACCUM)	1.000E+000
IG-FM-TRANS	FISSILE MATERIAL TRANSPORTED FROM WASTE PACKAGE	1.000E+000
IG-FM-TRANSPT	FISSILE MATERIAL TRANSPORTED FROM WASTE PACKAGE TO THE NEAR-	1.000E+000
IG-FM-TRANSPT-0	Developed Event (TOP EVENT SUBSTITUTION FOR IG-FM-TRANSPT)	0.000E+000
IG-FM-TRANSPT-1	Developed Event (TOP EVENT SUBSTITUTION FOR IG-FM-TRANSPT)	1.000E+000
IG-MAGMA-COOL	MAGMA COOLED	1.000E+000
IG-MAGMA-COOL-0	Developed Event (TOP EVENT SUBSTITUTION FOR IG-MAGMA-	0.000E+000

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
	COOL)	
IG-MAGMA-COOL-1	Developed Event (TOP EVENT SUBSTITUTION FOR IG-MAGMA-COOL)	1.000E+000
IG-MAGMA-FRAC	MAGMA FRACTURES AFTER COOLING	1.000E+000
IG-MAGMA-FRAC-0	Developed Event (TOP EVENT SUBSTITUTION FOR IG-MAGMA-FRAC)	0.000E+000
IG-MAGMA-FRAC-1	Developed Event (TOP EVENT SUBSTITUTION FOR IG-MAGMA-FRAC)	1.000E+000
IG-MAGMA-INT	MAGMA INTRUSION INTO WASTE PACKAGE	1.000E+000
IG-RAINFALL	RAINFALL OCCURS	1.000E+000
IG-SEEPAGE	SEEPAGE RETURNS	1.000E+000
IG-SEEPAGE-LL	Developed Event (TOP EVENT SUBSTITUTION FOR IG-SEEPAGE LITH)	4.622E-002
IG-SEEPAGE-LNL	Developed Event (TOP EVENT SUBSTITUTION FOR IG-SEEPAGE NONLI	1.062E-001
IG-SEEPAGE-ML	Developed Event (TOP EVENT SUBSTITUTION FOR IG-SEEPAGE LITH)	2.111E-001
IG-SEEPAGE-MNL	Developed Event (TOP EVENT SUBSTITUTION FOR IG-SEEPAGE NONLI	3.244E-001
IG-SEEPAGE-NWL	Developed Event (TOP EVENT SUBSTITUTION FOR /IG-SEEPAGE LITH	4.816E-001
IG-SEEPAGE-NWNL	Developed Event (TOP EVENT SUBSTITUTION FOR /IG-SEEPAGE NONL	7.371E-001
IG-SEEPAGE-UL	Developed Event (TOP EVENT SUBSTITUTION FOR IG-SEEPAGE LITH)	2.243E-001
IG-SEEPAGE-UNL	Developed Event (TOP EVENT SUBSTITUTION FOR IG-SEEPAGE NONLI	3.065E-001
IG-TOP-NO-0	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 0.0)	1.000E+000
IG-TOP-NO-1	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 1.0)	0.000E+000
IG-TOP-YES-0	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 0.0)	0.000E+000
IG-TOP-YES-1	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 1.0)	1.000E+000
IG-WP-DESTRYD	WASTE PACKAGE DESTROYED	1.000E+000
IG-WP-DESTRYD-0	Developed Event (TOP EVENT SUBSTITUTION FOR IG-WP-DESTRYD)	0.000E+000
IG-WP-DESTRYD-1	Developed Event (TOP EVENT SUBSTITUTION FOR IG-WP-DESTRYD)	1.000E+000
IG-WP-LOC	WASTE PACKAGE LOCATION	1.000E+000
IG-WP-RELOC	WASTE PACKAGE RELOCATION	1.000E+000
IG-WP-SLUMP	WASTE PACKAGE SLUMPS AND BREACHES	1.000E+000
	BASIC EVENTS FOR IN-PACKAGE CONFIGURATION EVENT TREES	
MS-IC-1A	INFILTRATION WATER REACHES DRIFT	1.000E+000
MS-IC-1A-NOM-LL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A	1.104E-002

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
	BASE CA	
MS-IC-1A-NOM-LNL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A BASE CA	3.518E-002
MS-IC-1A-NOM-ML	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A BASE CA	1.007E-001
MS-IC-1A-NOM-MNL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A BASE CA	2.127E-001
MS-IC-1A-NOM-NWL	Developed Event (TOP EVENT SUBSTITUTION FOR /MS-IC-1A BASE C	2.395E-001
MS-IC-1A-NOM-NWNL	Developed Event (TOP EVENT SUBSTITUTION FOR /MS-IC-1A BASE C	4.830E-001
MS-IC-1A-NOM-UL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A BASE CA	1.278E-001
MS-IC-1A-NOM-UNL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A BASE CA	2.351E-001
MS-IC-1A-SEIS-LL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A SEISMIC	4.622E-002
MS-IC-1A-SEIS-LNL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A SEISMIC	3.701E-002
MS-IC-1A-SEIS-ML	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A SEISMIC	2.111E-001
MS-IC-1A-SEIS-MNL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A SEISMIC	2.146E-001
MS-IC-1A-SEIS-NWL	Developed Event (TOP EVENT SUBSTITUTION FOR /MS-IC-1A SEISMI	4.816E-001
MS-IC-1A-SEIS-NWNL	Developed Event (TOP EVENT SUBSTITUTION FOR /MS-IC-1A SEISMI	4.867E-001
MS-IC-1A-SEIS-UL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A SEISMIC	2.243E-001
MS-IC-1A-SEIS-UNL	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-1A SEISMIC	2.351E-001
BASIC EVENTS FOR THE CONDENSATION TOP EVENT – *MS-IC-1B*		
MS-IC-1B	CONDENSATION WATER REACHES WASTE PACKAGE	0.000E+000
MS-IC-1B-0	Probability of No Condensation	0.000E+000
BASIC EVENTS FOR THE DRIP SHIELD FAILURE TOP EVENT – *MS-IC-2*		
MS-IC-2	WATER DRIPS ON WASTE PACKAGE	1.000E+000
MS-IC-2-BC	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-2 BASE CAS	0.000E+000
MS-IC-2-DE	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-2 DISRUPTI	1.000E+000
BASIC EVENTS FOR THE WASTE PACKAGE FAILURE TOP EVENT – *MS-IC-3A*		
MS-IC-3A	WASTE PACKAGE PENETRATION	1.000E+000
MS-IC-3A-0	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3A NO FAIL	0.000E+000

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
MS-IC-3A-A1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3A ADVECTI	1.000E+000
MS-IC-3A-A2	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3A ADVECTI	1.000E-001
MS-IC-3A-D1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3A DIFFUSI	1.000E-001
MS-IC-3A-D2	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3A DIFFUSI	9.000E-001
MS-IC-3A-D3	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3A DIFFUSI	1.000E-000
MS-IC-3A-NF	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3A NO FAIL	1.000E+000
BASIC EVENTS FOR THE BATHTUB CONFIGURATION TOP EVENT – *MS-IC-3B*		
MS-IC-3B	BATHTUB CONFIGURATION FORMS	1.000E+000
MS-IC-3B-0	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3B NO BATH	0.000E+000
MS-IC-3B-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-3B BATHTUB	1.000E+000
BASIC EVENTS FOR FAR-FIELD CONFIGURATION EVENT TREES		
MS-FF-1	TRANSPORT OF FM SOLUTES TO Tsw UNITS IN CARRIER PLUME	1.000E+000
MS-FF-10	FFM SOLUTES PRECIPITATE IN ORGANIC-RICH ZONES OF FRANKLIN L	1.000E+000
MS-FF-10-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-10)	1.000E+000
MS-FF-11	PRECIPITATION OF FM AS CARRIER PLUME IS ALTERED BY ROCKS	1.000E+000
MS-FF-11-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-11)	1.000E+000
MS-FF-12	TRANSPORT OF FM SOLUTES TO ALTERED TSbv	1.000E+000
MS-FF-13	SORPTION OF FM ON CLAYS AND ZEOLITES IN ALTERED TSbv	1.000E+000
MS-FF-13-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-13)	1.000E+000
MS-FF-14	ACCUMULATION OF FM SOLUTE IN TOPOGRAPHIC LOWS ABOVE TSbv	1.000E+000
MS-FF-15	CHEMICAL CHANGES IN PERCHED WATER PRECIPITATES FM	1.000E+000
MS-FF-15-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-15)	1.000E+000
MS-FF-16	TRANSPORT OF FM COLLOIDS TO TSw UNITS IN CARRIER PLUME	1.000E+000
MS-FF-17	HYDRODYNAMIC/CHROMATOGRAPHIC SEP OF FM COLLOIDS FROM NEUTRON	1.000E+000
MS-FF-18	Developed Event	1.000E+000
MS-FF-18-0	TRAPPING OF FM COLLOIDS IN DEAD-END FRACTURES AT BOUNDARY	1.000E+000
MS-FF-18-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-18)	1.000E+000
MS-FF-19	TRANSPORT OF FISSILE MATERIAL COLLOIDS TO ALTERED TSbv	1.000E+000
MS-FF-2	SEPARATION OF FISSILE MATERIAL FROM NEUTRON ABSORBERS	1.000E+000

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
MS-FF-20	SORPTION OF COLLOIDS IN CLAYS AND ZEOLITES IN ALTERED TSbv	1.000E+000
MS-FF-20-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-20)	1.000E+000
MS-FF-21	FITRATION OF COLLOIDS IN TOPOGRAPHIC LOWS ABOVE TSbv	1.000E+000
MS-FF-21-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-21)	1.000E+000
MS-FF-3	FM SOLUTES ARE TRANSPORTED TO WATER TABLE	1.000E+000
MS-FF-4	FM PRECIPITATES IN UPWELL ZONE OF HYDROTHERMAL FLUIDS AT FAU	1.000E+000
MS-FF-4-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-4)	1.000E+000
MS-FF-5	CONTAINMENT PLUME MIXES BELOW REDOX FROM (~200 m)	1.000E+000
MS-FF-6	PRECIPITATION OF FISSILE MATERIAL	1.000E+000
MS-FF-6-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-6)	1.000E+000
MS-FF-7	FM PRECIPITATES AT REDUCING ZONE (eg REMAINS OF ORGANINC MAT	1.000E+000
MS-FF-7-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-7)	1.000E+000
MS-FF-8	FM PRECIPITATES AT ORGANIC REDUCING ZONE AT PINCHOUT OF TUFF	1.000E+000
MS-FF-8-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-FF-8)	1.000E+000
MS-FF-9	FM SOLUTES ARE TRANSPORTED TO FRANKLIN LAKE PLAYA	1.000E+000
MS-FF-TOP-NO-0	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 0.0)	1.000E+000
MS-FF-TOP-NO-1	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 1.0)	0.000E+000
MS-FF-TOP-YES-0	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 0.0)	0.000E+000
MS-FF-TOP-YES-1	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 1.0)	1.000E+000
BASIC EVENTS FOR IN-PACKAGE CONFIGURATION EVENT TREES		
CONFIG-SCEN	CONFIGURATION SCENARIO SET UP	1.000E+000
MS-IC-10	WASTE PACKAGE INTERNAL STRUCTURES DEGRADE	0.000E+000
MS-IC-11	DEGRADED WF IS MOBILIZED	1.000E+000
MS-IC-11-0	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-11)	1.000E+000
MS-IC-11-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-11)	1.000E+000
MS-IC-11-2A	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-11)	0.000E+000
MS-IC-11-2B	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-11)	1.000E+000
MS-IC-12	WASTE PACKAGE BOTTOM FAILS DRAINING LIQUID	0.000E+000
MS-IC-13	DEGRADED WF AND WP COMPONENTS COLLECT AT BOTTOM OF WP	0.000E+000
MS-IC-14	SOLUBLE NEUTRON ABSORBERS FLUSHED FROM WASTE PACKAGE	0.000E+000
MS-IC-14-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-14)	1.000E+000
MS-IC-15	WASTE PACKAGE BOTTOM FAILS DRAINING LIQUID	0.000E+000
MS-IC-16	BASKET STRUCTURAL SUPPORTS MECHANICALLY COLLAPSE	0.000E+000
MS-IC-16-0	Developed Event (TOP EVENT SUBSTITUTION FOR /MS-IC-16)	1.000E+000
MS-IC-16-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-16[1])	1.000E+000

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
MS-IC-16-2	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-16[2])	1.000E+000
MS-IC-16-3	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-16[3])	1.000E+000
MS-IC-17	STRUCTURES CONTAINING NEUTRON ABSORBERS FULLY DEGRADE	0.000E+000
MS-IC-18	SOLUBLE NEUTRON ABSORBERS FLUSHED FROM DEGRADED PORTION OF B	0.000E+000
MS-IC-18-0	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-18)	1.000E+000
MS-IC-18-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-18)	1.000E+000
MS-IC-19	SOLUBLE NEUTRON ABSORBERS FLUSHED FROM WASTE PACKAGE	0.000E+000
MS-IC-19-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-18)	1.000E+000
MS-IC-20	WASTE FORM DEGRADES MOBILIZING FISSILE MATERIAL	0.000E+000
MS-IC-21	WASTE PACKAGE BOTTOM FAILS DRAINING LIQUID	0.000E+000
MS-IC-22	SIGNIFICANT NEUTRON ABSORBER DEGRADATION BEFORE STRUCTURAL C	0.000E+000
MS-IC-22-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-22[1])	1.000E+000
MS-IC-22-2	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-22[2])	1.000E+000
MS-IC-22-3	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-22[3])	1.000E+000
MS-IC-23	WASTE PACKAGE INTERNAL STRUCTURES MECHANICALLY COLLAPSE AND	0.000E+000
MS-IC-24	WASTE PACKAGE BOTTOM FALLS DRAINING LIQUID	0.000E+000
MS-IC-29	WP INTERNAL STRUCTURES DEGRADE SLOWER THAN WF	0.000E+000
MS-IC-30	WP INTERNAL STRUCTURES AND WF DEGRADE AT SIMILAR RATES	0.000E+000
MS-IC-31	WP INTERNAL STRUCTURES DEGRADE FASTER THAN WF	0.000E+000
MS-IC-32	WF DEGRADATION PRODUCTS HYDRATE IN INITIAL LOCATION	1.000E+000
MS-IC-32-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-32)	1.000E+000
MS-IC-33	WASTE PACKAGE INTERNAL STRUCTURES DEGRADE	0.000E+000
MS-IC-34	DEGRADATION WF IS MOBILIZED SEPARATING FROM NEUTRON ABSORBE	0.000E+000
MS-IC-34-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-34[1])	1.000E+000
MS-IC-34-2	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-34[2])	1.000E+000
MS-IC-35	HYDRATED WF AND INTERNAL COMPONENT DEGRADATION PRODUCTS COLL	0.000E+000
MS-IC-36	FLOW-THROUGH FLUSHING REMOVES SOLUBLE NEUTRON ABSORBERS	0.000E+000
MS-IC-36-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-36)	1.000E+000
MS-IC-37	INTACT WF SETTLES IN BOTTOM OF WP MIXED WITH HYDRATED CORRO	0.000E+000
MS-IC-38	FLOW-THROUGH FLUSHING REMOVES SOLUBLE NEUTRON ABSORBERS	0.000E+000
MS-IC-38-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-38)	1.000E+000
MS-IC-39	WASTE FORM DEGRADES MOBILIZING FISSILE MATERIAL	0.000E+000

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
MS-IC-40	WASTE PACKAGE MOSTLY DEGRADES WHILE WF LARGELY INTACT	0.000E+000
MS-IC-6	WASTE PACKAGE INTERNAL STRUCTURES DEGRADE SLOWER THAN WASTE	0.000E+000
MS-IC-7	WASTE PACKAGE INTERNAL STRUCTURES DEGRADE AT SAME RATE AS WF	0.000E+000
MS-IC-8	WASTE PACKAGE INTERNAL STRUCTURES DEGRADE FASTER THAN WF	0.000E+000
MS-IC-9	WASTE FORM DEGRADES IN PLACE	1.000E+000
MS-IC-9-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-IC-9)	1.000E+000
MS-IC-TOP-NO-0	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 0.0)	1.000E+000
MS-IC-TOP-NO-1	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 1.0)	0.000E+000
MS-IC-TOP-YES-0	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 0.0)	0.000E+000
MS-IC-TOP-YES-1	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 1.0)	1.000E+000
BASIC EVENTS FOR WASTE PACKAGE FILLING PROBABILITY TOP EVENT – *MS-IC-4*		
MS-IC-4	LIQUID ACCUMULATES IN WASTE PACKAGE	1.000E+000
MS-IC-4-0	TOP EVENT SUBSTITUTION TO HANDLE LOGIC	0.000E+000
MS-IC-4-SE-LL-12AP	Seismic faulting event; lower-bound seepage; litho; 12-PWR AP	1.129E-001
MS-IC-4-SE-LL-21AP	Seismic faulting event; lower-bound seepage; litho; 21-PWR AP	1.771E-001
MS-IC-4-SE-LL-21CR	Seismic faulting event; lower-bound seepage; litho; 21-PWR CR	1.771E-001
MS-IC-4-SE-LL-24AP	Seismic faulting event; lower-bound seepage; litho; 24-BWR AP	1.162E-001
MS-IC-4-SE-LL-44AP	Seismic faulting event; lower-bound seepage; litho; 44-BWR AP	1.760E-001
MS-IC-4-SE-LL-DOEL	Seismic faulting event; lower-bound seepage; litho; DOE LONG	6.364E-001
MS-IC-4-SE-LL-DOEM	Seismic faulting event; lower-bound seepage; litho; DOE MCO	3.225E-001
MS-IC-4-SE-LL-DOES	Seismic faulting event; lower-bound seepage; litho; DOE SHORT	6.816E-001
MS-IC-4-SE-LNL-12AP	Seismic faulting event; lower-bound seepage; nonlitho; 12-PWR AP	1.027E-01
MS-IC-4-SE-LNL-21AP	Seismic faulting event; lower-bound seepage; nonlitho; 21-PWR AP	1.581E-01
MS-IC-4-SE-LNL-21CR	Seismic faulting event; lower-bound seepage; nonlitho; 21-PWR CR	1.581E-01
MS-IC-4-SE-LNL-24AP	Seismic faulting event; lower-bound seepage; nonlitho; 24-BWR AP	1.066E-01
MS-IC-4-SE-LNL-44AP	Seismic faulting event; lower-bound seepage; nonlitho; 44-BWR AP	1.568E-01
MS-IC-4-SE-LNL-DOEL	Seismic faulting event; lower-bound seepage; nonlitho; DOE LONG	5.579E-01
MS-IC-4-SE-LNL-DOEM	Seismic faulting event; lower-bound seepage; nonlitho; DOE MCO	2.890E-01
MS-IC-4-SE-LNL-DOES	Seismic faulting event; lower-bound seepage; nonlitho; DOE SHORT	6.108E-01
MS-IC-4-SE-ML-12AP	Seismic faulting event; mean seepage; litho; 12-PWR AP	1.415E-01
MS-IC-4-SE-ML-21AP	Seismic faulting event; mean seepage; litho; 21-PWR AP	2.314E-01
MS-IC-4-SE-ML-21CR	Seismic faulting event; mean seepage; litho; 21-PWR CR	2.314E-01
MS-IC-4-SE-ML-24AP	Seismic faulting event; mean seepage; litho; 24-BWR AP	1.428E-01
MS-IC-4-SE-ML-44AP	Seismic faulting event; mean seepage; litho; 44-BWR AP	2.310E-01
MS-IC-4-SE-ML-DOEL	Seismic faulting event; mean seepage; litho; DOE LONG	8.644E-01
MS-IC-4-SE-ML-DOEM	Seismic faulting event; mean seepage; litho; DOE MCO	4.181E-01

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
MS-IC-4-SE-ML-DOES	Seismic faulting event; mean seepage; litho; DOE SHORT	8.830E-01
MS-IC-4-SE-MNL-12AP	Seismic faulting event; mean seepage; nonlitho; 12-PWR AP	1.378E-01
MS-IC-4-SE-MNL-21AP	Seismic faulting event; mean seepage; nonlitho; 21-PWR AP	2.242E-01
MS-IC-4-SE-MNL-21CR	Seismic faulting event; mean seepage; nonlitho; 21-PWR CR	2.242E-01
MS-IC-4-SE-MNL-24AP	Seismic faulting event; mean seepage; nonlitho; 24-BWR AP	1.394E-01
MS-IC-4-SE-MNL-44AP	Seismic faulting event; mean seepage; nonlitho; 44-BWR AP	2.237E-01
MS-IC-4-SE-MNL-DOEL	Seismic faulting event; mean seepage; nonlitho; DOE LONG	8.339E-01
MS-IC-4-SE-MNL-DOEM	Seismic faulting event; mean seepage; nonlitho; DOE MCO	4.055E-01
MS-IC-4-SE-MNL-DOES	Seismic faulting event; mean seepage; nonlitho; DOE SHORT	8.565E-01
MS-IC-4-SE-UL-12AP	Seismic faulting event; upper-bound seepage; litho; 12-PWR AP	1.486E-01
MS-IC-4-SE-UL-21AP	Seismic faulting event; upper-bound seepage; litho; 21-PWR AP	2.447E-01
MS-IC-4-SE-UL-21CR	Seismic faulting event; upper-bound seepage; litho; 21-PWR CR	2.447E-01
MS-IC-4-SE-UL-24AP	Seismic faulting event; upper-bound seepage; litho; 24-BWR AP	1.494E-01
MS-IC-4-SE-UL-44AP	Seismic faulting event; upper-bound seepage; litho; 44-BWR AP	2.445E-01
MS-IC-4-SE-UL-DOEL	Seismic faulting event; upper-bound seepage; litho; DOE LONG	9.205E-01
MS-IC-4-SE-UL-DOEM	Seismic faulting event; upper-bound seepage; litho; DOE MCO	4.416E-01
MS-IC-4-SE-UL-DOES	Seismic faulting event; upper-bound seepage; litho; DOE SHORT	9.325E-01
MS-IC-4-SE-UNL-12AP	Seismic faulting event; upper-bound seepage; nonlitho; 12-PWR AP	1.464E-01
MS-IC-4-SE-UNL-21AP	Seismic faulting event; upper-bound seepage; nonlitho; 21-PWR AP	2.404E-01
MS-IC-4-SE-UNL-21CR	Seismic faulting event; upper-bound seepage; nonlitho; 21-PWR CR	2.404E-01
MS-IC-4-SE-UNL-24AP	Seismic faulting event; upper-bound seepage; nonlitho; 24-BWR AP	1.474E-01
MS-IC-4-SE-UNL-44AP	Seismic faulting event; upper-bound seepage; nonlitho; 44-BWR AP	2.401E-01
MS-IC-4-SE-UNL-DOEL	Seismic faulting event; upper-bound seepage; nonlitho; DOE LONG	9.019E-01
MS-IC-4-SE-UNL-DOEM	Seismic faulting event; upper-bound seepage; nonlitho; DOE MCO	4.341E-01
MS-IC-4-SE-UNL-DOES	Seismic faulting event; upper-bound seepage; nonlitho; DOE SHORT	9.167E-01
BASIC EVENTS FOR NEAR-FIELD CONFIGURATION EVENT TREES		
MS-NF-10	SORPTION OF FISSILE MATERIAL SOLUTES IN TUFF	1.000E+000
MS-NF-10-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-10)	1.000E+000
MS-NF-11	PRECIPITATION OF FISSILE MATERIAL BY TUFF	1.000E+000
MS-NF-11-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-11)	1.000E+000
MS-NF-12	TRANSPORT OF FM FROM ONE OR MORE WPs TO LOW POINT	1.000E+000
MS-NF-12-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-12)	1.000E+000
MS-NF-13	EFFLUENT FLOWS TO CONFORM TO INVERT SURFACE	1.000E+000
MS-NF-13-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-13)	1.000E+000
MS-NF-14	ABSORBERS AND FISSILE MATERIAL SEPARATE	1.000E+000
MS-NF-15	FILTRATION AND CONC OF COLLOIS ON TOP OF INVERT BY WP CORR P	1.000E+000
MS-NF-15-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-15)	1.000E+000
MS-NF-16	TRANSPORT OF COLLOIDS INTO INVERT	1.000E+000

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
MS-NF-17	HYDRODYNAMIC/CHROMATOGRAPHIC SEP OF FM COLLOIDS FROM NEUT AB	1.000E+000
MS-NF-18	FILTRATION AND CONCENTRATION OF COLLOIDS IN FRACTURES	1.000E+000
MS-NF-19	DEGRADATION OF INVERT MATERIAL	1.000E+000
MS-NF-19-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-19 fail)	1.000E+000
MS-NF-19-90	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-19)	9.000E-001
MS-NF-2	WATER PONDS ON DRIFT FLOOR DUE TO SEALING AND/OR DAMMING	0.000E+000
MS-NF-22	FM AND ABSORBERS ACCUMULATE IN POND	1.000E+000
MS-NF-23	BASIN EFFECTIVELY SEALED	1.000E+000
MS-NF-24	FM ACCUMULATES IN CLAYS AT BOTTOM OF POOL	1.000E+000
MS-NF-25	NON-FISSILE BEARING WATER FLUSHES NEUTRON ABSORBERS	1.000E+000
MS-NF-25-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-25)	1.000E+000
MS-NF-26	INTACT WASTE FORM SITS IN POND ON DRIFT FLOOR	1.000E+000
MS-NF-26-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-26)	1.000E+000
MS-NF-3	AQUEOUS CORROSION OF WASTE PACKAGE	1.000E+000
MS-NF-4	CONTAINER BOTTOM BREACHES	1.000E+000
MS-NF-5	WF AND BASKET DEGRADATION MOBILIZES FM AND NEUTRON ABSORBER	1.000E+000
MS-NF-6	SOLUTION EFFLUENT FROM WP WITH FISSILE MATERIAL	1.000E+000
MS-NF-7	SLURRY EFFLUENT FROM WASTE PACKAGE WITH FISSILE MATERIAL	1.000E+000
MS-NF-8	FISSILE MATERIAL COLLOIDS IN LIQUID EFFLUENT	1.000E+000
MS-NF-9	TRANSPORT FROM WASTE PACKAGE TO INVERT	1.000E+000
MS-NF-DD	Accumulation of FM in invert due to dry diffusion	1.000E+000
MS-NF-DD-1	Developed Event (TOP EVENT SUBSTITUTION FOR MS-NF-DD)	1.000E+000
MS-NF-TOP-NO-0	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 0.0)	1.000E+000
MS-NF-TOP-NO-1	Developed Event (TOP EVENT SUBSTITUTION FOR NO = 1.0)	0.000E+000
MS-NF-TOP-YES-0	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 0.0)	0.000E+000
MS-NF-TOP-YES-1	Developed Event (TOP EVENT SUBSTITUTION FOR YES = 1.0)	1.000E+000
BASIC EVENTS FOR THE NEAR-FIELD TRANSFER TOP EVENT – *MS-NF-T*		
MS-NF-T	TRANSFER FROM NEAR FIELD	1.000E+000
MS-NF-T-0	No Transfer to Near Field	0.000E+000
MS-NF-T-1	Transfer to Near Field	1.000E+000
BASIC EVENTS FOR THE NEUTRON ABSORBER MATERIAL MISLOAD TOP EVENT – *NA-MISLOAD*		
NA-MISLOAD	NEUTRON ABSORBER MISLOAD	1.000E+000
NA-MISLOAD-12AP	TOP EVENT SUBSTITUTION FOR 12-PWR AP (NA-MISLOAD)	6.217E-011
NA-MISLOAD-21AP	TOP EVENT SUBSTITUTION FOR 21-PWR AP (NA-MISLOAD)	3.758E-009

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
NA-MISLOAD-21CR	TOP EVENT SUBSTITUTION FOR 21-PWR CR (NA-MISLOAD)	4.576E-008
NA-MISLOAD-DOE-NAM2	TOP EVENT SUBSTITUTION FOR DOE SNF w/ NAM (NA-MISLOAD) G2	3.906E-008
NA-MISLOAD-DOE-NAM3	TOP EVENT SUBSTITUTION FOR DOE SNF w/ NAM (NA-MISLOAD) G3	3.912E-008
NA-MISLOAD-DOE-NONAM	TOP EVENT SUBSTITUTION FOR DOE SNF w/o NAM (NA-MISLOAD)	0.000E+000
CRITICALITY FEPS CASE PROBABILITIES		
INIT-EVENT	DIFFERENT POTENTIAL INITIATING EVENTS	1.000E+000
BASE-CASE	BASE CASE EVENT	0.000E+000
SEISMIC-EVENT	SEISMIC DISRUPTIVE EVENT	1.000E+000
ROCKFALL-EVENT	ROCKFALL DISRUPTIVE EVENT	0.000E+000
IGNEOUS-EVENT	IGNEOUS DISRUPTIVE EVENT	1.740E-004
BASIC EVENTS FOR DEFINING THE SEISMIC DISRUPTIVE EVENT		
SEIS-RANGE	SEISMIC FREQUENCIES BROKEN INTO DECADE RANGES	1.000E+000
SEIS-2E-8TO1E-8	seismic event with frequencies ranging from 2e-8 to 1e-8	9.999E-001
SEIS-6E-8TO2E-8	seismic event with frequencies ranging from 6e-8 to 2e-8	3.999E-004
SEIS-2E-7TO6E-8	seismic event with frequencies ranging from 2e-7 to 6e-8	1.399E-003
SEIS-1E-4TO2E-7	seismic event with frequencies ranging from 1e-4 to 2e-7	6.313E-001
SEIS-DAMAGE	SEISMIC EVENT TIMING	1.000E+000
SEIS-GROUND	seismic damage due to ground motion	0.000E+000
SEIS-FAULT	seismic damage due to faulting	1.000E+000
SEIS-FAULT-0	no seismic damage due to faulting	0.000E+000
SEIS-FAULT-1	seismic damage due to faulting	1.000E+000
BASIC EVENTS FOR THE WASTE FORM MISLOAD TOP EVENT – *WF-MISLOAD*		
WF-MISLOAD	WASTE FORM MISLOAD	1.000E+000
WF-MISLOAD-12AP	Developed Event (top event substitution for 12-PWR AP WF-MIS	0.000E+000
WF-MISLOAD-21AP	Developed Event (top event substitution for 21-PWR AP WF-MIS	1.180E-005
WF-MISLOAD-21CR	Developed Event (top event substitution for 21-PWR CR WF-MIS	0.000E+000
WF-MISLOAD-44AP	Developed Event (top event substitution for 44-BWR AP WF-MIS	0.000E+000
WF-MISLOAD-DOE	Developed Event (top event substitution for FFTF WF-MISLOAD)	1.475E-008
BASIC EVENTS FOR THE WASTE FORM SOURCE TOP EVENT – *WF-SOURCE*		
WF-SOURCE	WASTE FORM SOURCE PERCENTAGES	1.000E+000
WF-SOURCE-CSNF	Developed Event (top event substitution for WF-SOURCE (CSNF)	3.358E-001
WF-SOURCE-DSNF	Developed Event (top event substitution for WF-SOURCE (DSNF)	3.092E-001
WF-SOURCE-NSNF	Developed Event (top event substitution for WF-SOURCE (NSNF)	2.670E-002

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
BASIC EVENTS FOR THE WASTE FORM TYPE FRACTION TOP EVENT – *WF-TYPE-PERC*		
WF-TYPE-PERC	WASTE FORM PERCENTAGES	1.000E+000
WF-TYPE-PWR	Developed Event (top event substitution for WF-TYPE (PWR)	3.901E-001
WF-TYPE-BWR	Developed Event (top event substitution for WF-TYPE (BWR)	3.901E-001
WF-TYPE-FFTF	Developed Event (top event substitution for WF-TYPE (FFTF)	9.810E-001
WF-TYPE-TRIGA	Developed Event (top event substitution for WF-TYPE (TRIGA)	4.740E-002
WF-TYPE-NREACT	Developed Event (top event substitution for WF-TYPE (NREACT)	6.900E-002
WF-TYPE-SHPWR	Developed Event (top event substitution for WF-TYPE (SHPWR)	2.004E-001
WF-TYPE-FSV	Developed Event (top event substitution for WF-TYPE (FSV)	1.740E-001
WF-TYPE-MD	Developed Event (top event substitution for WF-TYPE (MD)	3.528E-001
WF-TYPE-FERMI	Developed Event (top event substitution for WF-TYPE (FERMI)	9.500E-003
WF-TYPE-SHLWBR	Developed Event (top event substitution for WF-TYPE (SHLWBR)	2.670E-002
WF-TYPE-TMI	Developed Event (top event substitution for WF-TYPE (TMI)	1.012E-001
BASIC EVENTS FOR THE WASTE PACKAGE TYPE TOP EVENT – *WP-TYPE*		
WP-TYPE	WASTE PACKAGE TYPE PERCENT BREAKDOWN	1.000E+000
WP-TYPE-21PWRAP	Developed Event (top event substitution for WP-TYPE (21PWRAP	5.660E-002
WP-TYPE-21PWRCR	Developed Event (top event substitution for WP-TYPE (21PWRCR	2.080E-002
WP-TYPE-12PWRAP	Developed Event (top event substitution for WP-TYPE (12PWRAP	3.580E-002
WP-TYPE-44BWR	Developed Event (top event substitution for WP-TYPE (44BWRAP	2.880E-002
WP-TYPE-24BWR	Developed Event (top event substitution for WP-TYPE (24BWRAP	2.880E-002
WP-TYPE-FFTFSH	Developed Event (top event substitution for WP-TYPE (FFTFSH)	9.242E-001
WP-TYPE-FFTFL	Developed Event (top event substitution for WP-TYPE (FFTFL)	9.242E-001
WP-TYPE-NREACTSH	Developed Event (top event substitution for WP-TYPE (NREACTS	9.333E-001
WP-TYPE-NREACTL	Developed Event (top event substitution for WP-TYPE (NREACTL	1.670E-002
WP-TYPE-NREACTMCO	Developed Event (top event substitution for WP-TYPE (NREACTM	9.167E-001
WP-TYPE-SHPWRSH	Developed Event (top event substitution for WP-TYPE (SHPWRSH	6.030E-002
WP-TYPE-SHPWRL	Developed Event (top event substitution for WP-TYPE (SHPWRL)	6.030E-002
WP-TYPE-SHLWBRSH	Developed Event (top event substitution for WP-TYPE (SHLWBRS	7.849E-001
WP-TYPE-SHLWBRL	Developed Event (top event substitution for WP-TYPE (SHLWBRL	7.849E-001
WP-TYPE-MDSH	Developed Event (top event substitution for WP-TYPE (MDSH)	8.000E-004
WP-TYPE-MDL	Developed Event (top event substitution for WP-TYPE (MDL)	8.000E-004
WP-TYPE-FERMISH	Developed Event (top event substitution for WP-TYPE (FERMISH	5.758E-001
WP-TYPE-FERMIL	Developed Event (top event substitution for WP-TYPE (FERMIL)	5.758E-001
WP-TYPE-TMISH	Developed Event (top event substitution for WP-TYPE (TMISH)	9.773E-001
WP-TYPE-TMIL	Developed Event (top event substitution for WP-TYPE (TMIL)	9.773E-001
WP-TYPE-NAVALSH	Developed Event (top event substitution for WP-TYPE (NAVALSH	5.200E-001
WP-TYPE-NAVALL	Developed Event (top event substitution for WP-TYPE (NAVALL)	5.200E-001

Table B-1. Basic Event Assignments For SAPHIRE Criticality FEPs Analysis

Name	Description	Probability
INITIATING EVENTS FOR THE WASTE PACKAGE TYPE EVENT TREES		
WP01-21-PWR-AP	21-PWR with Absorber Plates Waste Package	1.000E+000
WP02-21-PWR-CR	21-PWR with Control Rods Waste Package	1.000E+000
WP03-12-PWR-AP	12-PWR with Absorber Plates Waste Package	1.000E+000
WP04-24-BWR-AP	24-BWR with Absorber Plates Waste Package	1.000E+000
WP05-44-BWR-AP	44-BWR with Absorber Plates Waste Package	1.000E+000
WP06-DOE1-SHORT	5 DHLW/DOE Short Waste Package with FFTF Fuel	1.000E+000
WP07-DOE1-LONG	5 DHLW/DOE Long Waste Package with FFTF Fuel	1.000E+000
WP08-DOE2-SHORT	5 DHLW/DOE Short Waste Package with TRIGA Fuel	1.000E+000
WP09-DOE3-SHORT	5 DHLW/DOE Short Waste Package with N Reactor Fuel	1.000E+000
WP10-DOE3-LONG	5 DHLW/DOE Long Waste Package with N Reactor Fuel	1.000E+000
WP11-DOE3-MCO	2-MCO/2-DHLW Waste Package with N Reactor Fuel	1.000E+000
WP12-DOE4-SHORT	5 DHLW/DOE Short Waste Package with Shippingport PWR	1.000E+000
WP13-DOE4-LONG	5 DHLW/DOE Long Waste Package with Shippingport PWR	1.000E+000
WP14-DOE5-SHORT	5 DHLW/DOE Short Waste Package with Shippingport LWBR	1.000E+000
WP15-DOE5-LONG	5 DHLW/DOE Long Waste Package with Shippingport LWBR	1.000E+000
WP16-DOE6-LONG	5 DHLW/DOE Long Waste Package with Fort St. Vrain Fuel	1.000E+000
WP17-DOE7-SHORT	5 DHLW/DOE Short Waste Package with Melt & Dilute Fuel	1.000E+000
WP18-DOE7-LONG	5 DHLW/DOE Long Waste Package with Melt & Dilute Fuel	1.000E+000
WP19-DOE8-SHORT	5 DHLW/DOE Short Waste Package with Fermi Fuel	1.000E+000
WP20-DOE8-LONG	5 DHLW/DOE Long Waste Package with Fermi Fuel	1.000E+000
WP21-DOE9-SHORT	5 DHLW/DOE Short Waste Package with TMI II Fuel	1.000E+000
WP22-DOE9-LONG	5 DHLW/DOE Long Waste Package with TMI II Fuel	1.000E+000

B.24 SAPHIRE END STATE RESULTS FOR CRITICALITY FEPS ANALYSIS

Table B-2 presents the criticality FEPs analysis probability results as calculated by SAPHIRE. The 11- to 12-character end-state names are encoded to capture the following information:

1. The criticality FEPs analysis cases
    - BC – base case
    - SG – seismic disruptive event, ground motion scenario
    - SF – seismic disruptive event, faulting scenario
    - RF – rock fall disruptive event
    - IE – igneous disruptive event, eruptive scenario
    - II – igneous disruptive event, intrusive scenario

2. The waste package/waste form type
    - -WP01 – 21–PWR Absorber Plate waste package
    - -WP02 – 21–PWR Control Rod waste package
    - -WP03 – 12–PWR Absorber Plate waste package
    - -WP04 – 24–BWR Absorber Plate waste package
    - -WP05 – 44–BWR Absorber Plate waste package
    - -WP06 – Mixed Oxide 5–DHLW/DOE Short waste package
    - -WP07 – Mixed Oxide 5–DHLW/DOE Long waste package
    - -WP08 – Uranium-Zirconium Hydride 5–DHLW/DOE Short waste package
    - -WP09 – Uranium Metal 5–DHLW/DOE Short waste package
    - -WP10 – Uranium Metal 5–DHLW/DOE Long waste package
    - -WP11 – Uranium Metal 2–MCO/2–DHLW MCO waste package
    - -WP12 – High-Enriched Uranium Oxide 5–DHLW/DOE Short waste package
    - -WP13 – High-Enriched Uranium Oxide 5–DHLW/DOE Long waste package
    - -WP14 – Uranium/Thorium Oxide 5–DHLW/DOE Short waste package
    - -WP15 – Uranium/Thorium Oxide 5–DHLW/DOE Long waste package
    - -WP16 – Uranium/Thorium Carbide 5–DHLW/DOE Long waste package
    - -WP17 – Aluminum Based 5–DHLW/DOE Short waste package
    - -WP18 – Aluminum Based 5–DHLW/DOE Long waste package
    - -WP19 – Uranium-Zirconium/Uranium-Molybdenum 5–DHLW/DOE Short waste package
    - -WP20 – Uranium-Zirconium/Uranium-Molybdenum 5-DHLW/DOE Long waste package
    - -WP21 – Low-Enriched Uranium Oxide 5–DHLW/DOE Short waste package
    - -WP22 – Low-Enriched Uranium Oxide 5–DHLW/DOE Long waste package

3. The configuration class
    - -IPDRY – in-package, configuration class IP-DRY
    - -IP1A – in-package, configuration class IP-1A
    - -IP1B – in-package, configuration class IP-1A
    - -IP2A – in-package, configuration class IP-1A
    - -IP3A – in-package, configuration class IP-1A

- -IP3B – in-package, configuration class IP-1A
- -IP3C – in-package, configuration class IP-1A
- -IP3D – in-package, configuration class IP-1A
- -IP4A – in-package, configuration class IP-1A
- -IP4B – in-package, configuration class IP-1A
- -IP5A – in-package, configuration class IP-1A
- -IP6A – in-package, configuration class IP-6A
- -NF1A – near-field, configuration class NF-1A
- -NF1B – near-field, configuration class NF-1B
- -NF1C – near-field, configuration class NF-1C
- -NFDD – near-field, configuration class NF-DD
- -NF4A – near-field, configuration class NF-4A
- -NF5A – near-field, configuration class NF-5A
- -FF1A – far-field, configuration class FF-1A
- -FF1B – far-field, configuration class FF-1B
- -FF1C – far-field, configuration class FF-1C
- -FF2A – far-field, configuration class FF-2A
- -FF2B – far-field, configuration class FF-2B
- -FF3A – far-field, configuration class FF-3A
- -FF3B – far-field, configuration class FF-3B
- -FF3C – far-field, configuration class FF-3C
- -FF3D – far-field, configuration class FF-3D
- -FF3E – far-field, configuration class FF-3E
- -IGE1 – igneous eruptive, configuration class IG-E1
- -IGE2 – igneous eruptive, configuration class IG-E2
- -IGE3 – igneous eruptive, configuration class IG-E3
- -IGE4 – igneous eruptive, configuration class IG-E4
- -IGI1 – igneous intrusive, configuration class IG-I1
- -IGI2 – igneous intrusive, configuration class IG-I2
- -IGI3 – igneous intrusive, configuration class IG-I3
- -IGI4 – igneous intrusive, configuration class IG-I4
- -IGI5 – igneous intrusive, configuration class IG-I5
- -IGI6 – igneous intrusive, configuration class IG-I6

The end states are assigned to each event tree sequence based on the project partition rules documented in Section B.22.

Table B-2. SAPHIRE End State Probabilities

End State Name	Configuration Class Probability
Igneous Disruptive Event Results, Eruptive Scenario	
IE-WP01-IGI1	1.109E-12
IE-WP01-IGI2	5.754E-13
IE-WP02-IGI1	6.211E-12
IE-WP02-IGI2	3.229E-12
IE-WP03-IGI1	8.438E-15
IE-WP03-IGI2	3.109E-15
IE-WP04-IGI1	8.438E-15
IE-WP04-IGI2	3.109E-15
IE-WP05-IGI1	8.438E-15
IE-WP05-IGI2	3.109E-15
IE-WP06-IGI1	2.010E-12
IE-WP06-IGI2	1.044E-12
IE-WP07-IGI1	2.010E-12
IE-WP07-IGI2	1.044E-12
IE-WP08-IGI1	8.438E-15
IE-WP08-IGI2	3.109E-15
IE-WP14-IGI1	5.301E-12
IE-WP14-IGI2	2.756E-12
IE-WP15-IGI1	5.301E-12
IE-WP15-IGI2	2.756E-12
IE-WP17-IGI1	8.438E-15
IE-WP17-IGI2	3.109E-15
IE-WP18-IGI1	8.438E-15
IE-WP18-IGI2	3.109E-15
IE-WP19-IGI1	5.309E-12
IE-WP19-IGI2	2.761E-12
IE-WP20-IGI1	5.309E-12
IE-WP20-IGI2	2.761E-12
Igneous Disruptive Event Results, Intrusive Scenario	
II-WP01-IGI1	1.421E-12
II-WP01-IGI2	7.381E-13
II-WP02-IGI1	7.962E-12
II-WP02-IGI2	4.140E-12
II-WP03-IGI1	1.088E-14
II-WP03-IGI2	3.997E-15
II-WP04-IGI1	1.088E-14
II-WP04-IGI2	3.997E-15
II-WP05-IGI1	1.088E-14
II-WP05-IGI2	3.997E-15
II-WP06-IGI1	2.577E-12
II-WP06-IGI2	1.338E-12
II-WP07-IGI1	2.577E-12

Table B-2. SAPHIRE End State Probabilities

End State Name	Configuration Class Probability
II-WP07-IGI2	1.338E-12
II-WP08-IGI1	1.088E-14
II-WP08-IGI2	3.997E-15
II-WP14-IGI1	6.797E-12
II-WP14-IGI2	3.534E-12
II-WP15-IGI1	6.797E-12
II-WP15-IGI2	3.534E-12
II-WP17-IGI1	1.088E-14
II-WP17-IGI2	3.997E-15
II-WP18-IGI1	1.088E-14
II-WP18-IGI2	3.997E-15
II-WP19-IGI1	6.807E-12
II-WP19-IGI2	3.539E-12
II-WP20-IGI1	6.807E-12
II-WP20-IGI2	3.539E-12
Seismic Disruptive Event Results, Faulting Scenario	
SF-WP01-IP1A	1.550E-11
SF-WP01-IP1B	1.550E-11
SF-WP01-IP4A	1.550E-11
SF-WP02-IP1A	8.690E-11
SF-WP02-IP1B	8.690E-11
SF-WP02-IP4A	8.690E-11
SF-WP03-IP1A	1.097E-13
SF-WP03-IP1B	1.097E-13
SF-WP03-IP4A	1.097E-13
SF-WP04-IP1A	1.096E-13
SF-WP04-IP1B	1.096E-13
SF-WP04-IP4A	1.096E-13
SF-WP05-IP1A	1.093E-13
SF-WP05-IP1B	1.093E-13
SF-WP05-IP4A	1.093E-13
SF-WP06-IP1A	2.812E-11
SF-WP06-IP1B	2.812E-11
SF-WP06-IP4A	2.812E-11
SF-WP07-IP1A	2.812E-11
SF-WP07-IP1B	2.812E-11
SF-WP07-IP4A	2.812E-11
SF-WP08-IP1A	1.108E-13
SF-WP08-IP1B	1.108E-13
SF-WP08-IP4A	1.108E-13
SF-WP14-IP1A	7.417E-11
SF-WP14-IP1B	7.417E-11
SF-WP14-IP4A	7.417E-11
SF-WP15-IP1A	7.417E-11
SF-WP15-IP1B	7.417E-11
SF-WP15-IP4A	7.417E-11

Table B-2. SAPHIRE End State Probabilities

End State Name	Configuration Class Probability
SF-WP17-IP1A	1.108E-13
SF-WP17-IP1B	1.108E-13
SF-WP17-IP4A	1.108E-13
SF-WP18-IP1A	1.107E-13
SF-WP18-IP1B	1.107E-13
SF-WP18-IP4A	1.107E-13
SF-WP19-IP1A	7.429E-11
SF-WP19-IP1B	7.429E-11
SF-WP19-IP4A	7.429E-11
SF-WP20-IP1A	7.429E-11
SF-WP20-IP1B	7.429E-11
SF-WP20-IP4A	7.429E-11
TOTALS =	**1.482E-09**

APPENDIX C

SEEPAGE ANALYSIS SPREADSHEETS (OUTPUT FROM MATHCAD FILES)

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APPENDIX C - SEEPAGE ANALYSIS SPREADSHEETS (OUTPUT FROM MATHCAD FILES)

The following sections presents the Mathcad analysis for the lower, mean, and upper seepage infiltration rates of the glacial transition climate in both the lithophysal and nonlithophysal zones. The following sections are broken into nominal seepage infiltration rates, seismic infiltration rates, and finally igneous infiltration rates in both the lithophysal and nonlithophysal zones.

C.1 NOMINAL SEEPAGE ANALYSIS FOR INFILTRATION RATE AND SEEPAGE FRACTION IN THE LITHOPHYSAL ZONE

This section presents the Mathcad analysis for calculating the nominal seepage fraction and nominal seepage infiltration rates (i.e., lower bound, mean, and upper bound) for the lithophysal zone during the glacial transition period. The seepage information used in the analysis was obtained from *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1). The information contained in this section has been abstracted from the "LA seepage glac Tptpll weibull.mcd" Mathcad file of Appendix G.

Seepage Flux and Seepage Fraction Calculation using *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1)

Latin Hypercube Sampling Routine to Generate Random Numbers

size of the sampling: $n := 20000$

$i := 1..n$

$RD_{i-1,0} := i \qquad RD_{i-1,1} := \mathrm{rnd}(1.0) \qquad RD_{i-1,2} := \mathrm{rnd}(1.0) \qquad RD_{i-1,3} := \mathrm{rnd}(1.0)$

$RD_{i-1,4} := \mathrm{rnd}(1.0) \qquad RD_{i-1,5} := \mathrm{rnd}(1.0) \qquad RD_{i-1,6} := \mathrm{rnd}(1.0)$

RK's are matrixes in which the first column contain a permutation on the integers on the interval [1,n].

$RK1 := \mathrm{csort}(RD,1) \qquad RK2 := \mathrm{csort}(RD,2) \qquad RK3 := \mathrm{csort}(RD,3)$

$RK4 := \mathrm{csort}(RD,4) \qquad RK5 := \mathrm{csort}(RD,5) \qquad RK6 := \mathrm{csort}(RD,6)$

Define sets of random values. Each random value is selected within one of the equiprobable n intervals that partition [0,1]. One set for each random variable.

$$X^{\langle 0\rangle} := \frac{RK1^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \qquad X^{\langle 1\rangle} := \frac{RK2^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \qquad X^{\langle 2\rangle} := \frac{RK3^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n}$$

$$X^{\langle 3\rangle} := \frac{RK4^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \qquad X^{\langle 4\rangle} := \frac{RK5^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \qquad X^{\langle 5\rangle} := \frac{RK6^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n}$$

$i := 0..n-1$

Capillary Strength 1/ α in (Pa)

$\alpha 1_{lb} := 402 \quad \alpha 1_{ub} := 780 \quad \alpha 1_{\mu} := 591$ spatial variability follows a uniform distribution

$\Delta\alpha 1_{l} := -105 \quad \Delta\alpha 1_{\mu} := 0 \quad \Delta\alpha 1_{u} := 105$ uncertainty follows a triangular distribution

Sampling from spatial variability to obtain the 1/ α value

$\alpha 1_i := \mathrm{qunif}\left(X_{i,0}, \alpha 1_{lb}, \alpha 1_{ub}\right)$ 1/α value

Sample from uncertainty triangular distribution to obtain $\Delta 1/\alpha$

Determine which equation to use:
if Random Number < RN $_{\Delta\alpha 1}$ then use Equation 1 ($\Delta\alpha$1eq1)
if Random Number > RN $_{\Delta\alpha 1}$ then use Equation 2 ($\Delta\alpha$1eq2)

$$RN_{\Delta\alpha 1} := \frac{\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)^2}{\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq1_i} := \Delta\alpha 1_{l} + \sqrt{X_{i,1}\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq2_i} := \Delta\alpha 1_{u} - \sqrt{\left(1 - X_{i,1}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{\mu}\right)}$$

$\Delta\alpha 1_i := \mathrm{if}\left[\left(X_{i,1} \le RN_{\Delta\alpha 1}\right), \Delta\alpha 1_{eq1_i}, \Delta\alpha 1_{eq2_i}\right]$ Δ1/α value

Overall Capillary Strength 1/ α + Δ1/α

$T_{1\alpha_i} := \alpha 1_i + \Delta\alpha 1_i$ 1/α value

Permeability k in TptpII Unit (in log 10)

$\mu_{kTl} := -11.5$ mean of lognormal distribution

$\sigma_{kTl} := 0.47$ standard deviation of lognormal distribution

$k_{Tl_i} := \ln\left(\text{qlnorm}\left(X_{i,2}, \mu_{kTl}, \sigma_{kTl}\right)\right)$

$\text{mean}\left(k_{Tl}\right) = -11.5$

$\text{Stdev}\left(k_{Tl}\right) = 0.47$

Permeability Δk in TptpII Unit (in log 10)

$\Delta k_{Tll} := -0.92$ $\Delta k_{Tl\mu} := 0$ $\Delta k_{Tlu} := 0.92$ uncertainty follows a triangular distribution

Sample from uncertainty triangular distribution to obtain Δk

Determine which equation to use:
if Random Number < $RN_{\Delta kTl}$ then use Equation 1 (ΔkTleq1)
if Random Number > $RN_{\Delta kTl}$ then use Equation 2 (ΔkTleq2)

$$RN_{\Delta kTl} := \frac{\left(\Delta k_{Tl\mu} - \Delta k_{Tll}\right)^2}{\left(\Delta k_{Tlu} - \Delta k_{Tll}\right)\cdot\left(\Delta k_{Tl\mu} - \Delta k_{Tll}\right)}$$

$$\Delta kTl_{eq1_i} := \Delta k_{Tll} + \sqrt{X_{i,3}\cdot\left(\Delta k_{Tlu} - \Delta k_{Tll}\right)\cdot\left(\Delta k_{Tl\mu} - \Delta k_{Tll}\right)}$$

$$\Delta kTl_{eq2_i} := \Delta k_{Tlu} - \sqrt{\left(1 - X_{i,3}\right)\cdot\left(\Delta k_{Tlu} - \Delta k_{Tll}\right)\cdot\left(\Delta k_{Tlu} - \Delta k_{Tl\mu}\right)}$$

$\Delta k_{Tl_i} := \text{if}\left[\left(X_{i,3} \le RN_{\Delta kTl}\right), \Delta kTl_{eq1_i}, \Delta kTl_{eq2_i}\right]$ Δk value

Overall Permeability k + Δk

$T1_{kTl_i} := k_{Tl_i} + \Delta k_{Tl_i}$

Permeability must lie between -14 and -10 (bounds of SMPA simulations)

$T_{kTl_i} := \text{if}\left(T1_{kTl_i} \ge -10, -10, \text{if}\left(T1_{kTl_i} \le -14, -14, T1_{kTl_i}\right)\right)$ k value

Flow Focusing Factor

$$f(x) := -0.3137\cdot x^4 + 5.4998\cdot x^3 - 35.66\cdot x^2 + 102.3\cdot x - 11.434$$

$$ff_i := \text{root}\left[f(x) - \left(X_{i,4}\cdot 100\right), x, 0, 6\right]$$

Percolation Flux (mm/yr)

The percolation flux used here is for the glacial transition period only. The percolation flux is based on sampling from the lower bound (TSPA repository location). DTN: LB0310AMRU0120.002 [DIRS 166116]

$nnn := 0..468$ number of data points

Lower Bound Percolation Flux

$PF1_l :=$

	0
0	3.68
1	2.65
2	2.41
3	2.13
4	2.41
5	2.4
6	2.12
7	2.76
8	1.4
9	2.21

$PFt_{l_{nnn}} := PF1_{l_{nnn,0}}$

$Z^{\langle 0 \rangle} := \mathrm{round}(\mathrm{runif}(n, 0, 468))$

$PF_{l_i} := PFt_{l_{\left(Z_{i,0}\right)}}$

Mean Bound Percolation Flux

$PF1_m :=$

	0
0	15.97
1	19.87
2	14.2
3	7.59
4	16.94
5	17.76
6	10.45
7	27.77
8	8.95
9	16.02

$PFt_{m_{nnn}} := PF1_{m_{nnn,0}}$

$PF_{m_i} := PFt_{m_{\left(Z_{i,0}\right)}}$

Upper Bound Percolation Flux

$PF1_u :=$

	0
0	40
1	36.19
2	35.73
3	27.83
4	30.74
5	40.03
6	31.86
7	57.08
8	18.33
9	27.91

$PFt_{u_{nnn}} := PF1_{u_{nnn,0}}$

$PF_{u_i} := PFt_{u_{\left(Z_{i,0}\right)}}$

Adjusted Percolation Flux

Take the flow focusing factor and multiply it to the percolation flux, which will be used to obtain the seepage rate, seepage fraction, and seepage percentage.

$q1_{pff_i} := PF_{l_i} \cdot ff_i$ $\quad qm_{pff_i} := PF_{m_i} \cdot ff_i$ $\quad qu_{pff_i} := PF_{u_i} \cdot ff_i$

$q_{pff} := \mathrm{augment}\left(q1_{pff}, qm_{pff}, qu_{pff}\right)$

Percolation Flux must lie between 1 and 1000 mm/yr (bounds of SMPA simulations)

$j := 0..2$

$q_{pff_{i,j}} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(q_{pff_{i,j}} \ge 1000, 1000, q_{pff_{i,j}}\right)\right)$

Seepage Information from SMPA analysis

$m := 2549$ data points

$SMPA_{data}{}^{<0>}$ is permeability value log(k [m^2])

$SMPA_{data}{}^{<1>}$ is capillary strength 1/alpha [Pa]

$SMPA_{data}{}^{<2>}$ is local percolation flux (mm/yr)

$SMPA_{data}{}^{<3>}$ is Mean Seepage [kg/yr/WP]

$SMPA_{data}{}^{<4>}$ is Std. Dev. Seepage [kg/yr/WP]

$SMPA_{data}{}^{<5>}$ is Mean Seepage [%]

$SMPA_{data}{}^{<6>}$ is Std. Dev. Seepage [%]

$SMPA_{data} :=$

	0	1	2	3	4	5	6
0	-14	100	1	27.73	4.09	98.86	14.59
1	-14	100	5	138.92	20.55	99.05	14.65
2	-14	100	10	277.9	41.19	99.07	14.68
3	-14	100	20	555.87	82.54	99.09	14.71
4	-14	100	50	1391.67	205.57	99.23	14.66
5	-14	100	100	2793.55	406.7	99.59	14.5
6	-14	100	200	5610	785	100	14
7	-14	100	300	8415	1178	100	14
8	-14	100	400	11220	1570	100	14
9	-14	100	500	14025	1963	100	14
10	-14	100	600	16830	2356	100	14
11	-14	100	700	19635	2748	100	14
12	-14	100	800	22440	3141	100	14
13	-14	100	900	25245	3590	100	14
14	-14	100	1000	28050	3989	100	14
15	-14	200	1	26.14	4.21	93.21	15

Set up routine to pick out correct mean seepage flux and seepage flux standard deviation based on sampled value of 1/ α, k, percolation flux.

$nx := 14 \quad ny := 9 \quad nz := 16$

$ii := 0..\,nx$

$x_{ii} := SMPA_{data_{ii,2}} \qquad xi_{ii} := ii$

$jj := 0..\,ny$

$y_{jj} := 100 \cdot jj + 100 \qquad yj_{jj} := jj$

$kk := 0..\,nz$

$z_{kk} := -14 + kk \cdot 0.25 \quad zk_{kk} := kk$

loc represents the location within the matrix of which value to pick for the interpolation process.

$$loc_{1_{i,j}} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms1_{i,j}} := SMPA_{data_{loc_{1_{i,j}},3}}$$

$$s_{msd1_{i,j}} := SMPA_{data_{loc_{1_{i,j}},4}}$$

$$loc_{2_{i,j}} := \left[\mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms2_{i,j}} := SMPA_{data_{loc_{2_{i,j}},3}}$$

$$s_{msd2_{i,j}} := SMPA_{data_{loc_{2_{i,j}},4}}$$

$$\begin{aligned} loc_{3_{i,j}} &:= \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots \\ &\quad + \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right) \end{aligned}$$

$$s_{ms3_{i,j}} := SMPA_{data_{loc_{3_{i,j}},3}}$$

$$s_{msd3_{i,j}} := SMPA_{data_{loc_{3_{i,j}},4}}$$

$$\begin{aligned} loc_{4_{i,j}} &:= \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots \\ &\quad + \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right) \end{aligned}$$

$$s_{ms4_{i,j}} := SMPA_{data_{loc_{4_{i,j}},3}}$$

$$s_{msd4_{i,j}} := SMPA_{data_{loc_{4_{i,j}},4}}$$

$$\begin{aligned} loc_{5_{i,j}} &:= \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots \\ &\quad + \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right) \end{aligned}$$

$$s_{ms5_{i,j}} := SMPA_{data_{loc_{5_{i,j}},3}}$$

$$s_{msd5_{i,j}} := SMPA_{data_{loc_{5_{i,j}},4}}$$

$$\begin{aligned} loc_{6_{i,j}} &:= \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots \\ &\quad + \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right) \end{aligned}$$

$$s_{ms6_{i,j}} := SMPA_{data_{loc_{6_{i,j}},3}}$$

$$s_{msd6_{i,j}} := SMPA_{data_{loc_{6_{i,j}},4}}$$

$$\begin{aligned} loc_{7_{i,j}} &:= \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots \\ &\quad + \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right) \end{aligned}$$

$$s_{ms7_{i,j}} := SMPA_{data_{loc_{7_{i,j}},3}}$$

$$s_{msd7_{i,j}} := SMPA_{data_{loc_{7_{i,j}},4}}$$

$$\begin{aligned} loc_{8_{i,j}} &:= \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots \\ &\quad + \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right) \end{aligned}$$

$$s_{ms8_{i,j}} := SMPA_{data_{loc_{8_{i,j}},3}}$$

$$s_{msd8_{i,j}} := SMPA_{data_{loc_{8_{i,j}},4}}$$

Develop the upper and lower bound for permeability (k) for Tptpll Unit

$$qq_i := -1 \cdot T_{kTl_i}$$

$$\mathrm{mantissa}(x) := x - \mathrm{floor}(qq)$$

$$tt_i := \mathrm{floor}\left(qq_i\right)$$

$$rr := \mathrm{round}(\mathrm{mantissa}(qq), 2)$$

$$yy1_i := \mathrm{if}\left(rr_i \le 0.25, 0, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.25, rr_i\right)\right)$$

$$zz1_i := \mathrm{if}\left(yy1_i \le 0.5, yy1_i, \mathrm{if}\left(0.5 < yy1_i \le 0.75, 0.5, 0.75\right)\right)$$

$$T_{kTl2_i} := -1 \cdot \left(tt_i + zz1_i\right)$$

$$yy2_i := \mathrm{if}\left(rr_i \le 0.25, 0.25, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.5, rr_i\right)\right)$$

$$zz2_i := \mathrm{if}\left(yy2_i \le 0.5, yy2_i, \mathrm{if}\left(0.5 < yy2_i \le 0.75, 0.75, 1\right)\right)$$

$$T_{kTl1_i} := -1 \cdot \left(tt_i + zz2_i\right)$$

Develop the upper and lower bound for capillary strength (1/ α).

$$hh1_i := \mathrm{floor}\left(\frac{T_{1\alpha_i}}{100}\right)$$

$$T_{1\alpha1_i} := \left(hh1_i \cdot 100\right)$$

$$hh2_i := \mathrm{ceil}\left(\frac{T_{1\alpha_i}}{100}\right)$$

$$T_{1\alpha2_i} := \left(hh2_i \cdot 100\right)$$

Lower Bound value adjusted percolation flux (q $_{\mathbf{pff}}$).

$$aaa1_{i,j} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(1 < q_{pff_{i,j}} \le 5, 1, q_{pff_{i,j}}\right)\right)$$

$$bbb1_{i,j} := \mathrm{if}\left(aaa1_{i,j} \le 5, aaa1_{i,j}, \mathrm{if}\left(5 < aaa1_{i,j} \le 10, 5, aaa1_{i,j}\right)\right)$$

$$ccc1_{i,j} := \mathrm{if}\left(bbb1_{i,j} \le 10, bbb1_{i,j}, \mathrm{if}\left(10 < bbb1_{i,j} \le 20, 10, bbb1_{i,j}\right)\right)$$

$$ddd1_{i,j} := \mathrm{if}\left(ccc1_{i,j} \le 20, ccc1_{i,j}, \mathrm{if}\left(20 < ccc1_{i,j} \le 50, 20, ccc1_{i,j}\right)\right)$$

$$eee1_{i,j} := \mathrm{if}\left(ddd1_{i,j} \le 50, ddd1_{i,j}, \mathrm{if}\left(50 < ddd1_{i,j} \le 100, 50, ddd1_{i,j}\right)\right)$$

$$fff1_{i,j} := \mathrm{if}\left(eee1_{i,j} \le 100, eee1_{i,j}, \mathrm{if}\left(100 < eee1_{i,j} \le 200, 100, eee1_{i,j}\right)\right)$$

$$ggg1_{i,j} := \mathrm{if}\left(fff1_{i,j} \le 200, fff1_{i,j}, \mathrm{if}\left(200 < fff1_{i,j} \le 300, 200, fff1_{i,j}\right)\right)$$

$$hhh1_{i,j} := \mathrm{if}\left(ggg1_{i,j} \le 300, ggg1_{i,j}, \mathrm{if}\left(300 < ggg1_{i,j} \le 400, 300, ggg1_{i,j}\right)\right)$$

$$iii1_{i,j} := \mathrm{if}\left(hhh1_{i,j} \le 400, hhh1_{i,j}, \mathrm{if}\left(400 < hhh1_{i,j} \le 500, 400, hhh1_{i,j}\right)\right)$$

$$jjj1_{i,j} := \mathrm{if}\left(iii1_{i,j} \le 500, iii1_{i,j}, \mathrm{if}\left(500 < iii1_{i,j} \le 600, 500, iii1_{i,j}\right)\right)$$

$$kkk1_{i,j} := if\left(jjj1_{i,j} \le 600, jjj1_{i,j}, if\left(600 < jjj1_{i,j} \le 700, 600, jjj1_{i,j}\right)\right)$$

$$mmm1_{i,j} := if\left(kkk1_{i,j} \le 700, kkk1_{i,j}, if\left(700 < kkk1_{i,j} \le 800, 700, kkk1_{i,j}\right)\right)$$

$$q_{pff1_{i,j}} := if\left(mmm1_{i,j} \le 800, mmm1_{i,j}, if\left(800 < mmm1_{i,j} \le 900, 800, 900\right)\right)$$

Upper Bound value adjusted percolation flux (q_{pff}).

$$aaa2_{i,j} := if\left(q_{pff_{i,j}} \le 1, 5, if\left(1 < q_{pff_{i,j}} \le 5, 5, q_{pff_{i,j}}\right)\right)$$

$$bbb2_{i,j} := if\left(aaa2_{i,j} \le 5, aaa2_{i,j}, if\left(5 < aaa2_{i,j} \le 10, 10, aaa2_{i,j}\right)\right)$$

$$ccc2_{i,j} := if\left(bbb2_{i,j} \le 10, bbb2_{i,j}, if\left(10 < bbb2_{i,j} \le 20, 20, bbb2_{i,j}\right)\right)$$

$$ddd2_{i,j} := if\left(ccc2_{i,j} \le 20, ccc2_{i,j}, if\left(20 < ccc2_{i,j} \le 50, 50, ccc2_{i,j}\right)\right)$$

$$eee2_{i,j} := if\left(ddd2_{i,j} \le 50, ddd2_{i,j}, if\left(50 < ddd2_{i,j} \le 100, 100, ddd2_{i,j}\right)\right)$$

$$fff2_{i,j} := if\left(eee2_{i,j} \le 100, eee2_{i,j}, if\left(100 < eee2_{i,j} \le 200, 200, eee2_{i,j}\right)\right)$$

$$ggg2_{i,j} := if\left(fff2_{i,j} \le 200, fff2_{i,j}, if\left(200 < fff2_{i,j} \le 300, 300, fff2_{i,j}\right)\right)$$

$$hhh2_{i,j} := if\left(ggg2_{i,j} \le 300, ggg2_{i,j}, if\left(300 < ggg2_{i,j} \le 400, 400, ggg2_{i,j}\right)\right)$$

$$iii2_{i,j} := if\left(hhh2_{i,j} \le 400, hhh2_{i,j}, if\left(400 < hhh2_{i,j} \le 500, 500, hhh2_{i,j}\right)\right)$$

$$jjj2_{i,j} := if\left(iii2_{i,j} \le 500, iii2_{i,j}, if\left(500 < iii2_{i,j} \le 600, 600, iii2_{i,j}\right)\right)$$

$$kkk2_{i,j} := if\left(jjj2_{i,j} \le 600, jjj2_{i,j}, if\left(600 < jjj2_{i,j} \le 700, 700, jjj2_{i,j}\right)\right)$$

$$mmm2_{i,j} := if\left(kkk2_{i,j} \le 700, kkk2_{i,j}, if\left(700 < kkk2_{i,j} \le 800, 800, kkk2_{i,j}\right)\right)$$

$$q_{pff2_{i,j}} := if\left(mmm2_{i,j} \le 800, mmm2_{i,j}, if\left(800 < mmm2_{i,j} \le 900, 900, 1000\right)\right)$$

Interpolate (Solve) for seepage flux (Tptpll Unit)

$$u_{T1\alpha_i} := \frac{T_{1\alpha_i} - T_{1\alpha1_i}}{T_{1\alpha2_i} - T_{1\alpha1_i}} \qquad v_{TkTl_i} := \frac{T_{kTl_i} - T_{kTl1_i}}{T_{kTl2_i} - T_{kTl1_i}} \qquad t_{qpff_{i,j}} := \frac{q_{pff_{i,j}} - q_{pff1_{i,j}}}{q_{pff2_{i,j}} - q_{pff1_{i,j}}}$$

$$\begin{aligned}
spflux_{Tlm_{i,j}} := &\left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms1_{i,j}} \cdots \\
&+ \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms2_{i,j}} \cdots \\
&+ \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms3_{i,j}} \cdots \\
&+ \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms4_{i,j}} \cdots \\
&+ \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms5_{i,j}} \cdots \\
&+ \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms6_{i,j}} \cdots \\
&+ \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms7_{i,j}} \cdots \\
&+ \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms8_{i,j}}
\end{aligned}$$

$$\begin{aligned} spflux_{Tlsd_{i,j}} := {} & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd1_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd2_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd3_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd4_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd5_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd6_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd7_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd8_{i,j}} \end{aligned}$$

Calculate mean seepage for (lower bound) Tptpll Unit.

$$QTl1_{lstdl_i} := -1.7321\cdot spflux_{Tlsd_{i,0}}$$

$$QTl1_{lstdu_i} := 1.7321\cdot spflux_{Tlsd_{i,0}}$$

$$QTl_{lstdl_i} := if\left(QTl1_{lstdl_i} = 0, -0.00001, QTl1_{lstdl_i}\right)$$

$$QTl_{lstd_i} := qunif\left(X_{i,5}, QTl_{lstdl_i}, QTl1_{lstdu_i}\right)$$

$$QTl1_{lspm_i} := spflux_{Tlm_{i,0}} + QTl_{lstd_i}$$

$$QTl2_{lspm_i} := if\left(QTl1_{lspm_i} \le 0.1, 0, QTl1_{lspm_i}\right)$$

$$QT2_{lperc_i} := \frac{QTl2_{lspm_i}\cdot 100}{q_{pff_{i,0}}\cdot 28.05}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{lperc_i} := if\left(QT2_{lperc_i} \le 0, 0, if\left(QT2_{lperc_i} \ge 100, 100, QT2_{lperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTl_{lspr_i} := QT3_{lperc_i}\cdot q_{pff_{i,0}}\cdot\frac{28.05}{100}$$

$$mean\left(QTl_{lspr}\right) = 0.415$$

Mean Seepage Flux (kg/yr/WP)

Determine the seepage fraction for Tptpll Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$$sort\left(QTl_{lspr}\right) =$$

	0
0	0
1	0
2	0
3	0
4	0

$$num1_{l_i} := if\left(QTl_{lspr_i} > 0, 1, 0\right)$$

Number of seepage rates greater than zero.

$$num_l := \sum_{i=0}^{n-1} num1_{l_i}$$

$$n_{lTl} := (n - 1) - num_l \qquad n_{lTl} = 19079$$

$\mathrm{spfrcl}_{\mathrm{Tl}} := \dfrac{\mathrm{num}_{\mathrm{l}}}{\mathrm{n}}$ $\mathrm{spfrcl}_{\mathrm{Tl}} = 0.046$

$\mathrm{n1}_{\mathrm{lTl}} := (\mathrm{n} - 1) - \left(\mathrm{n}_{\mathrm{lTl}} + 1\right)$ $\mathrm{n1}_{\mathrm{lTl}} = 919$

$\mathrm{Q11}_{\mathrm{lTl}} := \mathrm{sort}\left(\mathrm{QTl}_{\mathrm{lspr}}\right)$

$\mathrm{Q1}_{\mathrm{lTl}} := \mathrm{reverse}\left(\mathrm{Q11}_{\mathrm{lTl}}\right)$

$\mathrm{ab} := 0 .. \mathrm{n1}_{\mathrm{lTl}}$

$\mathrm{Q2}_{\mathrm{lTl}_{\mathrm{ab}}} := \left(\dfrac{1}{1} \cdot \mathrm{Q1}_{\mathrm{lTl}_{\mathrm{ab}}}\right)$

$\mathrm{Q}_{\mathrm{lTl}} := \mathrm{sort}\left(\mathrm{Q2}_{\mathrm{lTl}}\right)$

$\mathrm{mean}\left(\mathrm{Q}_{\mathrm{lTl}} \cdot 1\right) = 9.025$

$\mathrm{CDF}_{\mathrm{lTl}_{\mathrm{ab}}} := \dfrac{(\mathrm{ab} + 1) - 0.375}{\left(\mathrm{n1}_{\mathrm{lTl}} + 1\right) + 0.25}$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_1 := \mathrm{root}\left[\left[\frac{\left[\displaystyle\sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \left(\mathrm{Q}_{\mathrm{lTl}_i}\right)^{r} \cdot \ln\left(\mathrm{Q}_{\mathrm{lTl}_i}\right)\right]}{\displaystyle\sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \left(\mathrm{Q}_{\mathrm{lTl}_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{\mathrm{n1}_{\mathrm{lTl}}}\right) \cdot \sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \ln\left(\mathrm{Q}_{\mathrm{lTl}_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_1 = 0.534$$

$$\alpha_1 := \left[\frac{\displaystyle\sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \left(\mathrm{Q}_{\mathrm{lTl}_i}\right)^{\beta_1}}{\mathrm{n1}_{\mathrm{lTl}}}\right]^{\frac{1}{\beta_1}} \qquad \alpha_1 = 4.237$$

Plot of raw data versus Weibull distribution

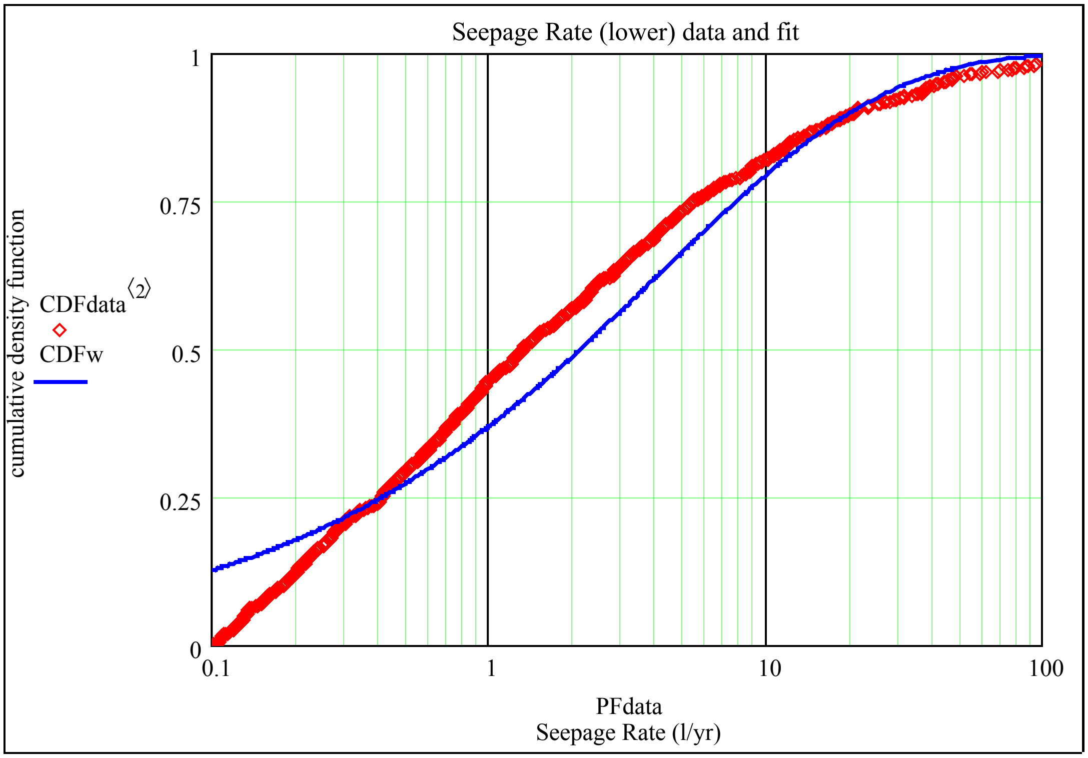
$\mathrm{ji} := 0 .. \mathrm{n1}_{\mathrm{lTl}}$

$\mathrm{PFdata}_{\mathrm{ji}} := \mathrm{Q}_{\mathrm{lTl}_{\mathrm{ji}}}$

$\mathrm{CDFdata}_{\mathrm{ji},2} := \mathrm{CDF}_{\mathrm{lTl}_{\mathrm{ji}}}$

$$\mathrm{CDFw1}_{\mathrm{ji}} := 1 - \exp\left[-\left(\frac{\mathrm{PFdata}_{\mathrm{ji}}}{\alpha_1}\right)^{\beta_1}\right]$$

$\mathrm{CDFw}_{\mathrm{ji},0} := \mathrm{CDFw1}_{\mathrm{ji}}$



Calculate mean seepage for (mean) Tptpll Unit.

$QTl1_{mstdl_i} := -1.7321 \cdot spflux_{Tlsd_{i,1}}$

$QTl1_{mstdu_i} := 1.7321 \cdot spflux_{Tlsd_{i,1}}$

$QTl_{mstdl_i} := if\left(QTl1_{mstdl_i} = 0, -0.00001, QTl1_{mstdl_i}\right)$

$QTl_{mstd_i} := qunif\left(X_{i,5}, QTl_{mstdl_i}, QTl1_{mstdu_i}\right)$

$QTl1_{mspm_i} := spflux_{Tlm_{i,1}} + QTl_{mstd_i}$

$QTl2_{mspm_i} := if\left(QTl1_{mspm_i} \le 0.1, 0, QTl1_{mspm_i}\right)$

$QT2_{mperc_i} := \dfrac{QTl2_{mspm_i} \cdot 100}{q_{pff_{i,1}} \cdot 28.052}$ Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$QT3_{mperc_i} := if\left(QT2_{mperc_i} \le 0, 0, if\left(QT2_{mperc_i} \ge 100, 100, QT2_{mperc_i}\right)\right)$ Check seepage percent to be above 100% and then adjusted back.

$QTl_{mspr_i} := QT3_{mperc_i} \cdot q_{pff_{i,1}} \cdot \dfrac{2 \cdot 28.05}{100}$ **Mean Seepage Flux (kg/yr/WP)**

$mean\left(QTl_{mspr}\right) = 33.425$

Determine the seepage fraction for Tptpll Unit (mean) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTl_{mspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{m_i} := \mathrm{if}\left(QTl_{mspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_m := \sum_{i=0}^{n-1} num1_{m_i}$$

$n_{mTl} := (n-1) - num_m$ $\quad n_{mTl} = 15088$

$spfrcm_{Tl} := \dfrac{num_m}{n}$ $\quad spfrcm_{Tl} = 0.246$

$n1_{mTl} := (n-1) - \left(n_{mTl} + 1\right)$ $\quad n1_{mTl} = 4.91 \times 10^3$

$Q11_{mTl} := \mathrm{sort}\left(QTl_{mspr}\right)$

$Q1_{mTl} := \mathrm{reverse}\left(Q11_{mTl}\right)$

$ab := 0 .. n1_{mTl}$

$Q2_{mTl_{ab}} := \left(\dfrac{1}{1} \cdot Q1_{mTl_{ab}}\right)$

$Q_{mTl} := \mathrm{sort}\left(Q2_{mTl}\right)$

$\mathrm{mean}\left(Q_{mTl} \cdot 1\right) = 136.122$

$$CDF_{mTl_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{mTl} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M [DIRS 104667], p. 109).

$$\beta_m := \mathrm{root}\left[\left[\frac{\left[\displaystyle\sum_{i=0}^{n1_{mTl}} \left(Q_{mTl_i}\right)^r \cdot \ln\left(Q_{mTl_i}\right)\right]}{\displaystyle\sum_{i=0}^{n1_{mTl}} \left(Q_{mTl_i}\right)^r} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{mTl}}\right) \cdot \sum_{i=0}^{n1_{mTl}} \ln\left(Q_{mTl_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_m = 0.438$$

$$\alpha_m := \left[\frac{\displaystyle\sum_{i=0}^{n1_{mTl}} \left(Q_{mTl_i}\right)^{\beta_m}}{n1_{mTl}}\right]^{\frac{1}{\beta_m}} \qquad \alpha_m = 4.56 \times 10^1$$

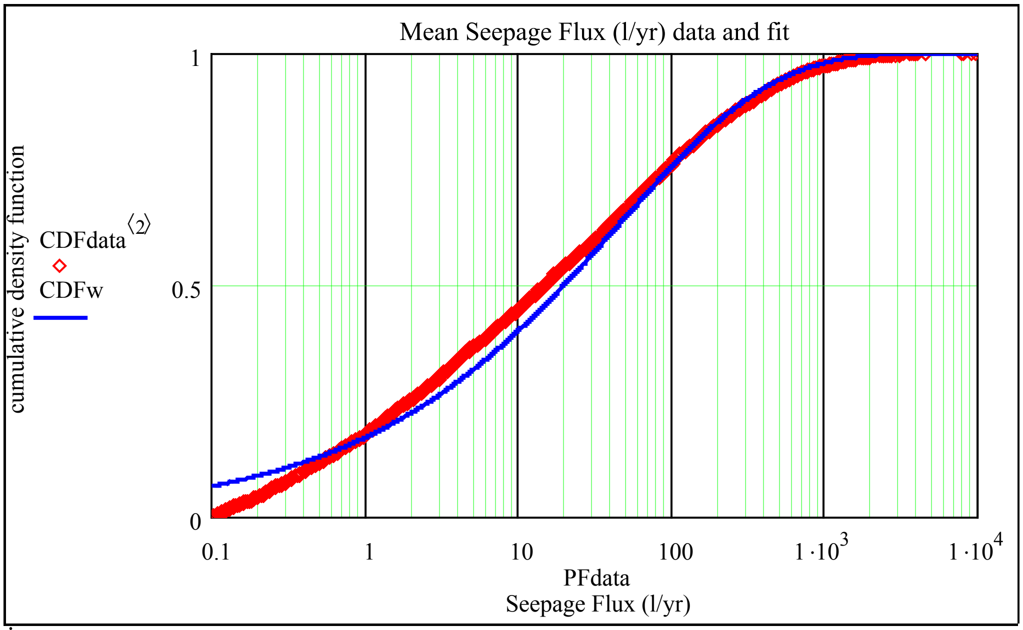
Plot of raw data versus Weibull distribution

$ji := 0 .. n1_{mTl}$

$PFdata_{ji} := Q_{mTl_{ji}}$

$CDFdata_{ji,2} := CDF_{mTl_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_m}\right)^{\beta_m}\right] \qquad CDFw_{ji,0} := CDFw1_{ji}$$



Calculate mean seepage for (upper bound) Tptpll Unit.

$$QT11_{ustdl_i} := -1.7321 \cdot spflux_{Tlsd_{i,2}}$$

$$QT11_{ustdu_i} := 1.7321 \cdot spflux_{Tlsd_{i,2}}$$

$$QTl_{ustdl_i} := if\left(QT11_{ustdl_i} = 0, -0.00001, QT11_{ustdl_i}\right)$$

$$QTl_{ustd_i} := qunif\left(X_{i,5}, QTl_{ustdl_i}, QT11_{ustdu_i}\right)$$

$$QT11_{uspm_i} := spflux_{Tlm_{i,2}} + QTl_{ustd_i}$$

$$QT12_{uspm_i} := if\left(QT11_{uspm_i} \le 0.1, 0, QT11_{uspm_i}\right)$$

$$QT2_{uperc_i} := \frac{QT12_{uspm_i} \cdot 100}{q_{pff_{i,2}} \cdot 28.05 \cdot 2}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{uperc_i} := if\left(QT2_{uperc_i} \le 0, 0, if\left(QT2_{uperc_i} \ge 100, 100, QT2_{uperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTl_{uspr_i} := QT3_{uperc_i} \cdot q_{pff_{i,2}} \cdot \frac{2 \cdot 28.05}{100}$$

Mean Seepage Flux (kg/yr/WP)

$$mean\left(QTl_{uspr}\right) = 104.665$$

Determine the seepage fraction for Tptpll Unit (upper bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTl_{mspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{u_i} := \mathrm{if}\left(QTl_{uspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_u := \sum_{i=0}^{n-1} num1_{u_i}$$

$n_{uTl} := (n-1) - num_u \qquad n_{uTl} = 12696$

$spfrcu_{Tl} := \frac{num_u}{n} \qquad spfrcu_{Tl} = 0.365$

$n1_{uTl} := (n-1) - \left(n_{uTl} + 1\right) \qquad n1_{uTl} = 7.302\times 10^{3}$

$Q11_{uTl} := \mathrm{sort}\left(QTl_{uspr}\right)$

$Q1_{uTl} := \mathrm{reverse}\left(Q11_{uTl}\right)$

$ab := 0 .. n1_{uTl}$

$Q2_{uTl_{ab}} := \left(\frac{1}{1} \cdot Q1_{uTl_{ab}}\right)$

$Q_{uTl} := \mathrm{sort}\left(Q2_{uTl}\right)$

$\mathrm{mean}\left(Q_{uTl} \cdot 1\right) = 286.636$

$$CDF_{uTl_{ab}} := \frac{(ab + 1) - 0.375}{\left(n1_{uTl} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M [DIRS 104667], p. 109).

$$\beta_u := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{uTl}} \left(Q_{uTl_i}\right)^{r} \cdot \ln\left(Q_{uTl_i}\right)\right]}{\sum_{i=0}^{n1_{uTl}} \left(Q_{uTl_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{uTl}}\right) \cdot \sum_{i=0}^{n1_{uTl}} \ln\left(Q_{uTl_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_u = 0.445$$

$$\alpha_u := \left[\frac{\sum_{i=0}^{n1_{uTl}} \left(Q_{uTl_i}\right)^{\beta_u}}{n1_{uTl}}\right]^{\frac{1}{\beta_u}} \qquad \alpha_u = 1.064\times 10^{2}$$

Plot of raw data versus Weibull distribution

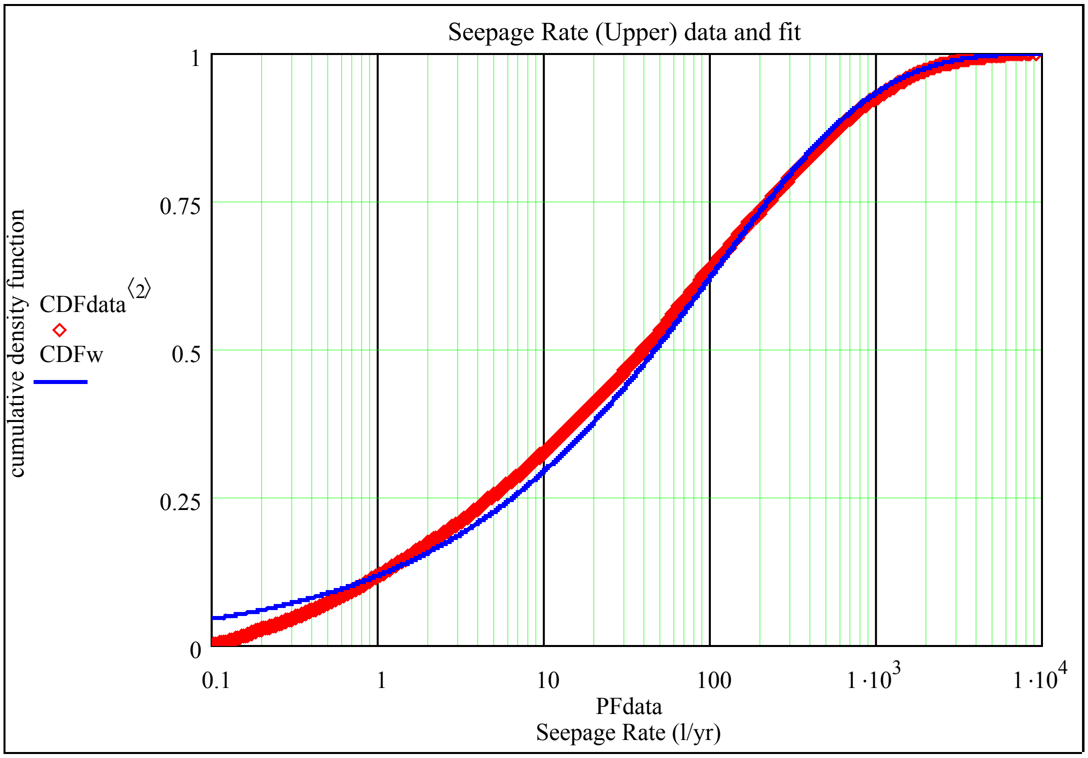
$ji := 0 .. n1_{uTl}$

$PFdata_{ji} := Q_{uTl_{ji}}$

$CDFdata_{ji,2} := CDF_{uTl_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_u}\right)^{\beta_u}\right]$$

$CDFw_{ji,0} := CDFw1_{ji}$



Overall Final Results

Lower Bound Results	Mean Results	Upper Bound Results	
$\alpha_l = 4.237$	$\alpha_m = 4.56\times 10^{1}$	$\alpha_u = 1.064\times 10^{2}$	
$\beta_l = 5.339\times 10^{-1}$	$\beta_m = 4.381\times 10^{-1}$	$\beta_u = 4.45\times 10^{-1}$	
$spfrcl_{Tl} = 4.6\times 10^{-2}$	$spfrcm_{Tl} = 2.455\times 10^{-1}$	$spfrcu_{Tl} = 3.651\times 10^{-1}$	**Seepage Fraction**
$mean(QTl_{lspr}) = 0.415$	$mean(QTl_{mspr}) = 33.425$	$mean(QTl_{uspr}) = 104.665$	**Data Set Mean**

C.2 NOMINAL SEEPAGE ANALYSIS FOR INFILTRATION RATE AND SEEPAGE FRACTION IN THE NONLITHOPHYSAL ZONE

This section presents the Mathcad analysis for calculating the nominal seepage fraction and nominal seepage infiltration rates (i.e., lower bound, mean, and upper bound) for the nonlithophysal zone during the glacial transition period. The seepage information used in the analysis was obtained from *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1). The information contained in this section has been abstracted from the "LA seepage glac Tptpmn weibull.mcd" Mathcad file of Appendix G.

Seepage Flux and Seepage Fraction Calculation using *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1)

Latin Hypercube Sampling Routine to Generate Random Numbers

size of the sampling: $n := 20000$

$i := 1 .. n$

$RD_{i-1,0} := i$ $RD_{i-1,1} := \mathrm{rnd}(1.0)$ $RD_{i-1,2} := \mathrm{rnd}(1.0)$ $RD_{i-1,3} := \mathrm{rnd}(1.0)$

$RD_{i-1,4} := \mathrm{rnd}(1.0)$ $RD_{i-1,5} := \mathrm{rnd}(1.0)$ $RD_{i-1,6} := \mathrm{rnd}(1.0)$

RK's are matrixes in which the first column contain a permutation on the integers on the interval [1,n].

$RK1 := \mathrm{csort}(RD, 1)$ $RK2 := \mathrm{csort}(RD, 2)$ $RK3 := \mathrm{csort}(RD, 3)$

$RK4 := \mathrm{csort}(RD, 4)$ $RK5 := \mathrm{csort}(RD, 5)$ $RK6 := \mathrm{csort}(RD, 6)$

Define sets of random values. Each random value is selected within one of the equiprobable n intervals that partition [0,1]. One set for each random variable.

$$X^{\langle 0\rangle} := \frac{RK1^{\langle 0\rangle} - 1 + \mathrm{runif}(n, 0, 1)}{n} \quad X^{\langle 1\rangle} := \frac{RK2^{\langle 0\rangle} - 1 + \mathrm{runif}(n, 0, 1)}{n} \quad X^{\langle 2\rangle} := \frac{RK3^{\langle 0\rangle} - 1 + \mathrm{runif}(n, 0, 1)}{n}$$

$$X^{\langle 3\rangle} := \frac{RK4^{\langle 0\rangle} - 1 + \mathrm{runif}(n, 0, 1)}{n} \quad X^{\langle 4\rangle} := \frac{RK5^{\langle 0\rangle} - 1 + \mathrm{runif}(n, 0, 1)}{n} \quad X^{\langle 5\rangle} := \frac{RK6^{\langle 0\rangle} - 1 + \mathrm{runif}(n, 0, 1)}{n}$$

$i := 0 .. n - 1$

Capillary Strength 1/ α in (Pa)

$\alpha 1_{lb} := 402$ $\alpha 1_{ub} := 780$ $\alpha 1_{\mu} := 591$ spatial variability follows a uniform distribution

$\Delta\alpha 1_{l} := -105$ $\Delta\alpha 1_{\mu} := 0$ $\Delta\alpha 1_{u} := 105$ uncertainty follows a triangular distribution

Sampling from spatial variability to obtain the 1/ α value

$\alpha 1_i := \mathrm{qunif}\left(X_{i,0}, \alpha 1_{lb}, \alpha 1_{ub}\right)$ 1/α value

Sample from uncertainty triangular distribution to obtain $\Delta 1/\alpha$

Determine which equation to use:
if Random Number < RN $_{\Delta\alpha 1}$ then use Equation 1 ($\Delta\alpha$1eq1)
if Random Number > RN $_{\Delta\alpha 1}$ then use Equation 2 ($\Delta\alpha$1eq2)

$$RN_{\Delta\alpha 1} := \frac{\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)^2}{\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq1_i} := \Delta\alpha 1_{l} + \sqrt{X_{i,1}\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq2_i} := \Delta\alpha 1_{u} - \sqrt{\left(1 - X_{i,1}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{\mu}\right)}$$

$\Delta\alpha 1_i := \mathrm{if}\left[\left(X_{i,1} \le RN_{\Delta\alpha 1}\right), \Delta\alpha 1_{eq1_i}, \Delta\alpha 1_{eq2_i}\right]$ Δ1/α value

Overall Capillary Strength 1/ α + Δ1/α

$T_{1\alpha_i} := \alpha 1_i + \Delta\alpha 1_i$ 1/α value

Permeability k in Tptpmn Unit (in log 10)

$\mu_{kTn} := -12.2$ mean of lognormal distribution

$\sigma_{kTn} := 0.34$ standard deviation of lognormal distribution

$k_{Tn_i} := \ln\left(\text{qlnorm}\left(X_{i,2}, \mu_{kTn}, \sigma_{kTn}\right)\right)$

$\text{mean}\left(k_{Tn}\right) = -12.2$

$\text{Stdev}\left(k_{Tn}\right) = 0.34$

Permeability Δk in Tptpmn Unit (in log 10)

$\Delta k_{Tnl} := -0.68$ $\Delta k_{Tn\mu} := 0$ $\Delta k_{Tnu} := 0.68$ uncertainty follows a triangular distribution

Sample from uncertainty triangular distribution to obtain Δk

Determine which equation to use:
if Random Number < $RN_{\Delta kTn}$ then use Equation 1 (ΔkTneq1)
if Random Number > $RN_{\Delta kTn}$ then use Equation 2 (ΔkTneq2)

$$RN_{\Delta kTn} := \frac{\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)^2}{\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)}$$

$$\Delta kTn_{eq1_i} := \Delta k_{Tnl} + \sqrt{X_{i,3}\cdot\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)}$$

$$\Delta kTn_{eq2_i} := \Delta k_{Tnu} - \sqrt{\left(1 - X_{i,3}\right)\cdot\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tnu} - \Delta k_{Tn\mu}\right)}$$

$\Delta k_{Tn_i} := \text{if}\left[\left(X_{i,3} \le RN_{\Delta kTn}\right), \Delta kTn_{eq1_i}, \Delta kTn_{eq2_i}\right]$ Δk value

Overall Permeability k + Δk

$T1_{kTn_i} := k_{Tn_i} + \Delta k_{Tn_i}$

Permeability must lie between -14 and -10 (bounds of SMPA simulations)

$T_{kTn_i} := \text{if}\left(T1_{kTn_i} \ge -10, -10, \text{if}\left(T1_{kTn_i} \le -14, -14, T1_{kTn_i}\right)\right)$ k value

Flow Focusing Factor

$$f(x) := -0.3137\cdot x^4 + 5.4998\cdot x^3 - 35.66\cdot x^2 + 102.3\cdot x - 11.434$$

$$ff_i := \text{root}\left[f(x) - \left(X_{i,4}\cdot 100\right), x, 0, 6\right]$$

Percolation Flux (mm/yr)

The percolation flux used here is for the glacial transition period only. The percolation flux is based on sampling from the lower bound (TSPA repository location). DTN: LB0310AMRU0120.002 [DIRS 166116]

$nnn := 0..468$ number of data points

Lower Bound Percolation Flux

$PF1_l :=$

	0
0	3.676
1	2.6504
2	2.4144
3	2.1296
4	2.4089
5	2.3999
6	2.117
7	2.7623
8	1.397
9	2.2144

Mean Bound Percolation Flux

$PF1_m :=$

	0
0	15.9704
1	19.8733
2	14.1961
3	7.5897
4	16.9397
5	17.7583
6	10.4511
7	27.7684
8	8.9546
9	16.0195

Upper Bound Percolation Flux

$PF1_u :=$

	0
0	40.0021
1	36.1863
2	35.7337
3	27.828
4	30.7394
5	40.0292
6	31.8601
7	57.0835
8	18.3271
9	27.9133

$PFt_{l_{nnn}} := PF1_{l_{nnn,0}}$ $\qquad PFt_{m_{nnn}} := PF1_{m_{nnn,0}}$ $\qquad PFt_{u_{nnn}} := PF1_{u_{nnn,0}}$

$Z^{\langle 0\rangle} := \mathrm{round}(\mathrm{runif}(n,0,468))$

$PF_{l_i} := PFt_{l_{\left(Z_{i,0}\right)}}$ $\qquad PF_{m_i} := PFt_{m_{\left(Z_{i,0}\right)}}$ $\qquad PF_{u_i} := PFt_{u_{\left(Z_{i,0}\right)}}$

Adjusted Percolation Flux

Take the flow focusing factor and multiply it to the percolation flux, which will be used to obtain the seepage rate, seepage fraction, and seepage percentage.

$q1_{pff_i} := PF_{l_i} \cdot ff_i$ $\qquad qm_{pff_i} := PF_{m_i} \cdot ff_i$ $\qquad qu_{pff_i} := PF_{u_i} \cdot ff_i$

$q_{pff} := \mathrm{augment}\left(q1_{pff}, qm_{pff}, qu_{pff}\right)$

Percolation Flux must lie between 1 and 1000 mm/yr (bounds of SMPA simulations)

$j := 0..2$

$q_{pff_{i,j}} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(q_{pff_{i,j}} \ge 1000, 1000, q_{pff_{i,j}}\right)\right)$

Seepage Information from SMPA analysis

$m := 2549$ data points

$SMPA_{data}{}^{<0>}$ is permeability value log(k [m^2])

$SMPA_{data}{}^{<1>}$ is capillary strength 1/alpha [Pa]

$SMPA_{data}{}^{<2>}$ is local percolation flux (mm/yr)

$SMPA_{data}{}^{<3>}$ is Mean Seepage [kg/yr/WP]

$SMPA_{data}{}^{<4>}$ is Std. Dev. Seepage [kg/yr/WP]

$SMPA_{data}{}^{<5>}$ is Mean Seepage [%]

$SMPA_{data}{}^{<6>}$ is Std. Dev. Seepage [%]

$SMPA_{data} :=$

	0	1	2	3	4	5	6
0	-14	100	1	27.73	4.09	98.86	14.59
1	-14	100	5	138.92	20.55	99.05	14.65
2	-14	100	10	277.9	41.19	99.07	14.68
3	-14	100	20	555.87	82.54	99.09	14.71
4	-14	100	50	1391.67	205.57	99.23	14.66
5	-14	100	100	2793.55	406.7	99.59	14.5
6	-14	100	200	5610	785	100	14
7	-14	100	300	8415	1178	100	14
8	-14	100	400	11220	1570	100	14
9	-14	100	500	14025	1963	100	14
10	-14	100	600	16830	2356	100	14
11	-14	100	700	19635	2748	100	14
12	-14	100	800	22440	3141	100	14
13	-14	100	900	25245	3590	100	14
14	-14	100	1000	28050	3989	100	14
15	-14	200	1	26.14	4.21	93.21	15

Set up routine to pick out correct mean seepage, seepage standard deviation, seepage percent, and seepage percent standard deviation based on sampled value of 1/ α, k, percolation flux.

$nx := 14 \qquad ny := 9 \qquad nz := 16$

$ii := 0 .. nx$

$x_{ii} := SMPA_{data_{ii,2}} \qquad xi_{ii} := ii$

$jj := 0 .. ny$

$y_{jj} := 100\cdot jj + 100 \qquad yj_{jj} := jj$

$kk := 0 .. nz$

$z_{kk} := -14 + kk\cdot 0.25 \qquad zk_{kk} := kk$

loc represents the location within the matrix of which value to pick for the interpolation process.

$$loc1_{i,j} := \text{floor}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{floor}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms1_{i,j}} := SMPA_{data_{loc1_{i,j},3}}$$

$$s_{msd1_{i,j}} := SMPA_{data_{loc1_{i,j},4}}$$

$$loc2_{i,j} := \left[\text{floor}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{ceil}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms2_{i,j}} := SMPA_{data_{loc2_{i,j},3}}$$

$$s_{msd2_{i,j}} := SMPA_{data_{loc2_{i,j},4}}$$

$$loc_{3_{i,j}} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms3_{i,j}} := SMPA_{data_{loc_{3_{i,j}},3}}$$

$$s_{msd3_{i,j}} := SMPA_{data_{loc_{3_{i,j}},4}}$$

$$loc_{4_{i,j}} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms4_{i,j}} := SMPA_{data_{loc_{4_{i,j}},3}}$$

$$s_{msd4_{i,j}} := SMPA_{data_{loc_{4_{i,j}},4}}$$

$$loc_{5_{i,j}} := \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms5_{i,j}} := SMPA_{data_{loc_{5_{i,j}},3}}$$

$$s_{msd5_{i,j}} := SMPA_{data_{loc_{5_{i,j}},4}}$$

$$loc_{6_{i,j}} := \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms6_{i,j}} := SMPA_{data_{loc_{6_{i,j}},3}}$$

$$s_{msd6_{i,j}} := SMPA_{data_{loc_{6_{i,j}},4}}$$

$$loc_{7_{i,j}} := \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms7_{i,j}} := SMPA_{data_{loc_{7_{i,j}},3}}$$

$$s_{msd7_{i,j}} := SMPA_{data_{loc_{7_{i,j}},4}}$$

$$loc_{8_{i,j}} := \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms8_{i,j}} := SMPA_{data_{loc_{8_{i,j}},3}}$$

$$s_{msd8_{i,j}} := SMPA_{data_{loc_{8_{i,j}},4}}$$

Develop the upper and lower bound for permeability (k) for Tptpmn Unit

$qq_i := -1 \cdot T_{kTn_i}$

$\mathrm{mantissa}(x) := x - \mathrm{floor}(qq)$

$tt_i := \mathrm{floor}\left(qq_i\right)$

$rr := \mathrm{round}(\mathrm{mantissa}(qq), 2)$

$yy1_i := \mathrm{if}\left(rr_i \le 0.25, 0, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.25, rr_i\right)\right)$

$zz1_i := \mathrm{if}\left(yy1_i \le 0.5, yy1_i, \mathrm{if}\left(0.5 < yy1_i \le 0.75, 0.5, 0.75\right)\right)$

$T_{kTn2_i} := -1 \cdot \left(tt_i + zz1_i\right)$

$yy2_i := \mathrm{if}\left(rr_i \le 0.25, 0.25, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.5, rr_i\right)\right)$

$zz2_i := \mathrm{if}\left(yy2_i \le 0.5, yy2_i, \mathrm{if}\left(0.5 < yy2_i \le 0.75, 0.75, 1\right)\right)$

$T_{kTn1_i} := -1 \cdot \left(tt_i + zz2_i\right)$

Develop the upper and lower bound for capillary strength (1/ α).

$hh1_i := \mathrm{floor}\left(\frac{T_{1\alpha_i}}{100}\right)$

$T_{1\alpha1_i} := \left(hh1_i \cdot 100\right)$

$hh2_i := \mathrm{ceil}\left(\frac{T_{1\alpha_i}}{100}\right)$

$T_{1\alpha2_i} := \left(hh2_i \cdot 100\right)$

Lower Bound value adjusted percolation flux (q_{pff}).

$aaa1_{i,j} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(1 < q_{pff_{i,j}} \le 5, 1, q_{pff_{i,j}}\right)\right)$

$bbb1_{i,j} := \mathrm{if}\left(aaa1_{i,j} \le 5, aaa1_{i,j}, \mathrm{if}\left(5 < aaa1_{i,j} \le 10, 5, aaa1_{i,j}\right)\right)$

$ccc1_{i,j} := \mathrm{if}\left(bbb1_{i,j} \le 10, bbb1_{i,j}, \mathrm{if}\left(10 < bbb1_{i,j} \le 20, 10, bbb1_{i,j}\right)\right)$

$ddd1_{i,j} := \mathrm{if}\left(ccc1_{i,j} \le 20, ccc1_{i,j}, \mathrm{if}\left(20 < ccc1_{i,j} \le 50, 20, ccc1_{i,j}\right)\right)$

$eee1_{i,j} := \mathrm{if}\left(ddd1_{i,j} \le 50, ddd1_{i,j}, \mathrm{if}\left(50 < ddd1_{i,j} \le 100, 50, ddd1_{i,j}\right)\right)$

$fff1_{i,j} := \mathrm{if}\left(eee1_{i,j} \le 100, eee1_{i,j}, \mathrm{if}\left(100 < eee1_{i,j} \le 200, 100, eee1_{i,j}\right)\right)$

$ggg1_{i,j} := \mathrm{if}\left(fff1_{i,j} \le 200, fff1_{i,j}, \mathrm{if}\left(200 < fff1_{i,j} \le 300, 200, fff1_{i,j}\right)\right)$

$hhh1_{i,j} := \mathrm{if}\left(ggg1_{i,j} \le 300, ggg1_{i,j}, \mathrm{if}\left(300 < ggg1_{i,j} \le 400, 300, ggg1_{i,j}\right)\right)$

$iii1_{i,j} := \mathrm{if}\left(hhh1_{i,j} \le 400, hhh1_{i,j}, \mathrm{if}\left(400 < hhh1_{i,j} \le 500, 400, hhh1_{i,j}\right)\right)$

$jjj1_{i,j} := \mathrm{if}\left(iii1_{i,j} \le 500, iii1_{i,j}, \mathrm{if}\left(500 < iii1_{i,j} \le 600, 500, iii1_{i,j}\right)\right)$

$$kkk1_{i,j} := \mathrm{if}\left(jjj1_{i,j} \le 600, jjj1_{i,j}, \mathrm{if}\left(600 < jjj1_{i,j} \le 700, 600, jjj1_{i,j}\right)\right)$$

$$mmm1_{i,j} := \mathrm{if}\left(kkk1_{i,j} \le 700, kkk1_{i,j}, \mathrm{if}\left(700 < kkk1_{i,j} \le 800, 700, kkk1_{i,j}\right)\right)$$

$$q_{pff1_{i,j}} := \mathrm{if}\left(mmm1_{i,j} \le 800, mmm1_{i,j}, \mathrm{if}\left(800 < mmm1_{i,j} \le 900, 800, 900\right)\right)$$

Upper Bound value adjusted percolation flux (q $_{pff}$).

$$aaa2_{i,j} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 5, \mathrm{if}\left(1 < q_{pff_{i,j}} \le 5, 5, q_{pff_{i,j}}\right)\right)$$

$$bbb2_{i,j} := \mathrm{if}\left(aaa2_{i,j} \le 5, aaa2_{i,j}, \mathrm{if}\left(5 < aaa2_{i,j} \le 10, 10, aaa2_{i,j}\right)\right)$$

$$ccc2_{i,j} := \mathrm{if}\left(bbb2_{i,j} \le 10, bbb2_{i,j}, \mathrm{if}\left(10 < bbb2_{i,j} \le 20, 20, bbb2_{i,j}\right)\right)$$

$$ddd2_{i,j} := \mathrm{if}\left(ccc2_{i,j} \le 20, ccc2_{i,j}, \mathrm{if}\left(20 < ccc2_{i,j} \le 50, 50, ccc2_{i,j}\right)\right)$$

$$eee2_{i,j} := \mathrm{if}\left(ddd2_{i,j} \le 50, ddd2_{i,j}, \mathrm{if}\left(50 < ddd2_{i,j} \le 100, 100, ddd2_{i,j}\right)\right)$$

$$fff2_{i,j} := \mathrm{if}\left(eee2_{i,j} \le 100, eee2_{i,j}, \mathrm{if}\left(100 < eee2_{i,j} \le 200, 200, eee2_{i,j}\right)\right)$$

$$ggg2_{i,j} := \mathrm{if}\left(fff2_{i,j} \le 200, fff2_{i,j}, \mathrm{if}\left(200 < fff2_{i,j} \le 300, 300, fff2_{i,j}\right)\right)$$

$$hhh2_{i,j} := \mathrm{if}\left(ggg2_{i,j} \le 300, ggg2_{i,j}, \mathrm{if}\left(300 < ggg2_{i,j} \le 400, 400, ggg2_{i,j}\right)\right)$$

$$iii2_{i,j} := \mathrm{if}\left(hhh2_{i,j} \le 400, hhh2_{i,j}, \mathrm{if}\left(400 < hhh2_{i,j} \le 500, 500, hhh2_{i,j}\right)\right)$$

$$jjj2_{i,j} := \mathrm{if}\left(iii2_{i,j} \le 500, iii2_{i,j}, \mathrm{if}\left(500 < iii2_{i,j} \le 600, 600, iii2_{i,j}\right)\right)$$

$$kkk2_{i,j} := \mathrm{if}\left(jjj2_{i,j} \le 600, jjj2_{i,j}, \mathrm{if}\left(600 < jjj2_{i,j} \le 700, 700, jjj2_{i,j}\right)\right)$$

$$mmm2_{i,j} := \mathrm{if}\left(kkk2_{i,j} \le 700, kkk2_{i,j}, \mathrm{if}\left(700 < kkk2_{i,j} \le 800, 800, kkk2_{i,j}\right)\right)$$

$$q_{pff2_{i,j}} := \mathrm{if}\left(mmm2_{i,j} \le 800, mmm2_{i,j}, \mathrm{if}\left(800 < mmm2_{i,j} \le 900, 900, 1000\right)\right)$$

Solve for seepage flux (Tptpmn Unit)

$$u_{T1\alpha_i} := \frac{T_{1\alpha_i} - T_{1\alpha 1_i}}{T_{1\alpha 2_i} - T_{1\alpha 1_i}} \qquad v_{TkTn_i} := \frac{T_{kTn_i} - T_{kTn1_i}}{T_{kTn2_i} - T_{kTn1_i}} \qquad t_{qpff_{i,j}} := \frac{q_{pff_{i,j}} - q_{pff1_{i,j}}}{q_{pff2_{i,j}} - q_{pff1_{i,j}}}$$

$$\begin{aligned} spflux_{Tnm_{i,j}} := & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms1_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms2_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms3_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms4_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms5_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms6_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms7_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms8_{i,j}} \end{aligned}$$

$$\begin{aligned}spflux_{Tnsd_{i,j}} := {} & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd1_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd2_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd3_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd4_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd5_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd6_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd7_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd8_{i,j}}\end{aligned}$$

Calculate mean seepage for Tptpmn Unit (lower bound).

$$QTn1_{lstdl_i} := -1.7321\cdot spflux_{Tnsd_{i,0}}$$

$$QTn1_{lstdu_i} := 1.7321\cdot spflux_{Tnsd_{i,0}}$$

$$QTn_{lstdl_i} := \text{if}\left(QTn1_{lstdl_i} = 0, -0.00001, QTn1_{lstdl_i}\right)$$

$$QTn_{lstd_i} := \text{qunif}\left(X_{i,5}, QTn_{lstdl_i}, QTn1_{lstdu_i}\right)$$

$$QTn1_{lspm_i} := spflux_{Tnm_{i,0}} + QTn_{lstd_i}$$

$$QTn2_{lspm_i} := \text{if}\left(QTn1_{lspm_i} \le 0.1, 0, QTn1_{lspm_i}\right)$$

$$QT2_{lperc_i} := \frac{QTn2_{lspm_i}\cdot 100}{q_{pff_{i,0}}\cdot 28.05}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{lperc_i} := \text{if}\left(QT2_{lperc_i} \le 0, 0, \text{if}\left(QT2_{lperc_i} \ge 100, 100, QT2_{lperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTn_{lspr_i} := QT3_{lperc_i}\cdot q_{pff_{i,0}}\cdot\frac{28.05}{100}$$

Mean Seepage Flux (kg/yr/WP)

$$\text{mean}\left(QTn_{lspr}\right) = 1.579$$

Determine the seepage fraction for Tptpmn Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$$\text{sort}\left(QTn_{lspr}\right) =$$

	0
0	0
1	0
2	0
3	0
4	0

$$num1_{l_i} := \text{if}\left(QTn_{lspr_i} > 0, 1, 0\right)$$

Number of seepage rates greater than zero.

$$num_l := \sum_{i=0}^{n-1} num1_{l_i}$$

$$n_{lTn} := (n-1) - num_l \qquad n_{lTn} = 17066$$

$$spfrcl_{Tn} := \frac{num_l}{n} \qquad spfrcl_{Tn} = 0.147$$

$n1_{lTn} := (n - 1) - \left(n_{lTn} + 1\right) \qquad n1_{lTn} = 2.932\times 10^{3}$

$Q11_{lTn} := \mathrm{sort}\left(QTn_{lspr}\right)$

$Q1_{lTn} := \mathrm{reverse}\left(Q11_{lTn}\right)$

$ab := 0 .. n1_{lTn}$

$Q2_{lTn_{ab}} := \left(Q1_{lTn_{ab}}\right)$

$Q_{lTn} := \mathrm{sort}\left(Q2_{lTn}\right)$

$\mathrm{mean}\left(Q_{lTn}\right) = 10.77$

$$CDF_{lTn_{ab}} := \frac{(ab + 1) - 0.375}{\left(n1_{lTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_l := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{r} \cdot \ln\left(Q_{lTn_i}\right)\right]}{\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{lTn}}\right) \cdot \sum_{i=0}^{n1_{lTn}} \ln\left(Q_{lTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_l = 0.528$$

$$\alpha_l := \left[\frac{\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{\beta_l}}{n1_{lTn}}\right]^{\frac{1}{\beta_l}} \qquad \alpha_l = 4.936$$

Plot of raw data versus Weibull distribution

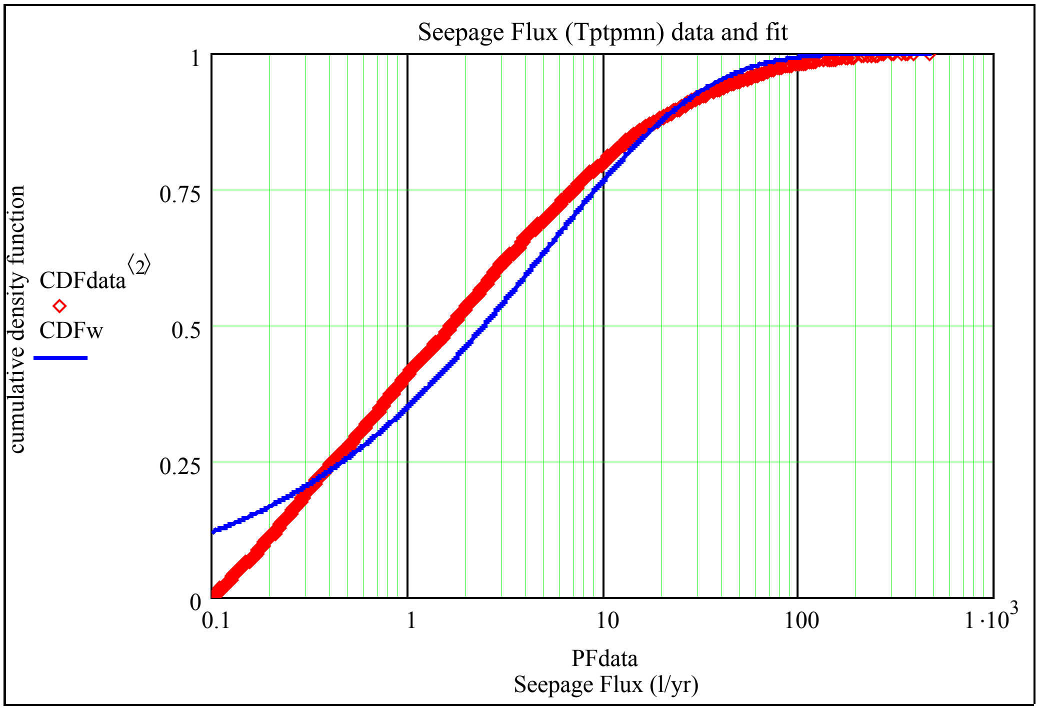
$ji := 0 .. n1_{lTn}$

$PFdata_{ji} := Q_{lTn_{ji}}$

$CDFdata_{ji,2} := CDF_{lTn_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_l}\right)^{\beta_l}\right]$$

$CDFw_{ji,0} := CDFw1_{ji}$



Calculate mean seepage for Tptpmn Unit (mean).

$QTn1_{mstdl_i} := -1.7321 \cdot spflux_{Tnsd_{i,1}}$

$QTn1_{mstdu_i} := 1.7321 \cdot spflux_{Tnsd_{i,1}}$

$QTn_{mstdl_i} := if\left(QTn1_{mstdl_i} = 0, -0.00001, QTn1_{mstdl_i}\right)$

$QTn_{mstd_i} := qunif\left(X_{i,5}, QTn_{mstdl_i}, QTn1_{mstdu_i}\right)$

$QTn1_{mspm_i} := spflux_{Tnm_{i,1}} + QTn_{mstd_i}$

$QTn2_{mspm_i} := if\left(QTn1_{mspm_i} \le 0.1, 0, QTn1_{mspm_i}\right)$

$QT2_{mperc_i} := \frac{QTn2_{mspm_i} \cdot 100}{q_{pff_{i,1}} \cdot 28.05}$ Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$QT3_{mperc_i} := if\left(QT2_{mperc_i} \le 0, 0, if\left(QT2_{mperc_i} \ge 100, 100, QT2_{mperc_i}\right)\right)$ Check seepage percent to be above 100% and then adjusted back.

$QTn_{mspr_i} := QT3_{mperc_i} \cdot q_{pff_{i,1}} \cdot \frac{28.05}{100}$ **Mean Seepage Flux (kg/yr/WP)**

$mean\left(QTn_{mspr}\right) = 92.669$

Determine the seepage fraction for Tptpmn Unit (mean) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\text{sort}\left(QTn_{mspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{m_i} := \text{if}\left(QTn_{mspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_m := \sum_{i=0}^{n-1} num1_{m_i}$$

$n_{mTn} := (n - 1) - num_m \qquad n_{mTn} = 9624$

$$spfrcm_{Tn} := \frac{num_m}{n} \qquad spfrcm_{Tn} = 0.519$$

$n1_{mTn} := (n - 1) - \left(n_{mTn} + 1\right) \qquad n1_{mTn} = 1.037\times 10^{4}$

$Q11_{mTn} := \text{sort}\left(QTn_{mspr}\right)$

$Q1_{mTn} := \text{reverse}\left(Q11_{mTn}\right)$

$ab := 0..\, n1_{mTn}$

$Q2_{mTn_{ab}} := \left(Q1_{mTn_{ab}}\right)$

$Q_{mTn} := \text{sort}\left(Q2_{mTn}\right)$

$\text{mean}\left(Q_{mTn}\right) = 178.639$

$$CDF_{mTn_{ab}} := \frac{(ab + 1) - 0.375}{\left(n1_{mTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_m := \text{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{r} \cdot \ln\left(Q_{mTn_i}\right)\right]}{\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{mTn}}\right) \cdot \sum_{i=0}^{n1_{mTn}} \ln\left(Q_{mTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_m = 0.468$$

$$\alpha_m := \left[\frac{\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{\beta_m}}{n1_{mTn}}\right]^{\frac{1}{\beta_m}} \qquad \alpha_m = 7.394\times 10^{1}$$

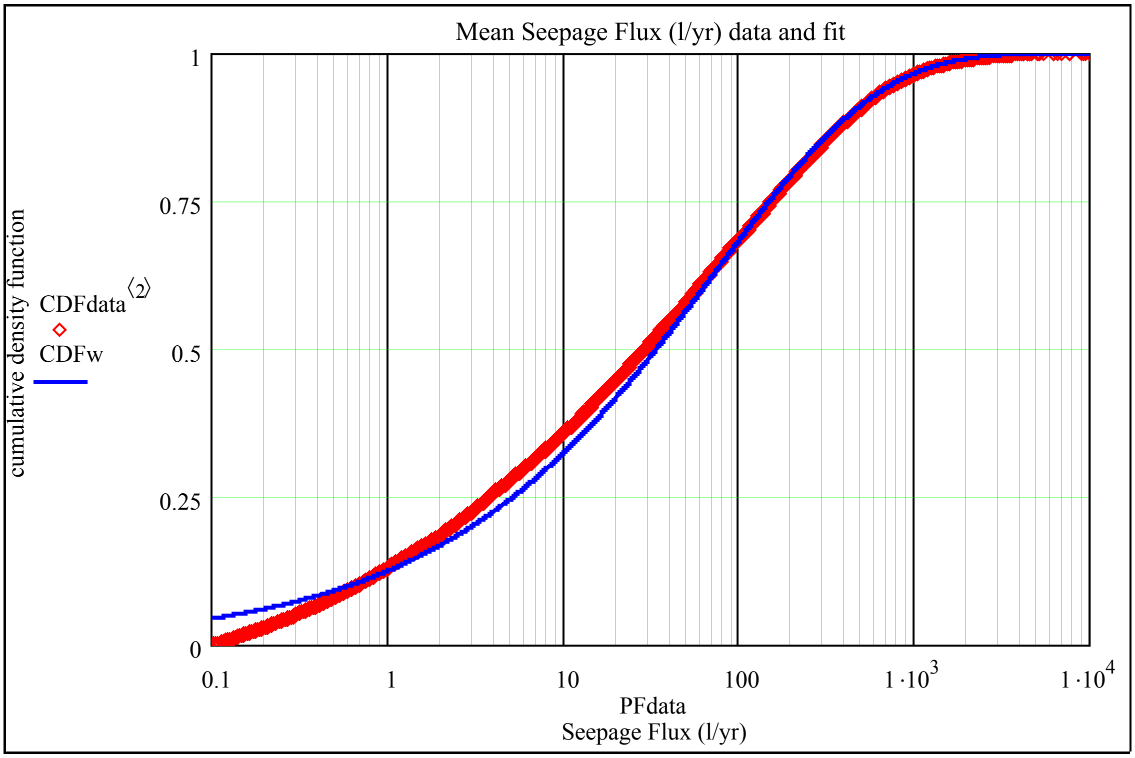
Plot of raw data versus Weibull distribution

$ji := 0..\, n1_{mTn}$

$PFdata_{ji} := Q_{mTn_{ji}}$

$CDFdata_{ji,2} := CDF_{mTn_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_m}\right)^{\beta_m}\right] \qquad CDFw_{ji,0} := CDFw1_{ji}$$



Calculate mean seepage for Tptpmn Unit (upper bound).

$QTn1_{ustdl_i} := -1.7321 \cdot spflux_{Tnsd_{i,2}}$

$QTn1_{ustdu_i} := 1.7321 \cdot spflux_{Tnsd_{i,2}}$

$QTn_{ustdl_i} := if\left(QTn1_{ustdl_i} = 0, -0.00001, QTn1_{ustdl_i}\right)$

$QTn_{ustd_i} := qunif\left(X_{i,5}, QTn_{ustdl_i}, QTn1_{ustdu_i}\right)$

$QTn1_{uspm_i} := spflux_{Tnm_{i,2}} + QTn_{ustd_i}$

$QTn2_{uspm_i} := if\left(QTn1_{uspm_i} \le 0.1, 0, QTn1_{uspm_i}\right)$

$QT2_{uperc_i} := \frac{QTn2_{uspm_i} \cdot 100}{q_{pff_{i,2}} \cdot 28.05}$ Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$QT3_{uperc_i} := if\left(QT2_{uperc_i} \le 0, 0, if\left(QT2_{uperc_i} \ge 100, 100, QT2_{uperc_i}\right)\right)$ Check seepage percent to be above 100% and then adjusted back.

$QTn_{uspr_i} := QT3_{uperc_i} \cdot q_{pff_{i,2}} \cdot \frac{28.05}{100}$ **Mean Seepage Flux (kg/yr/WP)**

$mean\left(QTn_{uspr}\right) = 263.501$

Determine the seepage fraction for Tptpmn Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTn_{uspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{u_i} := \mathrm{if}\left(QTn_{uspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_u := \sum_{i=0}^{n-1} num1_{u_i}$$

$n_{uTn} := (n-1) - num_u \qquad n_{uTn} = 6567$

$$spfrcu_{Tn} := \frac{num_u}{n} \qquad spfrcu_{Tn} = 0.672$$

$n1_{uTn} := (n-1) - \left(n_{uTn} + 1\right) \qquad n1_{uTn} = 1.343\times 10^{4}$

$Q11_{uTn} := \mathrm{sort}\left(QTn_{uspr}\right)$

$Q1_{uTn} := \mathrm{reverse}\left(Q11_{uTn}\right)$

$ab := 0 .. n1_{uTn}$

$$Q2_{uTn_{ab}} := \left(\frac{1}{1} \cdot Q1_{uTn_{ab}}\right)$$

$Q_{uTn} := \mathrm{sort}\left(Q2_{uTn}\right)$

$\mathrm{mean}\left(Q_{uTn} \cdot 1\right) = 392.348$

$$CDF_{uTn_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{uTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_u := \mathrm{root}\left[\left[\frac{\left[\displaystyle\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^{r} \cdot \ln\left(Q_{uTn_i}\right)\right]}{\displaystyle\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{uTn}}\right) \cdot \sum_{i=0}^{n1_{uTn}} \ln\left(Q_{uTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_u = 0.493$$

$$\alpha_u := \left[\frac{\displaystyle\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^{\beta_u}}{n1_{uTn}}\right]^{\frac{1}{\beta_u}} \qquad \alpha_u = 1.902\times 10^{2}$$

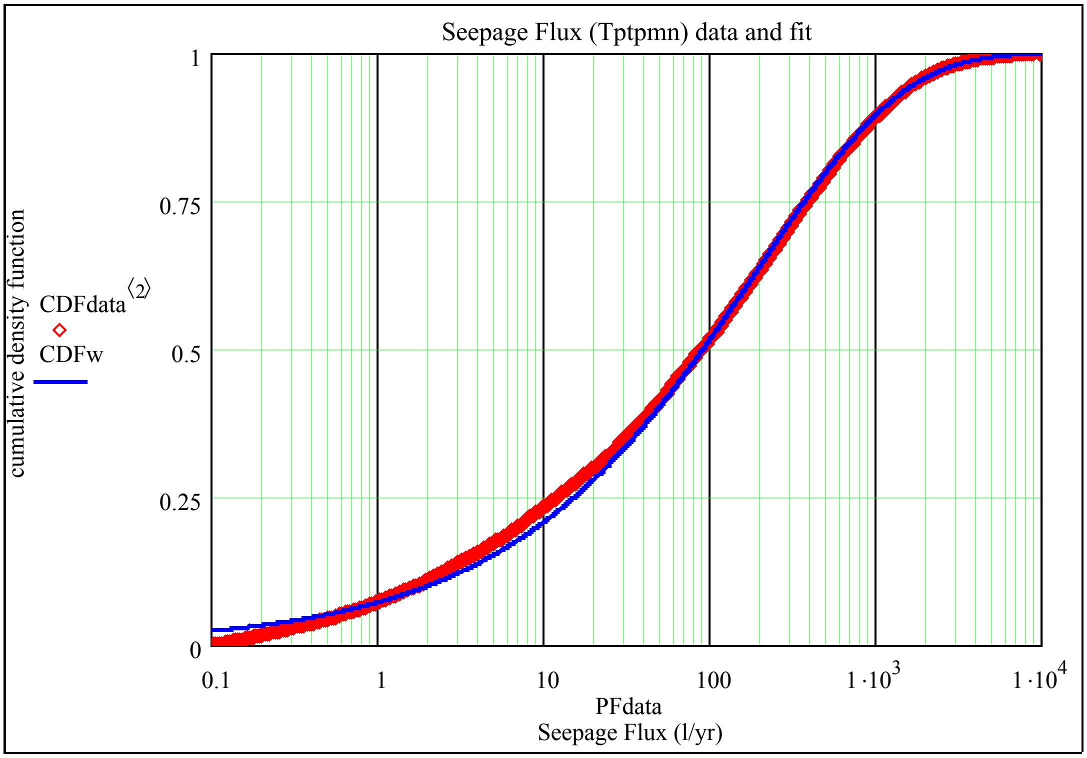
Plot of raw data versus Weibull distribution

$ji := 0 .. n1_{uTn}$

$PFdata_{ji} := Q_{uTn_{ji}}$

$CDFdata_{ji,2} := CDF_{uTn_{ji}}$

$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_u}\right)^{\beta_u}\right]$ $\qquad CDFw_{ji,0} := CDFw1_{ji}$



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Overall Final Results for Tptpmn Zone

Lower Bound Results	**Mean Results**	**Upper Bound Results**	
$\alpha_l = 4.936\times 10^{0}$	$\alpha_m = 7.394\times 10^{1}$	$\alpha_u = 1.902\times 10^{2}$	
$\beta_l = 5.282\times 10^{-1}$	$\beta_m = 4.677\times 10^{-1}$	$\beta_u = 4.932\times 10^{-1}$	
$spfrcl_{Tn} = 1.466\times 10^{-1}$	$spfrcm_{Tn} = 5.188\times 10^{-1}$	$spfrcu_{Tn} = 6.716\times 10^{-1}$	**Seepage Fraction**
$mean(QTn_{lspr}) = 1.579$	$mean(QTn_{mspr}) = 92.669$	$mean(QTn_{uspr}) = 263.501$	**Data Set Mean**

C.3 SEISMIC SEEPAGE ANALYSIS FOR INFILTRATION RATE AND SEEPAGE FRACTION IN THE LITHOPHYSAL ZONE

This section presents the Mathcad analysis for calculating the seepage fraction and seepage infiltration rates (i.e., lower bound, mean, and upper bound) in the lithophysal zone given a seismic event. The seepage calculation is for the glacial transition period only. The seepage calculation utilizes the drift collapse seepage model (BSC 2004 [DIRS 169131], Section 6.7.1.1). The seepage information and the process used in the analysis was obtained from *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1). The information contained in this section has been abstracted from the "LA seepage glac Tptpll collapse-seismic.mcd" Mathcad file of Appendix G.

Seepage Flux and Seepage Fraction Calculation using *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1)

Latin Hypercube Sampling Routine to Generate Random Numbers

size of the sampling: $n := 20000$

$i := 1..n$

$RD_{i-1,0} := i$ $\quad RD_{i-1,1} := rnd(1.0)$ $\quad RD_{i-1,2} := rnd(1.0)$ $\quad RD_{i-1,3} := rnd(1.0)$

$RD_{i-1,4} := rnd(1.0)$ $\quad RD_{i-1,5} := rnd(1.0)$ $\quad RD_{i-1,6} := rnd(1.0)$

RK's are matrixes in which the first column contain a permutation on the integers on the interval [1,n].

$RK1 := csort(RD,1)$ $\quad RK2 := csort(RD,2)$ $\quad RK3 := csort(RD,3)$

$RK4 := csort(RD,4)$ $\quad RK5 := csort(RD,5)$ $\quad RK6 := csort(RD,6)$

Define sets of random values. Each random value is selected within one of the equiprobable n intervals that partition [0,1]. One set for each random variable.

$$X^{\langle 0\rangle} := \frac{RK1^{\langle 0\rangle} - 1 + runif(n,0,1)}{n} \quad X^{\langle 1\rangle} := \frac{RK2^{\langle 0\rangle} - 1 + runif(n,0,1)}{n} \quad X^{\langle 2\rangle} := \frac{RK3^{\langle 0\rangle} - 1 + runif(n,0,1)}{n}$$

$$X^{\langle 3\rangle} := \frac{RK4^{\langle 0\rangle} - 1 + runif(n,0,1)}{n} \quad X^{\langle 4\rangle} := \frac{RK5^{\langle 0\rangle} - 1 + runif(n,0,1)}{n} \quad X^{\langle 5\rangle} := \frac{RK6^{\langle 0\rangle} - 1 + runif(n,0,1)}{n}$$

$i := 0..n-1$

Capillary Strength 1/ α in (Pa)

$\alpha1_{lb} := 402$ $\quad \alpha1_{ub} := 780$ $\quad \alpha1_{\mu} := 591$ spatial variability follows a uniform distribution

$\Delta\alpha1_{l} := -105$ $\quad \Delta\alpha1_{\mu} := 0$ $\quad \Delta\alpha1_{u} := 105$ uncertainty follows a triangular distribution

Sampling from spatial variability to obtain the 1/ α value

$\alpha1_i := qunif\left(X_{i,0}, \alpha1_{lb}, \alpha1_{ub}\right)$ 1/α value

Sample from uncertainty triangular distribution to obtain $\Delta 1/\alpha$

Determine which equation to use:
if Random Number < RN $_{\Delta\alpha 1}$ then use Equation 1 ($\Delta\alpha$1eq1)
if Random Number > RN $_{\Delta\alpha 1}$ then use Equation 2 ($\Delta\alpha$1eq2)

$$RN_{\Delta\alpha 1} := \frac{\left(\Delta\alpha1_{\mu} - \Delta\alpha1_{l}\right)^2}{\left(\Delta\alpha1_{u} - \Delta\alpha1_{l}\right)\cdot\left(\Delta\alpha1_{\mu} - \Delta\alpha1_{l}\right)}$$

$$\Delta\alpha1_{eq1_i} := \Delta\alpha1_{l} + \sqrt{X_{i,1}\cdot\left(\Delta\alpha1_{u} - \Delta\alpha1_{l}\right)\cdot\left(\Delta\alpha1_{\mu} - \Delta\alpha1_{l}\right)}$$

$$\Delta\alpha1_{eq2_i} := \Delta\alpha1_{u} - \sqrt{\left(1 - X_{i,1}\right)\cdot\left(\Delta\alpha1_{u} - \Delta\alpha1_{l}\right)\cdot\left(\Delta\alpha1_{u} - \Delta\alpha1_{\mu}\right)}$$

$\Delta\alpha1_i := if\left[\left(X_{i,1} \le RN_{\Delta\alpha 1}\right), \Delta\alpha1_{eq1_i}, \Delta\alpha1_{eq2_i}\right]$ Δ 1/α value

Overall Capillary Strength 1/ α + Δ1/α

$T_{1\alpha_i} := \alpha 1_i + \Delta\alpha 1_i$ 1/α value

Permeability k in TptpII Unit (in log 10)

$\mu_{kTl} := -11.5$ mean of lognormal distribution

$\sigma_{kTl} := 0.47$ standard deviation of lognormal distribution

$k_{Tl_i} := \ln\left(\text{qlnorm}\left(X_{i,2}, \mu_{kTl}, \sigma_{kTl}\right)\right)$

$\text{mean}\left(k_{Tl}\right) = -11.5$

$\text{Stdev}\left(k_{Tl}\right) = 0.47$

Permeability Δk in TptpII Unit (in log 10)

$\Delta k_{Tll} := -0.92$ $\Delta k_{Tl\mu} := 0$ $\Delta k_{Tlu} := 0.92$ uncertainty follows a triangular distribution

Sample from uncertainty triangular distribution to obtain Δk

Determine which equation to use:
if Random Number < $RN_{\Delta kTl}$ then use Equation 1 (ΔkTleq1)
if Random Number > $RN_{\Delta kTl}$ then use Equation 2 (ΔkTleq2)

$$RN_{\Delta kTl} := \frac{\left(\Delta k_{Tl\mu} - \Delta k_{Tll}\right)^2}{\left(\Delta k_{Tlu} - \Delta k_{Tll}\right)\cdot\left(\Delta k_{Tl\mu} - \Delta k_{Tll}\right)}$$

$$\Delta kTl_{eq1_i} := \Delta k_{Tll} + \sqrt{X_{i,3}\cdot\left(\Delta k_{Tlu} - \Delta k_{Tll}\right)\cdot\left(\Delta k_{Tl\mu} - \Delta k_{Tll}\right)}$$

$$\Delta kTl_{eq2_i} := \Delta k_{Tlu} - \sqrt{\left(1 - X_{i,3}\right)\cdot\left(\Delta k_{Tlu} - \Delta k_{Tll}\right)\cdot\left(\Delta k_{Tlu} - \Delta k_{Tl\mu}\right)}$$

$\Delta k_{Tl_i} := \text{if}\left[\left(X_{i,3} \le RN_{\Delta kTl}\right), \Delta kTl_{eq1_i}, \Delta kTl_{eq2_i}\right]$ Δk value

Overall Permeability k + Δk

$T1_{kTl_i} := k_{Tl_i} + \Delta k_{Tl_i}$

Permeability must lie between -14 and -10 (bounds of SMPA simulations)

$T_{kTl_i} := \text{if}\left(T1_{kTl_i} \ge -10, -10, \text{if}\left(T1_{kTl_i} \le -14, -14, T1_{kTl_i}\right)\right)$ k value

Flow Focusing Factor

$f(x) := -0.3137\cdot x^4 + 5.4998\cdot x^3 - 35.66\cdot x^2 + 102.3\cdot x - 11.434$

$ff_i := \text{root}\left[f(x) - \left(X_{i,4}\cdot 100\right), x, 0, 6\right]$

Percolation Flux (mm/yr)

The percolation flux used here is for the glacial transition period only. The percolation flux is based on sampling from the lower bound (TSPA repository location). DTN: LB0310AMRU0120.002 [DIRS 166116]

$nnn := 0..468$ number of data points

Lower Bound Percolation Flux

$PF1_l :=$

	0
0	3.68
1	2.65
2	2.41
3	2.13
4	2.41
5	2.4
6	2.12
7	2.76
8	1.4
9	2.21

$PFt_{l_{nnn}} := PF1_{l_{nnn,0}}$

Mean Bound Percolation Flux

$PF1_m :=$

	0
0	15.97
1	19.87
2	14.2
3	7.59
4	16.94
5	17.76
6	10.45
7	27.77
8	8.95
9	16.02

$PFt_{m_{nnn}} := PF1_{m_{nnn,0}}$

Upper Bound Percolation Flux

$PF1_u :=$

	0
0	40
1	36.19
2	35.73
3	27.83
4	30.74
5	40.03
6	31.86
7	57.08
8	18.33
9	27.91

$PFt_{u_{nnn}} := PF1_{u_{nnn,0}}$

$Z^{\langle 0 \rangle} := \text{round}(\text{runif}(n,0,468))$

$PF_{l_i} := PFt_{l_{\left(Z_{i,0}\right)}}$　　$PF_{m_i} := PFt_{m_{\left(Z_{i,0}\right)}}$　　$PF_{u_i} := PFt_{u_{\left(Z_{i,0}\right)}}$

Adjusted Percolation Flux

Take the flow focusing factor and multiply it to the percolation flux, which will be used to obtain the seepage rate, seepage fraction, and seepage percentage.

$q1_{pff_i} := PF_{l_i} \cdot ff_i$　　$qm_{pff_i} := PF_{m_i} \cdot ff_i$　　$qu_{pff_i} := PF_{u_i} \cdot ff_i$

$q_{pff} := \text{augment}\left(q1_{pff}, qm_{pff}, qu_{pff}\right)$

Percolation Flux must lie between 1 and 1000 mm/yr (bounds of SMPA simulations)

$j := 0..2$

$q_{pff_{i,j}} := \text{if}\left(q_{pff_{i,j}} \le 1, 1, \text{if}\left(q_{pff_{i,j}} \ge 1000, 1000, q_{pff_{i,j}}\right)\right)$

Seepage Information from SMPA analysis

$m := 2549$ data points

$SMPA_{data}{}^{<0>}$ is permeability value log(k [m^2])

$SMPA_{data}{}^{<1>}$ is capillary strength 1/alpha [Pa]

$SMPA_{data}{}^{<2>}$ is local percolation flux (mm/yr)

$SMPA_{data}{}^{<3>}$ is Mean Seepage [kg/yr/WP]

$SMPA_{data}{}^{<4>}$ is Std. Dev. Seepage [kg/yr/WP]

$SMPA_{data}{}^{<5>}$ is Mean Seepage [%]

$SMPA_{data}{}^{<6>}$ is Std. Dev. Seepage [%]

$SMPA_{data} :=$

	0	1	2	3	4	5	6
0	-14	100	1	56.44	5.47	100.6	9.75
1	-14	100	5	282.63	27.5	100.76	9.8
2	-14	100	10	566.16	55.13	100.92	9.83
3	-14	100	20	1135.12	109.85	101.17	9.79
4	-14	100	50	2849.95	272.25	101.6	9.71
5	-14	100	100	5726.78	535.98	102.08	9.55
6	-14	100	200	11523.63	1064.22	102.71	9.49
7	-14	100	300	17369.22	1583.08	103.2	9.41
8	-14	100	400	23241.94	2086.65	103.57	9.3
9	-14	100	500	29154.54	2552.38	103.94	9.1
10	-14	100	600	35097.8	2992.46	104.27	8.89
11	-14	100	700	41099.26	3411.36	104.66	8.69
12	-14	100	800	47084.03	3860.77	104.91	8.6
13	-14	100	900	53190.45	4145.2	105.35	8.21
14	-14	100	1000	59206.88	4520.61	105.54	8.06
15	-14	200	1	55.25	5.44	98.48	9.69

Set up routine to pick out correct mean seepage flux and seepage flux standard deviation based on sampled value of 1/ α, k, percolation flux.

$nx := 14 \quad ny := 9 \quad nz := 16$

$ii := 0..\,nx$

$x_{ii} := SMPA_{data_{ii,2}} \qquad xi_{ii} := ii$

$jj := 0..\,ny$

$y_{jj} := 100\cdot jj + 100 \qquad yj_{jj} := jj$

$kk := 0..\,nz$

$z_{kk} := -14 + kk\cdot 0.25 \quad zk_{kk} := kk$

loc represents the location within the matrix of which value to pick for the interpolation process.

$$loc_{1_{i,j}} := \text{floor}\left(\text{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \text{floor}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms1_{i,j}} := SMPA_{data_{loc_{1_{i,j}},3}}$$

$$s_{msd1_{i,j}} := SMPA_{data_{loc_{1_{i,j}},4}}$$

$$loc_{2_{i,j}} := \left[\text{floor}\left(\text{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \text{ceil}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms2_{i,j}} := SMPA_{data_{loc_{2_{i,j}},3}}$$

$$s_{msd2_{i,j}} := SMPA_{data_{loc_{2_{i,j}},4}}$$

$$\mathrm{loc}_{3_{i,j}} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms3_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{3_{i,j}},3}}$$

$$s_{msd3_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{3_{i,j}},4}}$$

$$\mathrm{loc}_{4_{i,j}} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms4_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{4_{i,j}},3}}$$

$$s_{msd4_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{4_{i,j}},4}}$$

$$\mathrm{loc}_{5_{i,j}} := \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms5_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{5_{i,j}},3}}$$

$$s_{msd5_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{5_{i,j}},4}}$$

$$\mathrm{loc}_{6_{i,j}} := \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms6_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{6_{i,j}},3}}$$

$$s_{msd6_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{6_{i,j}},4}}$$

$$\mathrm{loc}_{7_{i,j}} := \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms7_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{7_{i,j}},3}}$$

$$s_{msd7_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{7_{i,j}},4}}$$

$$\mathrm{loc}_{8_{i,j}} := \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTl_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1)\ \ldots$$
$$+\ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms8_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{8_{i,j}},3}}$$

$$s_{msd8_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{8_{i,j}},4}}$$

Develop the upper and lower bound for permeability (k) for TptpII Unit

$$qq_{i} := -1 \cdot T_{kTl_{i}}$$

$$\text{mantissa}(x) := x - \text{floor}(qq)$$

$$tt_{i} := \text{floor}\left(qq_{i}\right)$$

$$rr := \text{round}(\text{mantissa}(qq), 2)$$

$$yy1_{i} := \text{if}\left(rr_{i} \le 0.25, 0, \text{if}\left(0.25 < rr_{i} \le 0.5, 0.25, rr_{i}\right)\right)$$

$$zz1_{i} := \text{if}\left(yy1_{i} \le 0.5, yy1_{i}, \text{if}\left(0.5 < yy1_{i} \le 0.75, 0.5, 0.75\right)\right)$$

$$T_{kTl2_{i}} := -1 \cdot \left(tt_{i} + zz1_{i}\right)$$

$$yy2_{i} := \text{if}\left(rr_{i} \le 0.25, 0.25, \text{if}\left(0.25 < rr_{i} \le 0.5, 0.5, rr_{i}\right)\right)$$

$$zz2_{i} := \text{if}\left(yy2_{i} \le 0.5, yy2_{i}, \text{if}\left(0.5 < yy2_{i} \le 0.75, 0.75, 1\right)\right)$$

$$T_{kTl1_{i}} := -1 \cdot \left(tt_{i} + zz2_{i}\right)$$

Develop the upper and lower bound for capillary strength (1/ α).

$$hh1_{i} := \text{floor}\left(\frac{T_{1\alpha_{i}}}{100}\right)$$

$$T_{1\alpha1_{i}} := \left(hh1_{i} \cdot 100\right)$$

$$hh2_{i} := \text{ceil}\left(\frac{T_{1\alpha_{i}}}{100}\right)$$

$$T_{1\alpha2_{i}} := \left(hh2_{i} \cdot 100\right)$$

Lower Bound value adjusted percolation flux (q $_{\text{pff}}$).

$$aaa1_{i,j} := \text{if}\left(q_{pff_{i,j}} \le 1, 1, \text{if}\left(1 < q_{pff_{i,j}} \le 5, 1, q_{pff_{i,j}}\right)\right)$$

$$bbb1_{i,j} := \text{if}\left(aaa1_{i,j} \le 5, aaa1_{i,j}, \text{if}\left(5 < aaa1_{i,j} \le 10, 5, aaa1_{i,j}\right)\right)$$

$$ccc1_{i,j} := \text{if}\left(bbb1_{i,j} \le 10, bbb1_{i,j}, \text{if}\left(10 < bbb1_{i,j} \le 20, 10, bbb1_{i,j}\right)\right)$$

$$ddd1_{i,j} := \text{if}\left(ccc1_{i,j} \le 20, ccc1_{i,j}, \text{if}\left(20 < ccc1_{i,j} \le 50, 20, ccc1_{i,j}\right)\right)$$

$$eee1_{i,j} := \text{if}\left(ddd1_{i,j} \le 50, ddd1_{i,j}, \text{if}\left(50 < ddd1_{i,j} \le 100, 50, ddd1_{i,j}\right)\right)$$

$$fff1_{i,j} := \text{if}\left(eee1_{i,j} \le 100, eee1_{i,j}, \text{if}\left(100 < eee1_{i,j} \le 200, 100, eee1_{i,j}\right)\right)$$

$$ggg1_{i,j} := \text{if}\left(fff1_{i,j} \le 200, fff1_{i,j}, \text{if}\left(200 < fff1_{i,j} \le 300, 200, fff1_{i,j}\right)\right)$$

$$hhh1_{i,j} := \text{if}\left(ggg1_{i,j} \le 300, ggg1_{i,j}, \text{if}\left(300 < ggg1_{i,j} \le 400, 300, ggg1_{i,j}\right)\right)$$

$$iii1_{i,j} := \text{if}\left(hhh1_{i,j} \le 400, hhh1_{i,j}, \text{if}\left(400 < hhh1_{i,j} \le 500, 400, hhh1_{i,j}\right)\right)$$

$$jjj1_{i,j} := \text{if}\left(iii1_{i,j} \le 500, iii1_{i,j}, \text{if}\left(500 < iii1_{i,j} \le 600, 500, iii1_{i,j}\right)\right)$$

$kkk1_{i,j} := \text{if}\left(jjj1_{i,j} \le 600, jjj1_{i,j}, \text{if}\left(600 < jjj1_{i,j} \le 700, 600, jjj1_{i,j}\right)\right)$

$mmm1_{i,j} := \text{if}\left(kkk1_{i,j} \le 700, kkk1_{i,j}, \text{if}\left(700 < kkk1_{i,j} \le 800, 700, kkk1_{i,j}\right)\right)$

$q_{pff1_{i,j}} := \text{if}\left(mmm1_{i,j} \le 800, mmm1_{i,j}, \text{if}\left(800 < mmm1_{i,j} \le 900, 800, 900\right)\right)$

Upper Bound value adjusted percolation flux (q_{pff}).

$aaa2_{i,j} := \text{if}\left(q_{pff_{i,j}} \le 1, 5, \text{if}\left(1 < q_{pff_{i,j}} \le 5, 5, q_{pff_{i,j}}\right)\right)$

$bbb2_{i,j} := \text{if}\left(aaa2_{i,j} \le 5, aaa2_{i,j}, \text{if}\left(5 < aaa2_{i,j} \le 10, 10, aaa2_{i,j}\right)\right)$

$ccc2_{i,j} := \text{if}\left(bbb2_{i,j} \le 10, bbb2_{i,j}, \text{if}\left(10 < bbb2_{i,j} \le 20, 20, bbb2_{i,j}\right)\right)$

$ddd2_{i,j} := \text{if}\left(ccc2_{i,j} \le 20, ccc2_{i,j}, \text{if}\left(20 < ccc2_{i,j} \le 50, 50, ccc2_{i,j}\right)\right)$

$eee2_{i,j} := \text{if}\left(ddd2_{i,j} \le 50, ddd2_{i,j}, \text{if}\left(50 < ddd2_{i,j} \le 100, 100, ddd2_{i,j}\right)\right)$

$fff2_{i,j} := \text{if}\left(eee2_{i,j} \le 100, eee2_{i,j}, \text{if}\left(100 < eee2_{i,j} \le 200, 200, eee2_{i,j}\right)\right)$

$ggg2_{i,j} := \text{if}\left(fff2_{i,j} \le 200, fff2_{i,j}, \text{if}\left(200 < fff2_{i,j} \le 300, 300, fff2_{i,j}\right)\right)$

$hhh2_{i,j} := \text{if}\left(ggg2_{i,j} \le 300, ggg2_{i,j}, \text{if}\left(300 < ggg2_{i,j} \le 400, 400, ggg2_{i,j}\right)\right)$

$iii2_{i,j} := \text{if}\left(hhh2_{i,j} \le 400, hhh2_{i,j}, \text{if}\left(400 < hhh2_{i,j} \le 500, 500, hhh2_{i,j}\right)\right)$

$jjj2_{i,j} := \text{if}\left(iii2_{i,j} \le 500, iii2_{i,j}, \text{if}\left(500 < iii2_{i,j} \le 600, 600, iii2_{i,j}\right)\right)$

$kkk2_{i,j} := \text{if}\left(jjj2_{i,j} \le 600, jjj2_{i,j}, \text{if}\left(600 < jjj2_{i,j} \le 700, 700, jjj2_{i,j}\right)\right)$

$mmm2_{i,j} := \text{if}\left(kkk2_{i,j} \le 700, kkk2_{i,j}, \text{if}\left(700 < kkk2_{i,j} \le 800, 800, kkk2_{i,j}\right)\right)$

$q_{pff2_{i,j}} := \text{if}\left(mmm2_{i,j} \le 800, mmm2_{i,j}, \text{if}\left(800 < mmm2_{i,j} \le 900, 900, 1000\right)\right)$

Interpolate (Solve) for seepage flux (Tptpll Unit)

$$u_{T1\alpha_i} := \frac{T_{1\alpha_i} - T_{1\alpha1_i}}{T_{1\alpha2_i} - T_{1\alpha1_i}} \qquad v_{TkTl_i} := \frac{T_{kTl_i} - T_{kTl1_i}}{T_{kTl2_i} - T_{kTl1_i}} \qquad t_{qpff_{i,j}} := \frac{q_{pff_{i,j}} - q_{pff1_{i,j}}}{q_{pff2_{i,j}} - q_{pff1_{i,j}}}$$

$$\begin{aligned}
spflux_{Tlm_{i,j}} := {} & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms1_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms2_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms3_{i,j}} \cdots \\
& + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{ms4_{i,j}} \cdots \\
& + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms5_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms6_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms7_{i,j}} \cdots \\
& + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{ms8_{i,j}}
\end{aligned}$$

$$\begin{aligned} spflux_{Tlsd_{i,j}} := {} & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd1_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd2_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd3_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTl_i}\right)\cdot s_{msd4_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd5_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd6_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd7_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTl_i}\right)\cdot s_{msd8_{i,j}} \end{aligned}$$

Calculate mean seepage for (lower bound) Tptpll Unit.

$QTl1_{lstdl_i} := -1.7321\cdot spflux_{Tlsd_{i,0}}$

$QTl1_{lstdu_i} := 1.7321\cdot spflux_{Tlsd_{i,0}}$

$QTl_{lstdl_i} := \mathrm{if}\left(QTl1_{lstdl_i} = 0, -0.00001, QTl1_{lstdl_i}\right)$

$QTl_{lstd_i} := \mathrm{qunif}\left(X_{i,5}, QTl_{lstdl_i}, QTl1_{lstdu_i}\right)$

$QTl1_{lspm_i} := spflux_{Tlm_{i,0}} + QTl_{lstd_i}$

$QTl2_{lspm_i} := \mathrm{if}\left(QTl1_{lspm_i} \le 0.1, 0, QTl1_{lspm_i}\right)$

$QT2_{lperc_i} := \dfrac{QTl2_{lspm_i}\cdot 100}{q_{pff_{i,0}}\cdot 28.05\cdot 2}$ Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$QT3_{lperc_i} := \mathrm{if}\left(QT2_{lperc_i} \le 0, 0, \mathrm{if}\left(QT2_{lperc_i} \ge 100, 100, QT2_{lperc_i}\right)\right)$ Check seepage percent to be above 100% and then adjusted back.

$QTl_{lspr_i} := QT3_{lperc_i}\cdot q_{pff_{i,0}}\cdot\dfrac{2\cdot 28.05}{100}$

$\mathrm{mean}\left(QTl_{lspr}\right) = 4.377$ **Mean Seepage Flux (kg/yr/WP)**

Determine the seepage fraction for Tptpll Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTl_{lspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{l_i} := \mathrm{if}\left(QTl_{lspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_l := \sum_{i=0}^{n-1} num1_{l_i}$$

$n_{lTl} := (n - 1) - num_l$ $n_{lTl} = 16147$

$\mathrm{spfrcl}_{\mathrm{Tl}} := \frac{\mathrm{num}_{\mathrm{l}}}{\mathrm{n}}$ $\quad$ $\mathrm{spfrcl}_{\mathrm{Tl}} = 0.193$

$\mathrm{n1}_{\mathrm{lTl}} := (\mathrm{n} - 1) - \left(\mathrm{n}_{\mathrm{lTl}} + 1\right)$ $\quad$ $\mathrm{n1}_{\mathrm{lTl}} = 3.851 \times 10^{3}$

$\mathrm{Q11}_{\mathrm{lTl}} := \mathrm{sort}\left(\mathrm{QTl}_{\mathrm{lspr}}\right)$

$\mathrm{Q1}_{\mathrm{lTl}} := \mathrm{reverse}\left(\mathrm{Q11}_{\mathrm{lTl}}\right)$

$\mathrm{ab} := 0 .. \mathrm{n1}_{\mathrm{lTl}}$

$\mathrm{Q2}_{\mathrm{lTl}_{\mathrm{ab}}} := \left(\frac{1}{1} \cdot \mathrm{Q1}_{\mathrm{lTl}_{\mathrm{ab}}}\right)$

$\mathrm{Q}_{\mathrm{lTl}} := \mathrm{sort}\left(\mathrm{Q2}_{\mathrm{lTl}}\right)$

$\mathrm{mean}\left(\mathrm{Q}_{\mathrm{lTl}} \cdot 1\right) = 22.727$

$\mathrm{CDF}_{\mathrm{lTl}_{\mathrm{ab}}} := \frac{(\mathrm{ab} + 1) - 0.375}{\left(\mathrm{n1}_{\mathrm{lTl}} + 1\right) + 0.25}$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_{1} := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \left(\mathrm{Q}_{\mathrm{lTl}_{i}}\right)^{r} \cdot \ln\left(\mathrm{Q}_{\mathrm{lTl}_{i}}\right)\right]}{\sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \left(\mathrm{Q}_{\mathrm{lTl}_{i}}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{\mathrm{n1}_{\mathrm{lTl}}}\right) \cdot \sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \ln\left(\mathrm{Q}_{\mathrm{lTl}_{i}}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_{1} = 0.495$$

$$\alpha_{1} := \left[\frac{\sum_{i=0}^{\mathrm{n1}_{\mathrm{lTl}}} \left(\mathrm{Q}_{\mathrm{lTl}_{i}}\right)^{\beta_{1}}}{\mathrm{n1}_{\mathrm{lTl}}}\right]^{\frac{1}{\beta_{1}}} \qquad \alpha_{1} = 9.303$$

Plot of raw data versus Weibull distribution

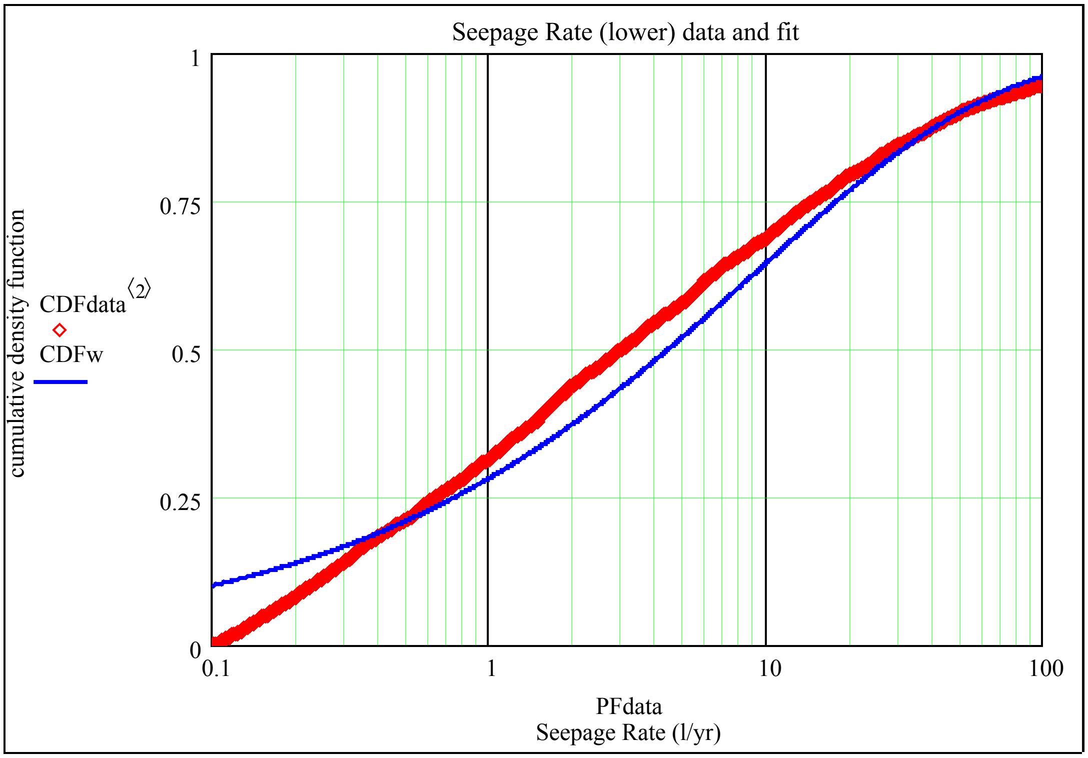
$\mathrm{ji} := 0 .. \mathrm{n1}_{\mathrm{lTl}}$

$\mathrm{PFdata}_{\mathrm{ji}} := \mathrm{Q}_{\mathrm{lTl}_{\mathrm{ji}}}$

$\mathrm{CDFdata}_{\mathrm{ji},2} := \mathrm{CDF}_{\mathrm{lTl}_{\mathrm{ji}}}$

$$\mathrm{CDFw1}_{\mathrm{ji}} := 1 - \exp\left[-\left(\frac{\mathrm{PFdata}_{\mathrm{ji}}}{\alpha_{1}}\right)^{\beta_{1}}\right]$$

$\mathrm{CDFw}_{\mathrm{ji},0} := \mathrm{CDFw1}_{\mathrm{ji}}$



Calculate mean seepage for (mean) Tptpll Unit.

$QTl1_{mstdl_i} := -1.7321 \cdot spflux_{Tlsd_{i,1}}$

$QTl1_{mstdu_i} := 1.7321 \cdot spflux_{Tlsd_{i,1}}$

$QTl_{mstdl_i} := if\left(QTl1_{mstdl_i} = 0, -0.00001, QTl1_{mstdl_i}\right)$

$QTl_{mstd_i} := qunif\left(X_{i,5}, QTl_{mstdl_i}, QTl1_{mstdu_i}\right)$

$QTl1_{mspm_i} := spflux_{Tlm_{i,1}} + QTl_{mstd_i}$

$QTl2_{mspm_i} := if\left(QTl1_{mspm_i} \le 0.1, 0, QTl1_{mspm_i}\right)$

$QT2_{mperc_i} := \dfrac{QTl2_{mspm_i} \cdot 100}{q_{pff_{i,1}} \cdot 28.052}$ Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$QT3_{mperc_i} := if\left(QT2_{mperc_i} \le 0, 0, if\left(QT2_{mperc_i} \ge 100, 100, QT2_{mperc_i}\right)\right)$ Check seepage percent to be above 100% and then adjusted back.

$QTl_{mspr_i} := QT3_{mperc_i} \cdot q_{pff_{i,1}} \cdot \dfrac{2 \cdot 28.05}{100}$ **Mean Seepage Flux (kg/yr/WP)**

$mean\left(QTl_{mspr}\right) = 186.288$

Determine the seepage fraction for Tptpll Unit (mean) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTl_{mspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{m_i} := \mathrm{if}\left(QTl_{mspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_m := \sum_{i=0}^{n-1} num1_{m_i}$$

$n_{mTl} := (n-1) - num_m \qquad n_{mTl} = 9701$

$spfrcm_{Tl} := \dfrac{num_m}{n} \qquad spfrcm_{Tl} = 0.515$

$n1_{mTl} := (n-1) - \left(n_{mTl} + 1\right) \qquad n1_{mTl} = 1.03 \times 10^{4}$

$Q11_{mTl} := \mathrm{sort}\left(QTl_{mspr}\right)$

$Q1_{mTl} := \mathrm{reverse}\left(Q11_{mTl}\right)$

$ab := 0 .. n1_{mTl}$

$Q2_{mTl_{ab}} := \left(\dfrac{1}{1} \cdot Q1_{mTl_{ab}}\right)$

$Q_{mTl} := \mathrm{sort}\left(Q2_{mTl}\right)$

$\mathrm{mean}\left(Q_{mTl} \cdot 1\right) = 361.795$

$CDF_{mTl_{ab}} := \dfrac{(ab + 1) - 0.375}{\left(n1_{mTl} + 1\right) + 0.25}$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M [DIRS 104667], p. 109).

$$\beta_m := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{mTl}} \left(Q_{mTl_i}\right)^{r} \cdot \ln\left(Q_{mTl_i}\right)\right]}{\sum_{i=0}^{n1_{mTl}} \left(Q_{mTl_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{mTl}}\right) \cdot \sum_{i=0}^{n1_{mTl}} \ln\left(Q_{mTl_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_m = 0.456$$

$$\alpha_m := \left[\frac{\sum_{i=0}^{n1_{mTl}} \left(Q_{mTl_i}\right)^{\beta_m}}{n1_{mTl}}\right]^{\frac{1}{\beta_m}} \qquad \alpha_m = 1.455 \times 10^{2}$$

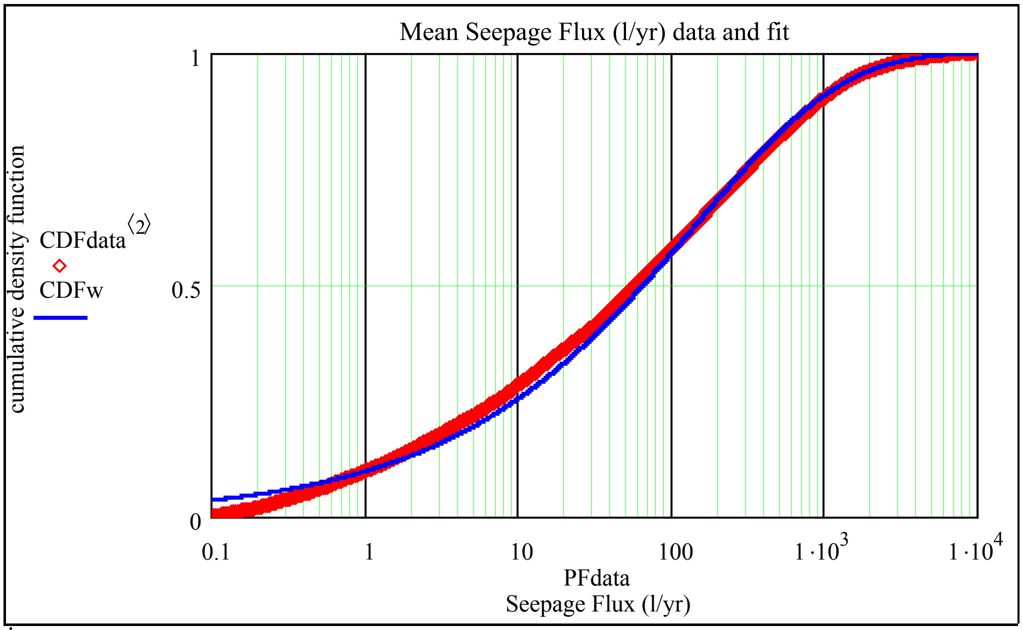
Plot of raw data versus Weibull distribution

$ji := 0 .. n1_{mTl}$

$PFdata_{ji} := Q_{mTl_{ji}}$

$CDFdata_{ji,2} := CDF_{mTl_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_m}\right)^{\beta_m}\right] \qquad CDFw_{ji,0} := CDFw1_{ji}$$



Calculate mean seepage for (upper bound) Tptpll Unit.

$$QTl1_{ustdl_i} := -1.7321 \cdot spflux_{Tlsd_{i,2}}$$

$$QTl1_{ustdu_i} := 1.7321 \cdot spflux_{Tlsd_{i,2}}$$

$$QTl_{ustdl_i} := if\left(QTl1_{ustdl_i} = 0, -0.00001, QTl1_{ustdl_i}\right)$$

$$QTl_{ustd_i} := qunif\left(X_{i,5}, QTl_{ustdl_i}, QTl1_{ustdu_i}\right)$$

$$QTl1_{uspm_i} := spflux_{Tlm_{i,2}} + QTl_{ustd_i}$$

$$QTl2_{uspm_i} := if\left(QTl1_{uspm_i} \le 0.1, 0, QTl1_{uspm_i}\right)$$

$$QT2_{uperc_i} := \frac{QTl2_{uspm_i} \cdot 100}{q_{pff_{i,2}} \cdot 28.052}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{uperc_i} := if\left(QT2_{uperc_i} \le 0, 0, if\left(QT2_{uperc_i} \ge 100, 100, QT2_{uperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTl_{uspr_i} := QT3_{uperc_i} \cdot q_{pff_{i,2}} \cdot \frac{2 \cdot 28.05}{100}$$ **Mean Seepage Flux (kg/yr/WP)**

$$mean\left(QTl_{uspr}\right) = 511.571$$

Determine the seepage fraction for Tptpll Unit (upper bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTl_{mspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{u_i} := \mathrm{if}\left(QTl_{uspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_u := \sum_{i=0}^{n-1} num1_{u_i}$$

$n_{uTl} := (n-1) - num_u \qquad n_{uTl} = 7183$

$spfrcu_{Tl} := \dfrac{num_u}{n} \qquad spfrcu_{Tl} = 0.641$

$n1_{uTl} := (n-1) - \left(n_{uTl} + 1\right) \qquad n1_{uTl} = 1.282\times 10^{4}$

$Q11_{uTl} := \mathrm{sort}\left(QTl_{uspr}\right)$

$Q1_{uTl} := \mathrm{reverse}\left(Q11_{uTl}\right)$

$ab := 0 .. n1_{uTl}$

$Q2_{uTl_{ab}} := \left(\dfrac{1}{1}\cdot Q1_{uTl_{ab}}\right)$

$Q_{uTl} := \mathrm{sort}\left(Q2_{uTl}\right)$

$\mathrm{mean}\left(Q_{uTl}\cdot 1\right) = 798.332$

$$CDF_{uTl_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{uTl} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M [DIRS 104667], p. 109).

$$\beta_u := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{uTl}} \left(Q_{uTl_i}\right)^{r}\cdot\ln\left(Q_{uTl_i}\right)\right]}{\sum_{i=0}^{n1_{uTl}} \left(Q_{uTl_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{uTl}}\right)\cdot\sum_{i=0}^{n1_{uTl}} \ln\left(Q_{uTl_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_u = 0.486$$

$$\alpha_u := \left[\frac{\sum_{i=0}^{n1_{uTl}} \left(Q_{uTl_i}\right)^{\beta_u}}{n1_{uTl}}\right]^{\frac{1}{\beta_u}} \qquad \alpha_u = 3.81\times 10^{2}$$

Plot of raw data versus Weibull distribution

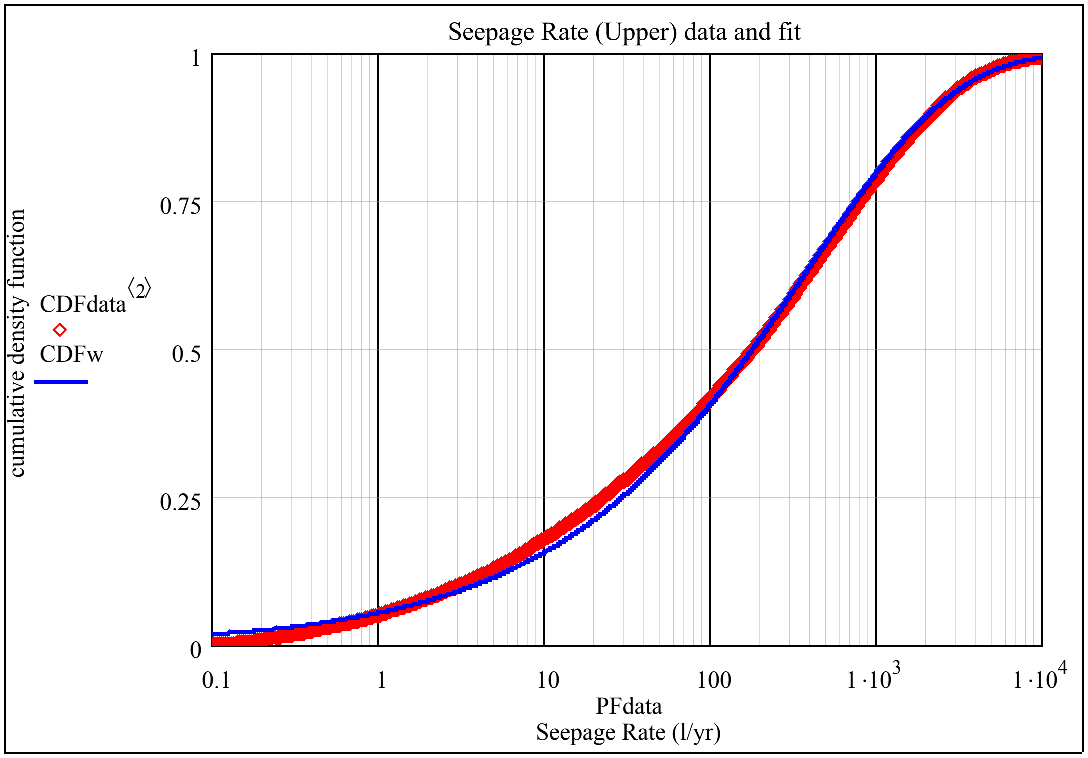
$ji := 0 .. n1_{uTl}$

$PFdata_{ji} := Q_{uTl_{ji}}$

$$CDFdata_{ji,2} := CDF_{uTl_{ji}}$$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_u}\right)^{\beta_u}\right]$$

$$CDFw_{ji,0} := CDFw1_{ji}$$



Overall Final Results

Lower Bound Results	**Mean Results**	**Upper Bound Results**	
$\alpha_l = 9.303$	$\alpha_m = 1.455\times 10^2$	$\alpha_u = 3.81\times 10^2$	
$\beta_l = 4.95\times 10^{-1}$	$\beta_m = 4.561\times 10^{-1}$	$\beta_u = 4.858\times 10^{-1}$	
$spfrcl_{Tl} = 1.926\times 10^{-1}$	$spfrcm_{Tl} = 5.149\times 10^{-1}$	$spfrcu_{Tl} = 6.408\times 10^{-1}$	**Seepage Fraction**
$mean\left(QTl_{lspr}\right) = 4.377$	$mean\left(QTl_{mspr}\right) = 186.288$	$mean\left(QTl_{uspr}\right) = 511.571$	**Data Set Mean**

C.4 SEISMIC SEEPAGE ANALYSIS FOR INFILTRATION RATE AND SEEPAGE FRACTION IN THE NONLITHOPHYSAL ZONE

This section presents the Mathcad analysis for calculating the seepage fraction and seepage infiltration rates (i.e., lower bound, mean, and upper bound) in the nonlithophysal zone given a seismic event. The seepage calculation is for the glacial transition period only. The seepage calculation utilizes the nominal seepage model (BSC 2004 [DIRS 169131], Section 6.7.1.1) but increases the results by 20 percent. The seepage information and the process used in the analysis was obtained from *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1). The information contained in this section has been abstracted from the "LA seepage glac Tptpmn seismic 1_2.mcd" Mathcad file of Appendix G.

Seepage Flux and Seepage Fraction Calculation using *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1)

Latin Hypercube Sampling Routine to Generate Random Numbers

size of the sampling: $n := 20000$

$i := 1 .. n$

$RD_{i-1,0} := i \quad RD_{i-1,1} := \mathrm{rnd}(1.0) \quad RD_{i-1,2} := \mathrm{rnd}(1.0) \quad RD_{i-1,3} := \mathrm{rnd}(1.0)$

$RD_{i-1,4} := \mathrm{rnd}(1.0) \quad RD_{i-1,5} := \mathrm{rnd}(1.0) \quad RD_{i-1,6} := \mathrm{rnd}(1.0)$

RK's are matrixes in which the first column contain a permutation on the integers on the interval [1,n].

$RK1 := \mathrm{csort}(RD,1) \quad RK2 := \mathrm{csort}(RD,2) \quad RK3 := \mathrm{csort}(RD,3)$

$RK4 := \mathrm{csort}(RD,4) \quad RK5 := \mathrm{csort}(RD,5) \quad RK6 := \mathrm{csort}(RD,6)$

Define sets of random values. Each random value is selected within one of the equiprobable n intervals that partition [0,1]. One set for each random variable.

$$X^{\langle 0\rangle} := \frac{RK1^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 1\rangle} := \frac{RK2^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 2\rangle} := \frac{RK3^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n}$$

$$X^{\langle 3\rangle} := \frac{RK4^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 4\rangle} := \frac{RK5^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 5\rangle} := \frac{RK6^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n}$$

$i := 0 .. n - 1$

Capillary Strength 1/ α in (Pa)

$\alpha 1_{lb} := 402 \quad \alpha 1_{ub} := 780 \quad \alpha 1_{\mu} := 591$ spatial variability follows a uniform distribution

$\Delta\alpha 1_{l} := -105 \quad \Delta\alpha 1_{\mu} := 0 \quad \Delta\alpha 1_{u} := 105$ uncertainty follows a triangular distribution

Sampling from spatial variability to obtain the 1/ α value

$\alpha 1_i := \mathrm{qunif}\left(X_{i,0}, \alpha 1_{lb}, \alpha 1_{ub}\right)$ 1/α value

Sample from uncertainty triangular distribution to obtain $\Delta 1/\alpha$

Determine which equation to use:
if Random Number < RN $_{\Delta\alpha 1}$ then use Equation 1 ($\Delta\alpha$1eq1)
if Random Number > RN $_{\Delta\alpha 1}$ then use Equation 2 ($\Delta\alpha$1eq2)

$$RN_{\Delta\alpha 1} := \frac{\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)^2}{\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq1_i} := \Delta\alpha 1_{l} + \sqrt{X_{i,1}\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq2_i} := \Delta\alpha 1_{u} - \sqrt{\left(1 - X_{i,1}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{\mu}\right)}$$

$\Delta\alpha 1_i := \mathrm{if}\left[\left(X_{i,1} \le RN_{\Delta\alpha 1}\right), \Delta\alpha 1_{eq1_i}, \Delta\alpha 1_{eq2_i}\right]$ Δ 1/α value

Overall Capillary Strength 1/ α + Δ1/α

$T_{1\alpha_i} := \alpha 1_i + \Delta\alpha 1_i$ 1/α value

Permeability k in Tptpmn Unit (in log 10)

$\mu_{kTn} := -12.2$ mean of lognormal distribution

$\sigma_{kTn} := 0.34$ standard deviation of lognormal distribution

$k_{Tn_i} := \ln\left(\text{qlnorm}\left(X_{i,2}, \mu_{kTn}, \sigma_{kTn}\right)\right)$

$\text{mean}\left(k_{Tn}\right) = -12.2$

$\text{Stdev}\left(k_{Tn}\right) = 0.34$

Permeability Δk in Tptpmn Unit (in log 10)

$\Delta k_{Tnl} := -0.68$ $\Delta k_{Tn\mu} := 0$ $\Delta k_{Tnu} := 0.68$ uncertainty follows a triangular distribution

Sample from uncertainty triangular distribution to obtain Δk

Determine which equation to use:
if Random Number < $RN_{\Delta kTn}$ then use Equation 1 (ΔkTneq1)
if Random Number > $RN_{\Delta kTn}$ then use Equation 2 (ΔkTneq2)

$$RN_{\Delta kTn} := \frac{\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)^2}{\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)}$$

$$\Delta kTn_{eq1_i} := \Delta k_{Tnl} + \sqrt{X_{i,3}\cdot\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)}$$

$$\Delta kTn_{eq2_i} := \Delta k_{Tnu} - \sqrt{\left(1 - X_{i,3}\right)\cdot\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tnu} - \Delta k_{Tn\mu}\right)}$$

$\Delta k_{Tn_i} := \text{if}\left[\left(X_{i,3} \le RN_{\Delta kTn}\right), \Delta kTn_{eq1_i}, \Delta kTn_{eq2_i}\right]$ Δk value

Overall Permeability k + Δk

$T1_{kTn_i} := k_{Tn_i} + \Delta k_{Tn_i}$

Permeability must lie between -14 and -10 (bounds of SMPA simulations)

$T_{kTn_i} := \text{if}\left(T1_{kTn_i} \ge -10, -10, \text{if}\left(T1_{kTn_i} \le -14, -14, T1_{kTn_i}\right)\right)$ k value

Flow Focusing Factor

$f(x) := -0.3137\cdot x^4 + 5.4998\cdot x^3 - 35.66\cdot x^2 + 102.3\cdot x - 11.434$

$ff_i := \text{root}\left[f(x) - \left(X_{i,4}\cdot 100\right), x, 0, 6\right]$

Percolation Flux (mm/yr)

The percolation flux used here is for the glacial transition period only. The percolation flux is based on sampling from the lower bound (TSPA repository location). DTN: LB0310AMRU0120.002 [DIRS 166116]

$nnn := 0..468$ number of data points

Lower Bound Percolation Flux

$PF1_l :=$

	0
0	3.676
1	2.6504
2	2.4144
3	2.1296
4	2.4089
5	2.3999
6	2.117
7	2.7623
8	1.397
9	2.2144

Mean Bound Percolation Flux

$PF1_m :=$

	0
0	15.9704
1	19.8733
2	14.1961
3	7.5897
4	16.9397
5	17.7583
6	10.4511
7	27.7684
8	8.9546
9	16.0195

Upper Bound Percolation Flux

$PF1_u :=$

	0
0	40.0021
1	36.1863
2	35.7337
3	27.828
4	30.7394
5	40.0292
6	31.8601
7	57.0835
8	18.3271
9	27.9133

$PFt_{l_{nnn}} := PF1_{l_{nnn,0}}$ $\qquad PFt_{m_{nnn}} := PF1_{m_{nnn,0}}$ $\qquad PFt_{u_{nnn}} := PF1_{u_{nnn,0}}$

$Z^{\langle 0\rangle} := \mathrm{round}(\mathrm{runif}(n,0,468))$

$PF_{l_i} := PFt_{l_{\left(Z_{i,0}\right)}}$ $\qquad PF_{m_i} := PFt_{m_{\left(Z_{i,0}\right)}}$ $\qquad PF_{u_i} := PFt_{u_{\left(Z_{i,0}\right)}}$

Adjusted Percolation Flux

Take the flow focusing factor and multiply it to the percolation flux, which will be used to obtain the seepage rate, seepage fraction, and seepage percentage.

$q1_{pff_i} := PF_{l_i} \cdot ff_i$ $\qquad qm_{pff_i} := PF_{m_i} \cdot ff_i$ $\qquad qu_{pff_i} := PF_{u_i} \cdot ff_i$

$q_{pff} := \mathrm{augment}\left(q1_{pff}, qm_{pff}, qu_{pff}\right)$

Percolation Flux must lie between 1 and 1000 mm/yr (bounds of SMPA simulations)

$j := 0..2$

$q_{pff_{i,j}} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(q_{pff_{i,j}} \ge 1000, 1000, q_{pff_{i,j}}\right)\right)$

Seepage Information from SMPA analysis

$m := 2549$ data points

$SMPA_{data}^{<0>}$ is permeability value log(k [m^2])

$SMPA_{data}^{<1>}$ is capillary strength 1/alpha [Pa]

$SMPA_{data}^{<2>}$ is local percolation flux (mm/yr)

$SMPA_{data}^{<3>}$ is Mean Seepage [kg/yr/WP]

$SMPA_{data}^{<4>}$ is Std. Dev. Seepage [kg/yr/WP]

$SMPA_{data}^{<5>}$ is Mean Seepage [%]

$SMPA_{data}^{<6>}$ is Std. Dev. Seepage [%]

$\mathrm{SMPA}_{\mathrm{data}} :=$

	0	1	2	3	4	5	6
0	-14	100	1	27.73	4.09	98.86	14.59
1	-14	100	5	138.92	20.55	99.05	14.65
2	-14	100	10	277.9	41.19	99.07	14.68
3	-14	100	20	555.87	82.54	99.09	14.71
4	-14	100	50	1391.67	205.57	99.23	14.66
5	-14	100	100	2793.55	406.7	99.59	14.5
6	-14	100	200	5610	785	100	14
7	-14	100	300	8415	1178	100	14
8	-14	100	400	11220	1570	100	14
9	-14	100	500	14025	1963	100	14
10	-14	100	600	16830	2356	100	14
11	-14	100	700	19635	2748	100	14
12	-14	100	800	22440	3141	100	14
13	-14	100	900	25245	3590	100	14
14	-14	100	1000	28050	3989	100	14
15	-14	200	1	26.14	4.21	93.21	15

Set up routine to pick out correct mean seepage, seepage standard deviation, seepage percent, and seepage percent standard deviation based on sampled value of 1/ α, k, percolation flux.

$nx := 14 \quad ny := 9 \quad nz := 16$

$ii := 0..nx$

$x_{ii} := \mathrm{SMPA}_{\mathrm{data}_{ii,2}} \qquad xi_{ii} := ii$

$jj := 0..ny$

$y_{jj} := 100 \cdot jj + 100 \qquad yj_{jj} := jj$

$kk := 0..nz$

$z_{kk} := -14 + kk \cdot 0.25 \quad zk_{kk} := kk$

loc represents the location within the matrix of which value to pick for the interpolation process.

$$loc1_{i,j} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right) \cdot (nx + 1) \cdot (ny + 1) + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right) \cdot (nx + 1) \ldots$$
$$+ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms1_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{loc1_{i,j},3}}$$

$$s_{msd1_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{loc1_{i,j},4}}$$

$$loc2_{i,j} := \left[\mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right) \cdot (nx + 1) \cdot (ny + 1)\right] + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right) \cdot (nx + 1) \ldots$$
$$+ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms2_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{loc2_{i,j},3}}$$

$$s_{msd2_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{loc2_{i,j},4}}$$

$$\mathrm{loc}_{3_{i,j}} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms3_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{3_{i,j}},3}}$$

$$s_{msd3_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{3_{i,j}},4}}$$

$$\mathrm{loc}_{4_{i,j}} := \mathrm{floor}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms4_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{4_{i,j}},3}}$$

$$s_{msd4_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{4_{i,j}},4}}$$

$$\mathrm{loc}_{5_{i,j}} := \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms5_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{5_{i,j}},3}}$$

$$s_{msd5_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{5_{i,j}},4}}$$

$$\mathrm{loc}_{6_{i,j}} := \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{floor}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms6_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{6_{i,j}},3}}$$

$$s_{msd6_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{6_{i,j}},4}}$$

$$\mathrm{loc}_{7_{i,j}} := \left[\mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{ceil}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms7_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{7_{i,j}},3}}$$

$$s_{msd7_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{7_{i,j}},4}}$$

$$\mathrm{loc}_{8_{i,j}} := \mathrm{ceil}\left(\mathrm{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \mathrm{ceil}\left(\mathrm{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots$$
$$+ \mathrm{floor}\left(\mathrm{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms8_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{8_{i,j}},3}}$$

$$s_{msd8_{i,j}} := \mathrm{SMPA}_{\mathrm{data}_{\mathrm{loc}_{8_{i,j}},4}}$$

Develop the upper and lower bound for permeability (k) for Tptpmn Unit

$qq_i := -1 \cdot T_{kTn_i}$

$\mathrm{mantissa}(x) := x - \mathrm{floor}(qq)$

$tt_i := \mathrm{floor}\left(qq_i\right)$

$rr := \mathrm{round}(\mathrm{mantissa}(qq), 2)$

$yy1_i := \mathrm{if}\left(rr_i \le 0.25, 0, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.25, rr_i\right)\right)$

$zz1_i := \mathrm{if}\left(yy1_i \le 0.5, yy1_i, \mathrm{if}\left(0.5 < yy1_i \le 0.75, 0.5, 0.75\right)\right)$

$T_{kTn2_i} := -1 \cdot \left(tt_i + zz1_i\right)$

$yy2_i := \mathrm{if}\left(rr_i \le 0.25, 0.25, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.5, rr_i\right)\right)$

$zz2_i := \mathrm{if}\left(yy2_i \le 0.5, yy2_i, \mathrm{if}\left(0.5 < yy2_i \le 0.75, 0.75, 1\right)\right)$

$T_{kTn1_i} := -1 \cdot \left(tt_i + zz2_i\right)$

Develop the upper and lower bound for capillary strength (1/ α).

$$hh1_i := \mathrm{floor}\left(\frac{T_{1\alpha_i}}{100}\right)$$

$T_{1\alpha1_i} := \left(hh1_i \cdot 100\right)$

$$hh2_i := \mathrm{ceil}\left(\frac{T_{1\alpha_i}}{100}\right)$$

$T_{1\alpha2_i} := \left(hh2_i \cdot 100\right)$

Lower Bound value adjusted percolation flux (q_{pff}).

$aaa1_{i,j} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(1 < q_{pff_{i,j}} \le 5, 1, q_{pff_{i,j}}\right)\right)$

$bbb1_{i,j} := \mathrm{if}\left(aaa1_{i,j} \le 5, aaa1_{i,j}, \mathrm{if}\left(5 < aaa1_{i,j} \le 10, 5, aaa1_{i,j}\right)\right)$

$ccc1_{i,j} := \mathrm{if}\left(bbb1_{i,j} \le 10, bbb1_{i,j}, \mathrm{if}\left(10 < bbb1_{i,j} \le 20, 10, bbb1_{i,j}\right)\right)$

$ddd1_{i,j} := \mathrm{if}\left(ccc1_{i,j} \le 20, ccc1_{i,j}, \mathrm{if}\left(20 < ccc1_{i,j} \le 50, 20, ccc1_{i,j}\right)\right)$

$eee1_{i,j} := \mathrm{if}\left(ddd1_{i,j} \le 50, ddd1_{i,j}, \mathrm{if}\left(50 < ddd1_{i,j} \le 100, 50, ddd1_{i,j}\right)\right)$

$fff1_{i,j} := \mathrm{if}\left(eee1_{i,j} \le 100, eee1_{i,j}, \mathrm{if}\left(100 < eee1_{i,j} \le 200, 100, eee1_{i,j}\right)\right)$

$ggg1_{i,j} := \mathrm{if}\left(fff1_{i,j} \le 200, fff1_{i,j}, \mathrm{if}\left(200 < fff1_{i,j} \le 300, 200, fff1_{i,j}\right)\right)$

$hhh1_{i,j} := \mathrm{if}\left(ggg1_{i,j} \le 300, ggg1_{i,j}, \mathrm{if}\left(300 < ggg1_{i,j} \le 400, 300, ggg1_{i,j}\right)\right)$

$iii1_{i,j} := \mathrm{if}\left(hhh1_{i,j} \le 400, hhh1_{i,j}, \mathrm{if}\left(400 < hhh1_{i,j} \le 500, 400, hhh1_{i,j}\right)\right)$

$jjj1_{i,j} := \mathrm{if}\left(iii1_{i,j} \le 500, iii1_{i,j}, \mathrm{if}\left(500 < iii1_{i,j} \le 600, 500, iii1_{i,j}\right)\right)$

$$kkk1_{i,j} := \text{if}\left(jjj1_{i,j} \le 600, jjj1_{i,j}, \text{if}\left(600 < jjj1_{i,j} \le 700, 600, jjj1_{i,j}\right)\right)$$

$$mmm1_{i,j} := \text{if}\left(kkk1_{i,j} \le 700, kkk1_{i,j}, \text{if}\left(700 < kkk1_{i,j} \le 800, 700, kkk1_{i,j}\right)\right)$$

$$q_{pff1_{i,j}} := \text{if}\left(mmm1_{i,j} \le 800, mmm1_{i,j}, \text{if}\left(800 < mmm1_{i,j} \le 900, 800, 900\right)\right)$$

Upper Bound value adjusted percolation flux (q_{pff}).

$$aaa2_{i,j} := \text{if}\left(q_{pff_{i,j}} \le 1, 5, \text{if}\left(1 < q_{pff_{i,j}} \le 5, 5, q_{pff_{i,j}}\right)\right)$$

$$bbb2_{i,j} := \text{if}\left(aaa2_{i,j} \le 5, aaa2_{i,j}, \text{if}\left(5 < aaa2_{i,j} \le 10, 10, aaa2_{i,j}\right)\right)$$

$$ccc2_{i,j} := \text{if}\left(bbb2_{i,j} \le 10, bbb2_{i,j}, \text{if}\left(10 < bbb2_{i,j} \le 20, 20, bbb2_{i,j}\right)\right)$$

$$ddd2_{i,j} := \text{if}\left(ccc2_{i,j} \le 20, ccc2_{i,j}, \text{if}\left(20 < ccc2_{i,j} \le 50, 50, ccc2_{i,j}\right)\right)$$

$$eee2_{i,j} := \text{if}\left(ddd2_{i,j} \le 50, ddd2_{i,j}, \text{if}\left(50 < ddd2_{i,j} \le 100, 100, ddd2_{i,j}\right)\right)$$

$$fff2_{i,j} := \text{if}\left(eee2_{i,j} \le 100, eee2_{i,j}, \text{if}\left(100 < eee2_{i,j} \le 200, 200, eee2_{i,j}\right)\right)$$

$$ggg2_{i,j} := \text{if}\left(fff2_{i,j} \le 200, fff2_{i,j}, \text{if}\left(200 < fff2_{i,j} \le 300, 300, fff2_{i,j}\right)\right)$$

$$hhh2_{i,j} := \text{if}\left(ggg2_{i,j} \le 300, ggg2_{i,j}, \text{if}\left(300 < ggg2_{i,j} \le 400, 400, ggg2_{i,j}\right)\right)$$

$$iii2_{i,j} := \text{if}\left(hhh2_{i,j} \le 400, hhh2_{i,j}, \text{if}\left(400 < hhh2_{i,j} \le 500, 500, hhh2_{i,j}\right)\right)$$

$$jjj2_{i,j} := \text{if}\left(iii2_{i,j} \le 500, iii2_{i,j}, \text{if}\left(500 < iii2_{i,j} \le 600, 600, iii2_{i,j}\right)\right)$$

$$kkk2_{i,j} := \text{if}\left(jjj2_{i,j} \le 600, jjj2_{i,j}, \text{if}\left(600 < jjj2_{i,j} \le 700, 700, jjj2_{i,j}\right)\right)$$

$$mmm2_{i,j} := \text{if}\left(kkk2_{i,j} \le 700, kkk2_{i,j}, \text{if}\left(700 < kkk2_{i,j} \le 800, 800, kkk2_{i,j}\right)\right)$$

$$q_{pff2_{i,j}} := \text{if}\left(mmm2_{i,j} \le 800, mmm2_{i,j}, \text{if}\left(800 < mmm2_{i,j} \le 900, 900, 1000\right)\right)$$

Solve for seepage flux (Tptpmn Unit)

$$u_{T1\alpha_i} := \frac{T_{1\alpha_i} - T_{1\alpha1_i}}{T_{1\alpha2_i} - T_{1\alpha1_i}} \qquad v_{TkTn_i} := \frac{T_{kTn_i} - T_{kTn1_i}}{T_{kTn2_i} - T_{kTn1_i}} \qquad t_{qpff_{i,j}} := \frac{q_{pff_{i,j}} - q_{pff1_{i,j}}}{q_{pff2_{i,j}} - q_{pff1_{i,j}}}$$

$$\begin{aligned} spflux_{Tnm_{i,j}} := {} & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms1_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms2_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms3_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{ms4_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms5_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms6_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms7_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{ms8_{i,j}} \end{aligned}$$

$$
\begin{aligned}
spflux_{Tnsd_{i,j}} := {} & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd1_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd2_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd3_{i,j}} \cdots \\
& + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd4_{i,j}} \cdots \\
& + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd5_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd6_{i,j}} \cdots \\
& + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd7_{i,j}} \cdots \\
& + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd8_{i,j}}
\end{aligned}
$$

Calculate mean seepage for Tptpmn Unit (lower bound).

$$QTn1_{lstdl_i} := -1.7321\cdot spflux_{Tnsd_{i,0}}$$

$$QTn1_{lstdu_i} := 1.7321\cdot spflux_{Tnsd_{i,0}}$$

$$QTn_{lstdl_i} := \mathrm{if}\left(QTn1_{lstdl_i} = 0, -0.00001, QTn1_{lstdl_i}\right)$$

$$QTn_{lstd_i} := \mathrm{qunif}\left(X_{i,5}, QTn_{lstdl_i}, QTn1_{lstdu_i}\right)$$

$$QTn1_{lspm_i} := 1.2\cdot\left(spflux_{Tnm_{i,0}} + QTn_{lstd_i}\right)$$

$$QTn2_{lspm_i} := \mathrm{if}\left(QTn1_{lspm_i} \le 0.1, 0, QTn1_{lspm_i}\right)$$

$$QT2_{lperc_i} := \frac{QTn2_{lspm_i}\cdot 100}{q_{pff_{i,0}}\cdot 28.05}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{lperc_i} := \mathrm{if}\left(QT2_{lperc_i} \le 0, 0, \mathrm{if}\left(QT2_{lperc_i} \ge 100, 100, QT2_{lperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTn_{lspr_i} := QT3_{lperc_i}\cdot q_{pff_{i,0}}\cdot\frac{28.05}{100}$$

Mean Seepage Flux (kg/yr/WP)

$$\mathrm{mean}\left(QTn_{lspr}\right) = 1.827$$

Determine the seepage fraction for Tptpmn Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$$\mathrm{sort}\left(QTn_{lspr}\right) =$$

	0
16914	0
16915	0
16916	0.1
16917	0.1
16918	0.101

$$num1_{l_i} := \mathrm{if}\left(QTn_{lspr_i} > 0, 1, 0\right)$$

Number of seepage rates greater than zero.

$$num_l := \sum_{i=0}^{n-1} num1_{l_i}$$

$$n_{lTn} := (n-1) - num_l \qquad n_{lTn} = 16915$$

$$spfrcl_{Tn} := \frac{num_l}{n} \qquad spfrcl_{Tn} = 0.154$$

$n1_{lTn} := (n - 1) - \left(n_{lTn} + 1\right)$ $\quad n1_{lTn} = 3.026\times 10^{3}$

$Q11_{lTn} := \mathrm{sort}\left(QTn_{lspr}\right)$

$Q1_{lTn} := \mathrm{reverse}\left(Q11_{lTn}\right)$

$ab := 0..\, n1_{lTn}$

$Q2_{lTn_{ab}} := \left(Q1_{lTn_{ab}}\right)$

$Q_{lTn} := \mathrm{sort}\left(Q2_{lTn}\right)$

$\mathrm{mean}\left(Q_{lTn}\right) = 12.515$

$$CDF_{lTn_{ab}} := \frac{(ab + 1) - 0.375}{\left(n1_{lTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_l := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{r}\cdot \ln\left(Q_{lTn_i}\right)\right]}{\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{lTn}}\right)\cdot \sum_{i=0}^{n1_{lTn}} \ln\left(Q_{lTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_l = 0.518$$

$$\alpha_l := \left[\frac{\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{\beta_l}}{n1_{lTn}}\right]^{\frac{1}{\beta_l}} \qquad \alpha_l = 5.512$$

Plot of raw data versus Weibull distribution

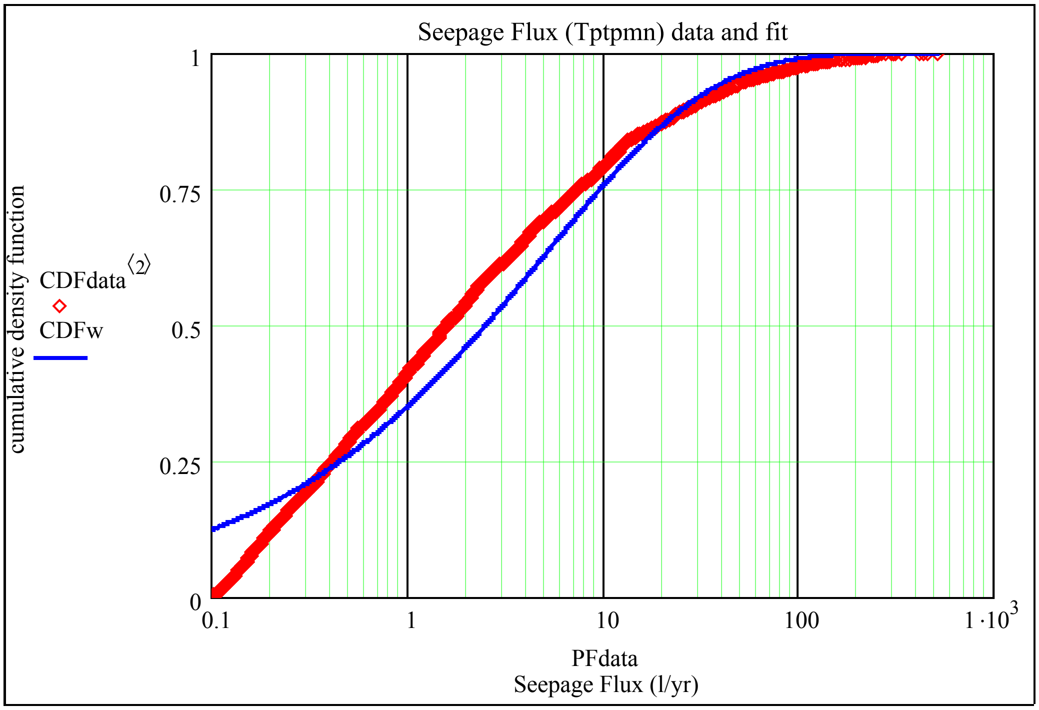
$ji := 0..\, n1_{lTn}$

$PFdata_{ji} := Q_{lTn_{ji}}$

$CDFdata_{ji,2} := CDF_{lTn_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_l}\right)^{\beta_l}\right]$$

$CDFw_{ji,0} := CDFw1_{ji}$



Calculate mean seepage for Tptpmn Unit (mean).

$QTn1_{mstdl_i} := -1.7321 \cdot spflux_{Tnsd_{i,1}}$

$QTn1_{mstdu_i} := 1.7321 \cdot spflux_{Tnsd_{i,1}}$

$QTn_{mstdl_i} := \mathrm{if}\left(QTn1_{mstdl_i} = 0, -0.00001, QTn1_{mstdl_i}\right)$

$QTn_{mstd_i} := \mathrm{qunif}\left(X_{i,5}, QTn_{mstdl_i}, QTn1_{mstdu_i}\right)$

$QTn1_{mspm_i} := 1.2 \cdot \left(spflux_{Tnm_{i,1}} + QTn_{mstd_i}\right)$

$QTn2_{mspm_i} := \mathrm{if}\left(QTn1_{mspm_i} \le 0.1, 0, QTn1_{mspm_i}\right)$

$QT2_{mperc_i} := \dfrac{QTn2_{mspm_i} \cdot 100}{q_{pff_{i,1}} \cdot 28.05}$ Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$QT3_{mperc_i} := \mathrm{if}\left(QT2_{mperc_i} \le 0, 0, \mathrm{if}\left(QT2_{mperc_i} \ge 100, 100, QT2_{mperc_i}\right)\right)$ Check seepage percent to be above 100% and then adjusted back.

$QTn_{mspr_i} := QT3_{mperc_i} \cdot q_{pff_{i,1}} \cdot \dfrac{28.05}{100}$ **Mean Seepage Flux (kg/yr/WP)**

$\mathrm{mean}\left(QTn_{mspr}\right) = 108.73$

Determine the seepage fraction for Tptpmn Unit (mean) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTn_{mspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{m_i} := \mathrm{if}\left(QTn_{mspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_m := \sum_{i=0}^{n-1} num1_{m_i}$$

$n_{mTn} := (n-1) - num_m \qquad n_{mTn} = 9544$

$spfrcm_{Tn} := \dfrac{num_m}{n} \qquad spfrcm_{Tn} = 0.523$

$n1_{mTn} := (n-1) - \left(n_{mTn} + 1\right) \qquad n1_{mTn} = 1.045\times 10^{4}$

$Q11_{mTn} := \mathrm{sort}\left(QTn_{mspr}\right)$

$Q1_{mTn} := \mathrm{reverse}\left(Q11_{mTn}\right)$

$ab := 0 .. n1_{mTn}$

$Q2_{mTn_{ab}} := \left(Q1_{mTn_{ab}}\right)$

$Q_{mTn} := \mathrm{sort}\left(Q2_{mTn}\right)$

$\mathrm{mean}\left(Q_{mTn}\right) = 210.55$

$$CDF_{mTn_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{mTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_m := \mathrm{root}\left[\left[\frac{\left[\displaystyle\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{r} \cdot \ln\left(Q_{mTn_i}\right)\right]}{\displaystyle\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{mTn}}\right) \cdot \sum_{i=0}^{n1_{mTn}} \ln\left(Q_{mTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_m = 0.464$$

$$\alpha_m := \left[\frac{\displaystyle\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{\beta_m}}{n1_{mTn}}\right]^{\frac{1}{\beta_m}} \qquad \alpha_m = 8.627\times 10^{1}$$

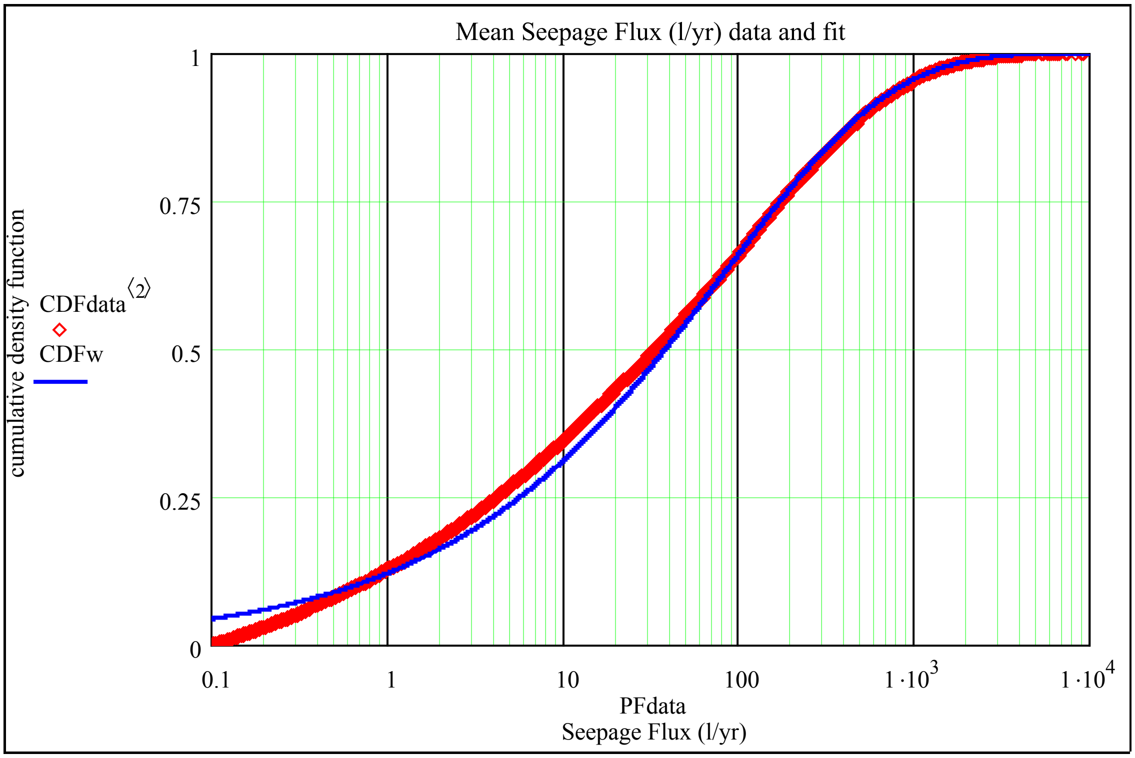
Plot of raw data versus Weibull distribution

$ji := 0 .. n1_{mTn}$

$PFdata_{ji} := Q_{mTn_{ji}}$

$CDFdata_{ji,2} := CDF_{mTn_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_m}\right)^{\beta_m}\right] \qquad CDFw_{ji,0} := CDFw1_{ji}$$



Calculate mean seepage for Tptpmn Unit (upper bound).

$QTn1_{ustdl_i} := -1.7321 \cdot spflux_{Tnsd_{i,2}}$

$QTn1_{ustdu_i} := 1.7321 \cdot spflux_{Tnsd_{i,2}}$

$QTn_{ustdl_i} := if\left(QTn1_{ustdl_i} = 0, -0.00001, QTn1_{ustdl_i}\right)$

$QTn_{ustd_i} := qunif\left(X_{i,5}, QTn_{ustdl_i}, QTn1_{ustdu_i}\right)$

$QTn1_{uspm_i} := 1.2 \cdot \left(spflux_{Tnm_{i,2}} + QTn_{ustd_i}\right)$

$QTn2_{uspm_i} := if\left(QTn1_{uspm_i} \le 0.1, 0, QTn1_{uspm_i}\right)$

$QT2_{uperc_i} := \dfrac{QTn2_{uspm_i} \cdot 100}{q_{pff_{i,2}} \cdot 28.05}$ Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$QT3_{uperc_i} := if\left(QT2_{uperc_i} \le 0, 0, if\left(QT2_{uperc_i} \ge 100, 100, QT2_{uperc_i}\right)\right)$ Check seepage percent to be above 100% and then adjusted back.

$QTn_{uspr_i} := QT3_{uperc_i} \cdot q_{pff_{i,2}} \cdot \dfrac{28.05}{100}$ **Mean Seepage Flux (kg/yr/WP)**

$mean\left(QTn_{uspr}\right) = 307.199$

Determine the seepage fraction for Tptpmn Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTn_{uspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{u_i} := \mathrm{if}\left(QTn_{uspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_u := \sum_{i=0}^{n-1} num1_{u_i}$$

$n_{uTn} := (n-1) - num_u \qquad n_{uTn} = 6520$

$$spfrcu_{Tn} := \frac{num_u}{n} \qquad spfrcu_{Tn} = 0.674$$

$n1_{uTn} := (n-1) - \left(n_{uTn} + 1\right) \qquad n1_{uTn} = 1.348\times 10^4$

$Q11_{uTn} := \mathrm{sort}\left(QTn_{uspr}\right)$

$Q1_{uTn} := \mathrm{reverse}\left(Q11_{uTn}\right)$

$ab := 0..\, n1_{uTn}$

$$Q2_{uTn_{ab}} := \left(\frac{1}{1}\cdot Q1_{uTn_{ab}}\right)$$

$Q_{uTn} := \mathrm{sort}\left(Q2_{uTn}\right)$

$\mathrm{mean}\left(Q_{uTn}\cdot 1\right) = 462.2$

$$CDF_{uTn_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{uTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_u := \mathrm{root}\left[\left[\frac{\left[\displaystyle\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^r \cdot \ln\left(Q_{uTn_i}\right)\right]}{\displaystyle\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^r} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{uTn}}\right)\cdot \sum_{i=0}^{n1_{uTn}} \ln\left(Q_{uTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_u = 0.492$$

$$\alpha_u := \left[\frac{\displaystyle\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^{\beta_u}}{n1_{uTn}}\right]^{\frac{1}{\beta_u}} \qquad \alpha_u = 2.245\times 10^2$$

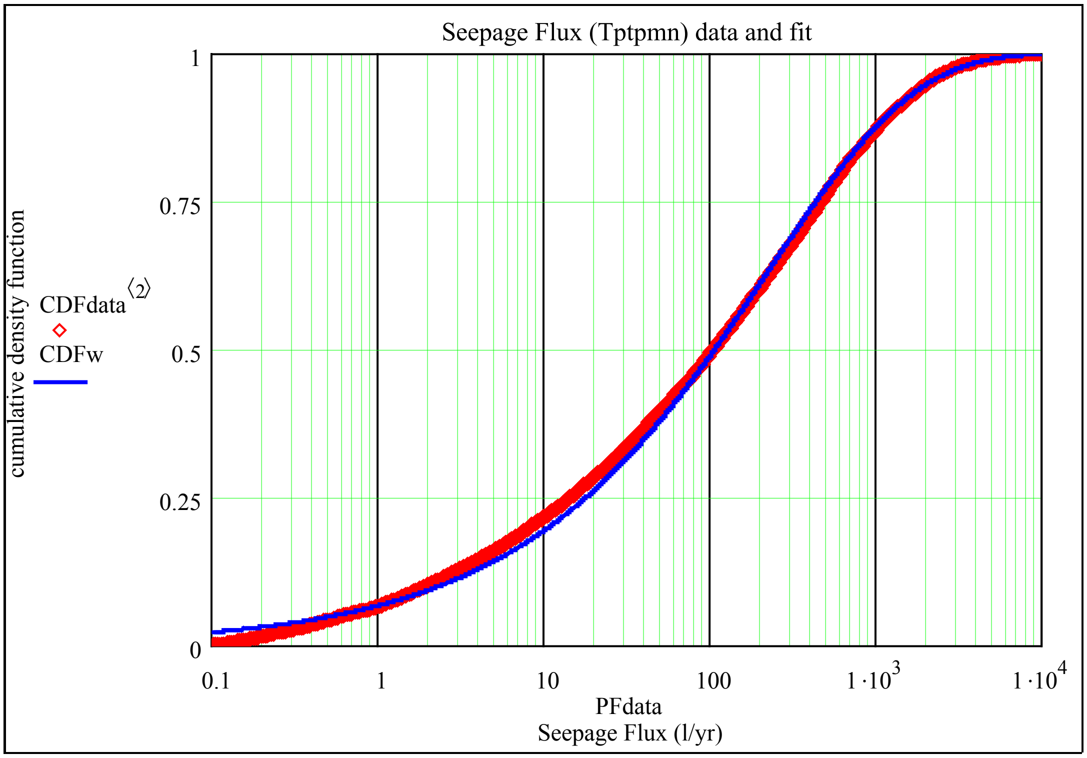
Plot of raw data versus Weibull distribution

$ji := 0..\, n1_{uTn}$

$PFdata_{ji} := Q_{uTn_{ji}}$

$CDFdata_{ji,2} := CDF_{uTn_{ji}}$

$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_u}\right)^{\beta_u}\right] \qquad CDFw_{ji,0} := CDFw1_{ji}$



Overall Final Results for Tptpmn Zone (1.2 times nominal)

Lower Bound Results	**Mean Results**	**Upper Bound Results**	
$\alpha_l = 5.099\times 10^{0}$	$\alpha_m = 8.414\times 10^{1}$	$\alpha_u = 2.232\times 10^{2}$	
$\beta_l = 5.135\times 10^{-1}$	$\beta_m = 4.619\times 10^{-1}$	$\beta_u = 4.932\times 10^{-1}$	
$spfrcl_{Tn} = 1.542\times 10^{-1}$	$spfrcm_{Tn} = 5.234\times 10^{-1}$	$spfrcu_{Tn} = 6.716\times 10^{-1}$	**Seepage Fraction**
$mean(QTn_{lspr}) = 1.827$	$mean(QTn_{mspr}) = 108.73$	$mean(QTn_{uspr}) = 307.199$	**Data Set Mean**

C.5 IGNEOUS SEEPAGE ANALYSIS FOR INFILTRATION RATE AND SEEPAGE FRACTION IN THE NONLITHOPHYSAL ZONE

This section presents the Mathcad analysis for calculating the seepage fraction and seepage infiltration rates (i.e., lower bound, mean, and upper bound) in the nonlithophysal zone given an igneous event. The seepage calculation is for the glacial transition period only. The seepage calculation utilizes the collapsed seepage model (BSC 2004 [DIRS 169131], Section 6.5.1.7). The seepage information and the process used in the analysis was obtained from *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1). The information contained in this section has been abstracted from the “LA seepage glac Tptpmn collapse-igneous.mcd” Mathcad file of Appendix G.

Seepage Flux and Seepage Fraction Calculation using *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131], Section 6.7.1.1)

Latin Hypercube Sampling Routine to Generate Random Numbers

size of the sampling: $n := 20000$

$i := 1 .. n$

$RD_{i-1,0} := i$ $\quad RD_{i-1,1} := \mathrm{rnd}(1.0)$ $\quad RD_{i-1,2} := \mathrm{rnd}(1.0)$ $\quad RD_{i-1,3} := \mathrm{rnd}(1.0)$

$RD_{i-1,4} := \mathrm{rnd}(1.0)$ $\quad RD_{i-1,5} := \mathrm{rnd}(1.0)$ $\quad RD_{i-1,6} := \mathrm{rnd}(1.0)$

RK's are matrixes in which the first column contain a permutation on the integers on the interval [1,n].

$RK1 := \mathrm{csort}(RD, 1)$ $\quad RK2 := \mathrm{csort}(RD, 2)$ $\quad RK3 := \mathrm{csort}(RD, 3)$

$RK4 := \mathrm{csort}(RD, 4)$ $\quad RK5 := \mathrm{csort}(RD, 5)$ $\quad RK6 := \mathrm{csort}(RD, 6)$

Define sets of random values. Each random value is selected within one of the equiprobable n intervals that partition [0,1]. One set for each random variable.

$$X^{\langle 0\rangle} := \frac{RK1^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 1\rangle} := \frac{RK2^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 2\rangle} := \frac{RK3^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n}$$

$$X^{\langle 3\rangle} := \frac{RK4^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 4\rangle} := \frac{RK5^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n} \quad X^{\langle 5\rangle} := \frac{RK6^{\langle 0\rangle} - 1 + \mathrm{runif}(n,0,1)}{n}$$

$i := 0 .. n - 1$

Capillary Strength 1/ α in (Pa)

$\alpha 1_{lb} := 402$ $\quad \alpha 1_{ub} := 780$ $\quad \alpha 1_{\mu} := 591$ spatial variability follows a uniform distribution

$\Delta\alpha 1_{l} := -105$ $\quad \Delta\alpha 1_{\mu} := 0$ $\quad \Delta\alpha 1_{u} := 105$ uncertainty follows a triangular distribution

Sampling from spatial variability to obtain the 1/ α value

$\alpha 1_{i} := \mathrm{qunif}\left(X_{i,0}, \alpha 1_{lb}, \alpha 1_{ub}\right)$ 1/α value

Sample from uncertainty triangular distribution to obtain $\Delta 1/\alpha$

Determine which equation to use:
if Random Number < RN $_{\Delta\alpha 1}$ then use Equation 1 ($\Delta\alpha$1eq1)
if Random Number > RN $_{\Delta\alpha 1}$ then use Equation 2 ($\Delta\alpha$1eq2)

$$RN_{\Delta\alpha 1} := \frac{\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)^2}{\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq1_i} := \Delta\alpha 1_{l} + \sqrt{X_{i,1}\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{\mu} - \Delta\alpha 1_{l}\right)}$$

$$\Delta\alpha 1_{eq2_i} := \Delta\alpha 1_{u} - \sqrt{\left(1 - X_{i,1}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{l}\right)\cdot\left(\Delta\alpha 1_{u} - \Delta\alpha 1_{\mu}\right)}$$

$\Delta\alpha 1_{i} := \mathrm{if}\left[\left(X_{i,1} \le RN_{\Delta\alpha 1}\right), \Delta\alpha 1_{eq1_i}, \Delta\alpha 1_{eq2_i}\right]$ Δ 1/α value

Overall Capillary Strength 1/ α + Δ1/α

$T_{1\alpha_i} := \alpha 1_i + \Delta\alpha 1_i$ 1/α value

Permeability k in Tptpmn Unit (in log 10)

$\mu_{kTn} := -12.2$ mean of lognormal distribution

$\sigma_{kTn} := 0.34$ standard deviation of lognormal distribution

$k_{Tn_i} := \ln\left(\mathrm{qlnorm}\left(X_{i,2}, \mu_{kTn}, \sigma_{kTn}\right)\right)$

$\mathrm{mean}\left(k_{Tn}\right) = -12.2$

$\mathrm{Stdev}\left(k_{Tn}\right) = 0.34$

Permeability Δk in Tptpmn Unit (in log 10)

$\Delta k_{Tnl} := -0.68$ $\Delta k_{Tn\mu} := 0$ $\Delta k_{Tnu} := 0.68$ uncertainty follows a triangular distribution

Sample from uncertainty triangular distribution to obtain Δk

Determine which equation to use:
if Random Number < $RN_{\Delta kTn}$ then use Equation 1 (ΔkTneq1)
if Random Number > $RN_{\Delta kTn}$ then use Equation 2 (ΔkTneq2)

$$RN_{\Delta kTn} := \frac{\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)^2}{\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)}$$

$$\Delta kTn_{eq1_i} := \Delta k_{Tnl} + \sqrt{X_{i,3}\cdot\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tn\mu} - \Delta k_{Tnl}\right)}$$

$$\Delta kTn_{eq2_i} := \Delta k_{Tnu} - \sqrt{\left(1 - X_{i,3}\right)\cdot\left(\Delta k_{Tnu} - \Delta k_{Tnl}\right)\cdot\left(\Delta k_{Tnu} - \Delta k_{Tn\mu}\right)}$$

$\Delta k_{Tn_i} := \mathrm{if}\left[\left(X_{i,3} \le RN_{\Delta kTn}\right), \Delta kTn_{eq1_i}, \Delta kTn_{eq2_i}\right]$ Δk value

Overall Permeability k + Δk

$T1_{kTn_i} := k_{Tn_i} + \Delta k_{Tn_i}$

Permeability must lie between -14 and -10 (bounds of SMPA simulations)

$T_{kTn_i} := \mathrm{if}\left(T1_{kTn_i} \ge -10, -10, \mathrm{if}\left(T1_{kTn_i} \le -14, -14, T1_{kTn_i}\right)\right)$ k value

Flow Focusing Factor

$f(x) := -0.3137\cdot x^4 + 5.4998\cdot x^3 - 35.66\cdot x^2 + 102.3\cdot x - 11.434$

$ff_i := \mathrm{root}\left[f(x) - \left(X_{i,4}\cdot 100\right), x, 0, 6\right]$

Percolation Flux (mm/yr)

The percolation flux used here is for the glacial transition period only. The percolation flux is based on sampling from the lower bound (TSPA repository location). DTN: LB0310AMRU0120.002 [DIRS 166116]

$nnn := 0..468$ number of data points

Lower Bound Percolation Flux

$PF1_l :=$

	0
0	3.676
1	2.6504
2	2.4144
3	2.1296
4	2.4089
5	2.3999
6	2.117
7	2.7623
8	1.397
9	2.2144

Mean Bound Percolation Flux

$PF1_m :=$

	0
0	15.9704
1	19.8733
2	14.1961
3	7.5897
4	16.9397
5	17.7583
6	10.4511
7	27.7684
8	8.9546
9	16.0195

Upper Bound Percolation Flux

$PF1_u :=$

	0
0	40.0021
1	36.1863
2	35.7337
3	27.828
4	30.7394
5	40.0292
6	31.8601
7	57.0835
8	18.3271
9	27.9133

$PFt_{l_{nnn}} := PF1_{l_{nnn,0}}$ $\quad$ $PFt_{m_{nnn}} := PF1_{m_{nnn,0}}$ $\quad$ $PFt_{u_{nnn}} := PF1_{u_{nnn,0}}$

$Z^{\langle 0 \rangle} := \mathrm{round}(\mathrm{runif}(n, 0, 468))$

$PF_{l_i} := PFt_{l_{\left(Z_{i,0}\right)}}$ $\quad$ $PF_{m_i} := PFt_{m_{\left(Z_{i,0}\right)}}$ $\quad$ $PF_{u_i} := PFt_{u_{\left(Z_{i,0}\right)}}$

Adjusted Percolation Flux

Take the flow focusing factor and multiply it to the percolation flux, which will be used to obtain the seepage rate, seepage fraction, and seepage percentage.

$q1_{pff_i} := PF_{l_i} \cdot ff_i$ $\quad$ $qm_{pff_i} := PF_{m_i} \cdot ff_i$ $\quad$ $qu_{pff_i} := PF_{u_i} \cdot ff_i$

$q_{pff} := \mathrm{augment}\left(q1_{pff}, qm_{pff}, qu_{pff}\right)$

Percolation Flux must lie between 1 and 1000 mm/yr (bounds of SMPA simulations)

$j := 0..2$

$q_{pff_{i,j}} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(q_{pff_{i,j}} \ge 1000, 1000, q_{pff_{i,j}}\right)\right)$

Seepage Information from SMPA analysis

$m := 2549$ data points

$SMPA_{data}{}^{<0>}$ is permeability value log(k [m^2])

$SMPA_{data}{}^{<1>}$ is capillary strength 1/alpha [Pa]

$SMPA_{data}{}^{<2>}$ is local percolation flux (mm/yr)

$SMPA_{data}{}^{<3>}$ is Mean Seepage [kg/yr/WP]

$SMPA_{data}{}^{<4>}$ is Std. Dev. Seepage [kg/yr/WP]

$SMPA_{data}{}^{<5>}$ is Mean Seepage [%]

$SMPA_{data}{}^{<6>}$ is Std. Dev. Seepage [%]

$SMPA_{data} :=$

	0	1	2	3	4	5	6
0	-14	100	1	56.44	5.47	100.6	9.75
1	-14	100	5	282.63	27.5	100.76	9.8
2	-14	100	10	566.16	55.13	100.92	9.83
3	-14	100	20	1135.12	109.85	101.17	9.79
4	-14	100	50	2849.95	272.25	101.6	9.71
5	-14	100	100	5726.78	535.98	102.08	9.55
6	-14	100	200	11523.63	1064.22	102.71	9.49
7	-14	100	300	17369.22	1583.08	103.2	9.41
8	-14	100	400	23241.94	2086.65	103.57	9.3
9	-14	100	500	29154.54	2552.38	103.94	9.1
10	-14	100	600	35097.8	2992.46	104.27	8.89
11	-14	100	700	41099.26	3411.36	104.66	8.69
12	-14	100	800	47084.03	3860.77	104.91	8.6
13	-14	100	900	53190.45	4145.2	105.35	8.21
14	-14	100	1000	59206.88	4520.61	105.54	8.06
15	-14	200	1	55.25	5.44	98.48	9.69

Set up routine to pick out correct mean seepage, seepage standard deviation, seepage percent, and seepage percent standard deviation based on sampled value of 1/ α, k, percolation flux.

$nx := 14 \quad ny := 9 \quad nz := 16$

$ii := 0..\, nx$

$x_{ii} := SMPA_{data_{ii,2}} \qquad xi_{ii} := ii$

$jj := 0..\, ny$

$y_{jj} := 100 \cdot jj + 100 \qquad yj_{jj} := jj$

$kk := 0..\, nz$

$z_{kk} := -14 + kk \cdot 0.25 \quad zk_{kk} := kk$

loc represents the location within the matrix of which value to pick for the interpolation process.

$$loc1_{i,j} := \text{floor}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right) \cdot (nx + 1) \cdot (ny + 1) + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right) \cdot (nx + 1) \ ... \\ + \text{floor}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms1_{i,j}} := SMPA_{data_{loc1_{i,j},3}}$$

$$s_{msd1_{i,j}} := SMPA_{data_{loc1_{i,j},4}}$$

$$loc2_{i,j} := \left[\text{floor}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right) \cdot (nx + 1) \cdot (ny + 1)\right] + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right) \cdot (nx + 1) \ ... \\ + \text{ceil}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms2_{i,j}} := SMPA_{data_{loc2_{i,j},3}}$$

$$s_{msd2_{i,j}} := SMPA_{data_{loc2_{i,j},4}}$$

$$loc_{3_{i,j}} := \text{floor}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \text{ceil}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{ceil}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms3_{i,j}} := SMPA_{data_{loc_{3_{i,j}},3}}$$

$$s_{msd3_{i,j}} := SMPA_{data_{loc_{3_{i,j}},4}}$$

$$loc_{4_{i,j}} := \text{floor}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \text{ceil}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{floor}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms4_{i,j}} := SMPA_{data_{loc_{4_{i,j}},3}}$$

$$s_{msd4_{i,j}} := SMPA_{data_{loc_{4_{i,j}},4}}$$

$$loc_{5_{i,j}} := \left[\text{ceil}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{floor}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms5_{i,j}} := SMPA_{data_{loc_{5_{i,j}},3}}$$

$$s_{msd5_{i,j}} := SMPA_{data_{loc_{5_{i,j}},4}}$$

$$loc_{6_{i,j}} := \text{ceil}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \text{floor}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{ceil}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms6_{i,j}} := SMPA_{data_{loc_{6_{i,j}},3}}$$

$$s_{msd6_{i,j}} := SMPA_{data_{loc_{6_{i,j}},4}}$$

$$loc_{7_{i,j}} := \left[\text{ceil}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1)\right] + \text{ceil}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{ceil}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms7_{i,j}} := SMPA_{data_{loc_{7_{i,j}},3}}$$

$$s_{msd7_{i,j}} := SMPA_{data_{loc_{7_{i,j}},4}}$$

$$loc_{8_{i,j}} := \text{ceil}\left(\text{linterp}\left(z, zk, T_{kTn_i}\right)\right)\cdot(nx+1)\cdot(ny+1) + \text{ceil}\left(\text{linterp}\left(y, yj, T_{1\alpha_i}\right)\right)\cdot(nx+1) \ldots + \text{floor}\left(\text{linterp}\left(x, xi, q_{pff_{i,j}}\right)\right)$$

$$s_{ms8_{i,j}} := SMPA_{data_{loc_{8_{i,j}},3}}$$

$$s_{msd8_{i,j}} := SMPA_{data_{loc_{8_{i,j}},4}}$$

Develop the upper and lower bound for permeability (k) for Tptpmn Unit

$qq_i := -1 \cdot T_{kTn_i}$

$\mathrm{mantissa}(x) := x - \mathrm{floor}(qq)$

$tt_i := \mathrm{floor}\left(qq_i\right)$

$rr := \mathrm{round}(\mathrm{mantissa}(qq), 2)$

$yy1_i := \mathrm{if}\left(rr_i \le 0.25, 0, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.25, rr_i\right)\right)$

$zz1_i := \mathrm{if}\left(yy1_i \le 0.5, yy1_i, \mathrm{if}\left(0.5 < yy1_i \le 0.75, 0.5, 0.75\right)\right)$

$T_{kTn2_i} := -1 \cdot \left(tt_i + zz1_i\right)$

$yy2_i := \mathrm{if}\left(rr_i \le 0.25, 0.25, \mathrm{if}\left(0.25 < rr_i \le 0.5, 0.5, rr_i\right)\right)$

$zz2_i := \mathrm{if}\left(yy2_i \le 0.5, yy2_i, \mathrm{if}\left(0.5 < yy2_i \le 0.75, 0.75, 1\right)\right)$

$T_{kTn1_i} := -1 \cdot \left(tt_i + zz2_i\right)$

Develop the upper and lower bound for capillary strength (1/ α).

$$hh1_i := \mathrm{floor}\left(\frac{T_{1\alpha_i}}{100}\right)$$

$T_{1\alpha1_i} := \left(hh1_i \cdot 100\right)$

$$hh2_i := \mathrm{ceil}\left(\frac{T_{1\alpha_i}}{100}\right)$$

$T_{1\alpha2_i} := \left(hh2_i \cdot 100\right)$

Lower Bound value adjusted percolation flux (q_{pff}).

$aaa1_{i,j} := \mathrm{if}\left(q_{pff_{i,j}} \le 1, 1, \mathrm{if}\left(1 < q_{pff_{i,j}} \le 5, 1, q_{pff_{i,j}}\right)\right)$

$bbb1_{i,j} := \mathrm{if}\left(aaa1_{i,j} \le 5, aaa1_{i,j}, \mathrm{if}\left(5 < aaa1_{i,j} \le 10, 5, aaa1_{i,j}\right)\right)$

$ccc1_{i,j} := \mathrm{if}\left(bbb1_{i,j} \le 10, bbb1_{i,j}, \mathrm{if}\left(10 < bbb1_{i,j} \le 20, 10, bbb1_{i,j}\right)\right)$

$ddd1_{i,j} := \mathrm{if}\left(ccc1_{i,j} \le 20, ccc1_{i,j}, \mathrm{if}\left(20 < ccc1_{i,j} \le 50, 20, ccc1_{i,j}\right)\right)$

$eee1_{i,j} := \mathrm{if}\left(ddd1_{i,j} \le 50, ddd1_{i,j}, \mathrm{if}\left(50 < ddd1_{i,j} \le 100, 50, ddd1_{i,j}\right)\right)$

$fff1_{i,j} := \mathrm{if}\left(eee1_{i,j} \le 100, eee1_{i,j}, \mathrm{if}\left(100 < eee1_{i,j} \le 200, 100, eee1_{i,j}\right)\right)$

$ggg1_{i,j} := \mathrm{if}\left(fff1_{i,j} \le 200, fff1_{i,j}, \mathrm{if}\left(200 < fff1_{i,j} \le 300, 200, fff1_{i,j}\right)\right)$

$hhh1_{i,j} := \mathrm{if}\left(ggg1_{i,j} \le 300, ggg1_{i,j}, \mathrm{if}\left(300 < ggg1_{i,j} \le 400, 300, ggg1_{i,j}\right)\right)$

$iii1_{i,j} := \mathrm{if}\left(hhh1_{i,j} \le 400, hhh1_{i,j}, \mathrm{if}\left(400 < hhh1_{i,j} \le 500, 400, hhh1_{i,j}\right)\right)$

$jjj1_{i,j} := \mathrm{if}\left(iii1_{i,j} \le 500, iii1_{i,j}, \mathrm{if}\left(500 < iii1_{i,j} \le 600, 500, iii1_{i,j}\right)\right)$

$$\mathrm{kkk1}_{i,j} := \mathrm{if}\left(\mathrm{jjj1}_{i,j} \le 600, \mathrm{jjj1}_{i,j}, \mathrm{if}\left(600 < \mathrm{jjj1}_{i,j} \le 700, 600, \mathrm{jjj1}_{i,j}\right)\right)$$

$$\mathrm{mmm1}_{i,j} := \mathrm{if}\left(\mathrm{kkk1}_{i,j} \le 700, \mathrm{kkk1}_{i,j}, \mathrm{if}\left(700 < \mathrm{kkk1}_{i,j} \le 800, 700, \mathrm{kkk1}_{i,j}\right)\right)$$

$$q_{\mathrm{pff1}_{i,j}} := \mathrm{if}\left(\mathrm{mmm1}_{i,j} \le 800, \mathrm{mmm1}_{i,j}, \mathrm{if}\left(800 < \mathrm{mmm1}_{i,j} \le 900, 800, 900\right)\right)$$

Upper Bound value adjusted percolation flux (q_{pff}).

$$\mathrm{aaa2}_{i,j} := \mathrm{if}\left(q_{\mathrm{pff}_{i,j}} \le 1, 5, \mathrm{if}\left(1 < q_{\mathrm{pff}_{i,j}} \le 5, 5, q_{\mathrm{pff}_{i,j}}\right)\right)$$

$$\mathrm{bbb2}_{i,j} := \mathrm{if}\left(\mathrm{aaa2}_{i,j} \le 5, \mathrm{aaa2}_{i,j}, \mathrm{if}\left(5 < \mathrm{aaa2}_{i,j} \le 10, 10, \mathrm{aaa2}_{i,j}\right)\right)$$

$$\mathrm{ccc2}_{i,j} := \mathrm{if}\left(\mathrm{bbb2}_{i,j} \le 10, \mathrm{bbb2}_{i,j}, \mathrm{if}\left(10 < \mathrm{bbb2}_{i,j} \le 20, 20, \mathrm{bbb2}_{i,j}\right)\right)$$

$$\mathrm{ddd2}_{i,j} := \mathrm{if}\left(\mathrm{ccc2}_{i,j} \le 20, \mathrm{ccc2}_{i,j}, \mathrm{if}\left(20 < \mathrm{ccc2}_{i,j} \le 50, 50, \mathrm{ccc2}_{i,j}\right)\right)$$

$$\mathrm{eee2}_{i,j} := \mathrm{if}\left(\mathrm{ddd2}_{i,j} \le 50, \mathrm{ddd2}_{i,j}, \mathrm{if}\left(50 < \mathrm{ddd2}_{i,j} \le 100, 100, \mathrm{ddd2}_{i,j}\right)\right)$$

$$\mathrm{fff2}_{i,j} := \mathrm{if}\left(\mathrm{eee2}_{i,j} \le 100, \mathrm{eee2}_{i,j}, \mathrm{if}\left(100 < \mathrm{eee2}_{i,j} \le 200, 200, \mathrm{eee2}_{i,j}\right)\right)$$

$$\mathrm{ggg2}_{i,j} := \mathrm{if}\left(\mathrm{fff2}_{i,j} \le 200, \mathrm{fff2}_{i,j}, \mathrm{if}\left(200 < \mathrm{fff2}_{i,j} \le 300, 300, \mathrm{fff2}_{i,j}\right)\right)$$

$$\mathrm{hhh2}_{i,j} := \mathrm{if}\left(\mathrm{ggg2}_{i,j} \le 300, \mathrm{ggg2}_{i,j}, \mathrm{if}\left(300 < \mathrm{ggg2}_{i,j} \le 400, 400, \mathrm{ggg2}_{i,j}\right)\right)$$

$$\mathrm{iii2}_{i,j} := \mathrm{if}\left(\mathrm{hhh2}_{i,j} \le 400, \mathrm{hhh2}_{i,j}, \mathrm{if}\left(400 < \mathrm{hhh2}_{i,j} \le 500, 500, \mathrm{hhh2}_{i,j}\right)\right)$$

$$\mathrm{jjj2}_{i,j} := \mathrm{if}\left(\mathrm{iii2}_{i,j} \le 500, \mathrm{iii2}_{i,j}, \mathrm{if}\left(500 < \mathrm{iii2}_{i,j} \le 600, 600, \mathrm{iii2}_{i,j}\right)\right)$$

$$\mathrm{kkk2}_{i,j} := \mathrm{if}\left(\mathrm{jjj2}_{i,j} \le 600, \mathrm{jjj2}_{i,j}, \mathrm{if}\left(600 < \mathrm{jjj2}_{i,j} \le 700, 700, \mathrm{jjj2}_{i,j}\right)\right)$$

$$\mathrm{mmm2}_{i,j} := \mathrm{if}\left(\mathrm{kkk2}_{i,j} \le 700, \mathrm{kkk2}_{i,j}, \mathrm{if}\left(700 < \mathrm{kkk2}_{i,j} \le 800, 800, \mathrm{kkk2}_{i,j}\right)\right)$$

$$q_{\mathrm{pff2}_{i,j}} := \mathrm{if}\left(\mathrm{mmm2}_{i,j} \le 800, \mathrm{mmm2}_{i,j}, \mathrm{if}\left(800 < \mathrm{mmm2}_{i,j} \le 900, 900, 1000\right)\right)$$

Solve for seepage flux (Tptpmn Unit)

$$u_{\mathrm{T1}\alpha_i} := \frac{T_{1\alpha_i} - T_{1\alpha 1_i}}{T_{1\alpha 2_i} - T_{1\alpha 1_i}} \qquad v_{\mathrm{TkTn}_i} := \frac{T_{\mathrm{kTn}_i} - T_{\mathrm{kTn1}_i}}{T_{\mathrm{kTn2}_i} - T_{\mathrm{kTn1}_i}} \qquad t_{\mathrm{qpff}_{i,j}} := \frac{q_{\mathrm{pff}_{i,j}} - q_{\mathrm{pff1}_{i,j}}}{q_{\mathrm{pff2}_{i,j}} - q_{\mathrm{pff1}_{i,j}}}$$

$$\begin{aligned}
\mathrm{spflux}_{\mathrm{Tnm}_{i,j}} := {} & \left(1 - t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(1 - u_{\mathrm{T1}\alpha_i}\right)\cdot\left(1 - v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms1}_{i,j}} \cdots \\
& + \left(t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(1 - u_{\mathrm{T1}\alpha_i}\right)\cdot\left(1 - v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms2}_{i,j}} \cdots \\
& + \left(t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(u_{\mathrm{T1}\alpha_i}\right)\cdot\left(1 - v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms3}_{i,j}} \cdots \\
& + \left(1 - t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(u_{\mathrm{T1}\alpha_i}\right)\cdot\left(1 - v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms4}_{i,j}} \cdots \\
& + \left(1 - t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(1 - u_{\mathrm{T1}\alpha_i}\right)\cdot\left(v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms5}_{i,j}} \cdots \\
& + \left(t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(1 - u_{\mathrm{T1}\alpha_i}\right)\cdot\left(v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms6}_{i,j}} \cdots \\
& + \left(t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(u_{\mathrm{T1}\alpha_i}\right)\cdot\left(v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms7}_{i,j}} \cdots \\
& + \left(1 - t_{\mathrm{qpff}_{i,j}}\right)\cdot\left(u_{\mathrm{T1}\alpha_i}\right)\cdot\left(v_{\mathrm{TkTn}_i}\right)\cdot s_{\mathrm{ms8}_{i,j}}
\end{aligned}$$

$$\begin{aligned} spflux_{Tnsd_{i,j}} := {} & \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd1_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd2_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd3_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(1 - v_{TkTn_i}\right)\cdot s_{msd4_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd5_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(1 - u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd6_{i,j}} \cdots \\ & + \left(t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd7_{i,j}} \cdots \\ & + \left(1 - t_{qpff_{i,j}}\right)\cdot\left(u_{T1\alpha_i}\right)\cdot\left(v_{TkTn_i}\right)\cdot s_{msd8_{i,j}} \end{aligned}$$

Calculate mean seepage for Tptpmn Unit (lower bound).

$$QTn1_{lstdl_i} := -1.7321 \cdot spflux_{Tnsd_{i,0}}$$

$$QTn1_{lstdu_i} := 1.7321 \cdot spflux_{Tnsd_{i,0}}$$

$$QTn_{lstdl_i} := \mathrm{if}\left(QTn1_{lstdl_i} = 0, -0.00001, QTn1_{lstdl_i}\right)$$

$$QTn_{lstd_i} := \mathrm{qunif}\left(X_{i,5}, QTn_{lstdl_i}, QTn1_{lstdu_i}\right)$$

$$QTn1_{lspm_i} := spflux_{Tnm_{i,0}} + QTn_{lstd_i}$$

$$QTn2_{lspm_i} := \mathrm{if}\left(QTn1_{lspm_i} \le 0.1, 0, QTn1_{lspm_i}\right)$$

$$QT2_{lperc_i} := \frac{QTn2_{lspm_i} \cdot 100}{q_{pff_{i,0}} \cdot 28.052}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{lperc_i} := \mathrm{if}\left(QT2_{lperc_i} \le 0, 0, \mathrm{if}\left(QT2_{lperc_i} \ge 100, 100, QT2_{lperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTn_{lspr_i} := QT3_{lperc_i} \cdot q_{pff_{i,0}} \cdot \frac{28.052}{100}$$

Mean Seepage Flux (kg/yr/WP)

$$\mathrm{mean}\left(QTn_{lspr}\right) = 12.942$$

Determine the seepage fraction for Tptpmn Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$$\mathrm{sort}\left(QTn_{lspr}\right) =$$

	0
0	0
1	0
2	0
3	0
4	0

$$num1_{l_i} := \mathrm{if}\left(QTn_{lspr_i} > 0, 1, 0\right)$$

Number of seepage rates greater than zero.

$$num_l := \sum_{i=0}^{n-1} num1_{l_i}$$

$$n_{lTn} := (n - 1) - num_l \qquad n_{lTn} = 11151$$

$$spfrcl_{Tn} := \frac{num_l}{n} \qquad spfrcl_{Tn} = 0.442$$

$n1_{lTn} := (n-1) - \left(n_{lTn} + 1\right) \qquad n1_{lTn} = 8.847 \times 10^{3}$

$Q11_{lTn} := \text{sort}\left(QTn_{lspr}\right)$

$Q1_{lTn} := \text{reverse}\left(Q11_{lTn}\right)$

$ab := 0 .. n1_{lTn}$

$Q2_{lTn_{ab}} := \left(Q1_{lTn_{ab}}\right)$

$Q_{lTn} := \text{sort}\left(Q2_{lTn}\right)$

$\text{mean}\left(Q_{lTn}\right) = 29.255$

$$CDF_{lTn_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{lTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_l := \text{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{r} \cdot \ln\left(Q_{lTn_i}\right)\right]}{\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{lTn}}\right) \cdot \sum_{i=0}^{n1_{lTn}} \ln\left(Q_{lTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_l = 0.523$$

$$\alpha_l := \left[\frac{\sum_{i=0}^{n1_{lTn}} \left(Q_{lTn_i}\right)^{\beta_l}}{n1_{lTn}}\right]^{\frac{1}{\beta_l}} \qquad \alpha_l = 13.947$$

Plot of raw data versus Weibull distribution

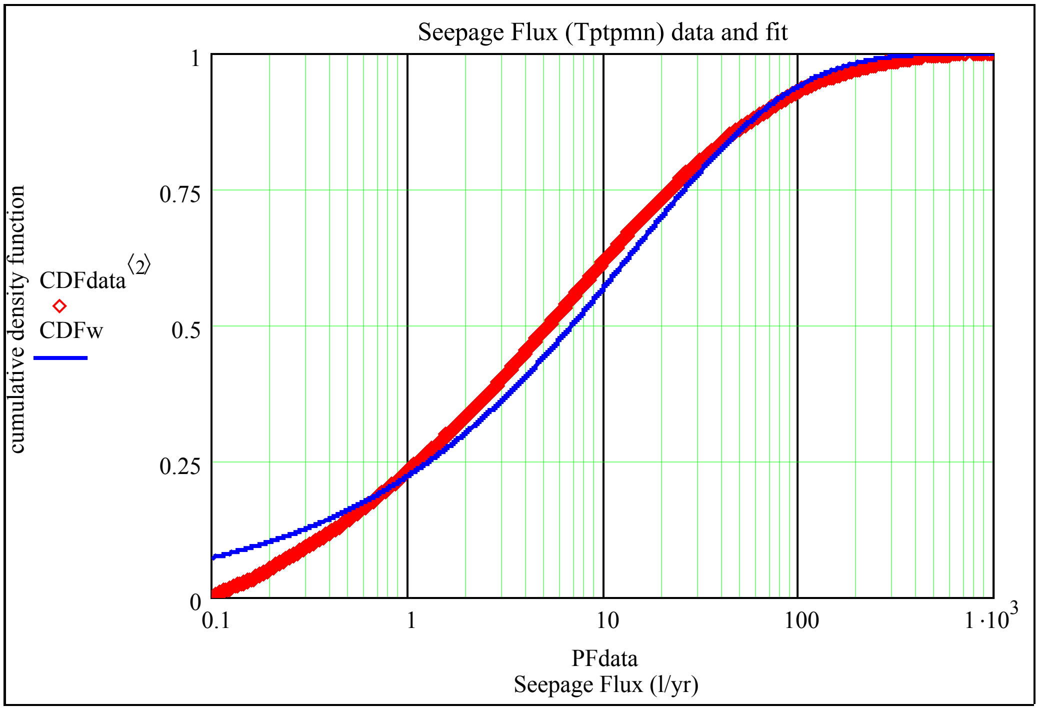
$ji := 0 .. n1_{lTn}$

$PFdata_{ji} := Q_{lTn_{ji}}$

$CDFdata_{ji,2} := CDF_{lTn_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_l}\right)^{\beta_l}\right]$$

$CDFw_{ji,0} := CDFw1_{ji}$



Calculate mean seepage for Tptpmn Unit (mean).

$$QTn1_{mstdl_i} := -1.7321 \cdot spflux_{Tnsd_{i,1}}$$

$$QTn1_{mstdu_i} := 1.7321 \cdot spflux_{Tnsd_{i,1}}$$

$$QTn_{mstdl_i} := \mathrm{if}\left(QTn1_{mstdl_i} = 0, -0.00001, QTn1_{mstdl_i}\right)$$

$$QTn_{mstd_i} := \mathrm{qunif}\left(X_{i,5}, QTn_{mstdl_i}, QTn1_{mstdu_i}\right)$$

$$QTn1_{mspm_i} := spflux_{Tnm_{i,1}} + QTn_{mstd_i}$$

$$QTn2_{mspm_i} := \mathrm{if}\left(QTn1_{mspm_i} \le 0.1, 0, QTn1_{mspm_i}\right)$$

$$QT2_{mperc_i} := \frac{QTn2_{mspm_i} \cdot 100}{q_{pff_{i,1}} \cdot 28.052}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{mperc_i} := \mathrm{if}\left(QT2_{mperc_i} \le 0, 0, \mathrm{if}\left(QT2_{mperc_i} \ge 100, 100, QT2_{mperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTn_{mspr_i} := QT3_{mperc_i} \cdot q_{pff_{i,1}} \cdot \frac{28.052}{100}$$

Mean Seepage Flux (kg/yr/WP)

$$\mathrm{mean}\left(QTn_{mspr}\right) = 396.869$$

Determine the seepage fraction for Tptpmn Unit (mean) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTn_{mspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$\mathrm{num1}_{m_i} := \mathrm{if}\left(QTn_{mspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$\mathrm{num}_m := \sum_{i=0}^{n-1} \mathrm{num1}_{m_i}$$

$n_{mTn} := (n-1) - \mathrm{num}_m \qquad n_{mTn} = 4172$

$\mathrm{spfrcm}_{Tn} := \dfrac{\mathrm{num}_m}{n} \qquad \mathrm{spfrcm}_{Tn} = 0.791$

$n1_{mTn} := (n-1) - \left(n_{mTn} + 1\right) \qquad n1_{mTn} = 1.583\times 10^{4}$

$Q11_{mTn} := \mathrm{sort}\left(QTn_{mspr}\right)$

$Q1_{mTn} := \mathrm{reverse}\left(Q11_{mTn}\right)$

$ab := 0 .. n1_{mTn}$

$Q2_{mTn_{ab}} := \left(Q1_{mTn_{ab}}\right)$

$Q_{mTn} := \mathrm{sort}\left(Q2_{mTn}\right)$

$\mathrm{mean}\left(Q_{mTn}\right) = 501.509$

$$CDF_{mTn_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{mTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_m := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{r}\cdot \ln\left(Q_{mTn_i}\right)\right]}{\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{mTn}}\right)\cdot \sum_{i=0}^{n1_{mTn}} \ln\left(Q_{mTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_m = 0.527$$

$$\alpha_m := \left[\frac{\sum_{i=0}^{n1_{mTn}} \left(Q_{mTn_i}\right)^{\beta_m}}{n1_{mTn}}\right]^{\frac{1}{\beta_m}} \qquad \alpha_m = 2.725\times 10^{2}$$

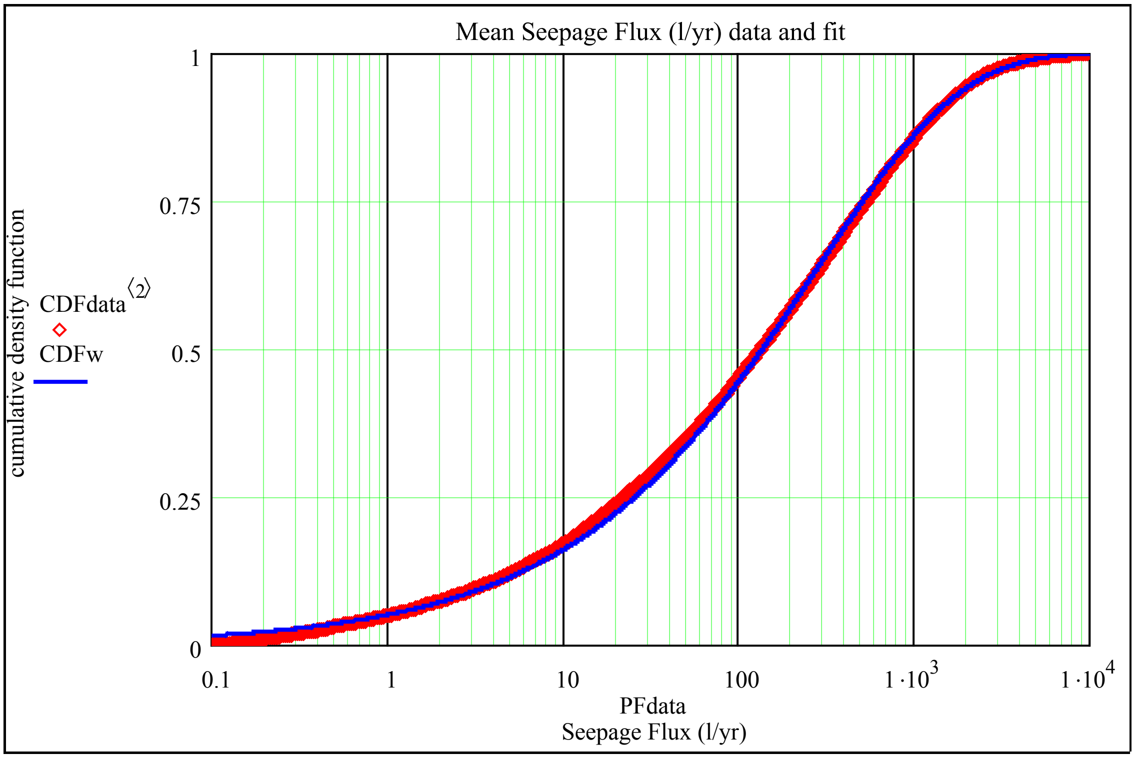
Plot of raw data versus Weibull distribution

$ji := 0 .. n1_{mTn}$

$PFdata_{ji} := Q_{mTn_{ji}}$

$CDFdata_{ji,2} := CDF_{mTn_{ji}}$

$$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_m}\right)^{\beta_m}\right] \qquad CDFw_{ji,0} := CDFw1_{ji}$$



Calculate mean seepage for Tptpmn Unit (upper bound).

$$QTn1_{ustdl_i} := -1.7321 \cdot spflux_{Tnsd_{i,2}}$$

$$QTn1_{ustdu_i} := 1.7321 \cdot spflux_{Tnsd_{i,2}}$$

$$QTn_{ustdl_i} := \mathrm{if}\left(QTn1_{ustdl_i} = 0, -0.00001, QTn1_{ustdl_i}\right)$$

$$QTn_{ustd_i} := \mathrm{qunif}\left(X_{i,5}, QTn_{ustdl_i}, QTn1_{ustdu_i}\right)$$

$$QTn1_{uspm_i} := spflux_{Tnm_{i,2}} + QTn_{ustd_i}$$

$$QTn2_{uspm_i} := \mathrm{if}\left(QTn1_{uspm_i} \le 0.1, 0, QTn1_{uspm_i}\right)$$

$$QT2_{uperc_i} := \frac{QTn2_{uspm_i} \cdot 100}{q_{pff_{i,2}} \cdot 28.052}$$

Equation to calculate seepage percent based on seepage rate (see SMPA data table) (based on DTN: LB0310AMRU0120.002 [DIRS 166116]).

$$QT3_{uperc_i} := \mathrm{if}\left(QT2_{uperc_i} \le 0, 0, \mathrm{if}\left(QT2_{uperc_i} \ge 100, 100, QT2_{uperc_i}\right)\right)$$

Check seepage percent to be above 100% and then adjusted back.

$$QTn_{uspr_i} := QT3_{uperc_i} \cdot q_{pff_{i,2}} \cdot \frac{28.052}{100}$$

Mean Seepage Flux (kg/yr/WP)

$$\mathrm{mean}\left(QTn_{uspr}\right) = 990.107$$

Determine the seepage fraction for Tptpmn Unit (lower bound) within the repository and then fit the output data to distribution.

Seepage fraction represents the non-zero seepage rates based on the LHS sampling of all of the parameters.

$\mathrm{sort}\left(QTn_{uspr}\right) =$

	0
0	0
1	0
2	0
3	0
4	0

$num1_{u_i} := \mathrm{if}\left(QTn_{uspr_i} > 0, 1, 0\right)$ Number of seepage rates greater than zero.

$$num_u := \sum_{i=0}^{n-1} num1_{u_i}$$

$n_{uTn} := (n-1) - num_u \qquad n_{uTn} = 2483$

$$spfrcu_{Tn} := \frac{num_u}{n} \qquad spfrcu_{Tn} = 0.876$$

$n1_{uTn} := (n-1) - \left(n_{uTn} + 1\right) \qquad n1_{uTn} = 1.752\times 10^{4}$

$Q11_{uTn} := \mathrm{sort}\left(QTn_{uspr}\right)$

$Q1_{uTn} := \mathrm{reverse}\left(Q11_{uTn}\right)$

$ab := 0 .. n1_{uTn}$

$$Q2_{uTn_{ab}} := \left(\frac{1}{1}\cdot Q1_{uTn_{ab}}\right)$$

$Q_{uTn} := \mathrm{sort}\left(Q2_{uTn}\right)$

$\mathrm{mean}\left(Q_{uTn}\cdot 1\right) = 1.131\times 10^{3}$

$$CDF_{uTn_{ab}} := \frac{(ab+1) - 0.375}{\left(n1_{uTn} + 1\right) + 0.25}$$

Fit the seepage rates to a Weibull distribution.

The following equations are from *What Every Engineer Should Know About Reliability and Risk Analysis* (Modarres, M, [DIRS 104667], p. 109).

$$\beta_u := \mathrm{root}\left[\left[\frac{\left[\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^{r}\cdot \ln\left(Q_{uTn_i}\right)\right]}{\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^{r}} - \left(\frac{1}{r}\right) - \left[\left(\frac{1}{n1_{uTn}}\right)\cdot \sum_{i=0}^{n1_{uTn}} \ln\left(Q_{uTn_i}\right)\right]\right], r, 0.1, 4\right] \qquad \beta_u = 0.59$$

$$\alpha_u := \left[\frac{\sum_{i=0}^{n1_{uTn}} \left(Q_{uTn_i}\right)^{\beta_u}}{n1_{uTn}}\right]^{\frac{1}{\beta_u}} \qquad \alpha_u = 7.414\times 10^{2}$$

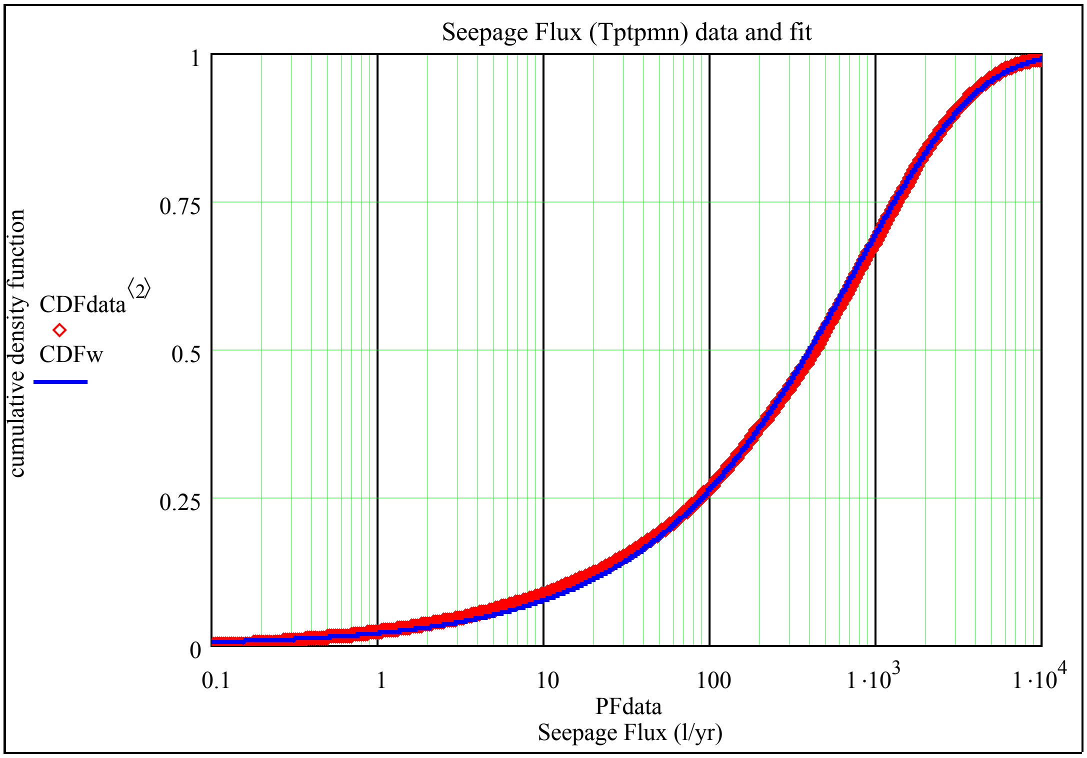
Plot of raw data versus Weibull distribution

$ji := 0 .. n1_{uTn}$

$PFdata_{ji} := Q_{uTn_{ji}}$

$CDFdata_{ji,2} := CDF_{uTn_{ji}}$

$CDFw1_{ji} := 1 - \exp\left[-\left(\frac{PFdata_{ji}}{\alpha_u}\right)^{\beta_u}\right]$ $\qquad CDFw_{ji,0} := CDFw1_{ji}$



Overall Final Results for Tptpmn Zone

Lower Bound Results	**Mean Results**	**Upper Bound Results**	
$\alpha_l = 1.395\times 10^{1}$	$\alpha_m = 2.725\times 10^{2}$	$\alpha_u = 7.414\times 10^{2}$	
$\beta_l = 5.233\times 10^{-1}$	$\beta_m = 5.269\times 10^{-1}$	$\beta_u = 5.902\times 10^{-1}$	
$spfrcl_{Tn} = 4.424\times 10^{-1}$	$spfrcm_{Tn} = 7.913\times 10^{-1}$	$spfrcu_{Tn} = 8.758\times 10^{-1}$	**Seepage Fraction**
$mean(QTn_{lspr}) = 12.942$	$mean(QTn_{mspr}) = 396.869$	$mean(QTn_{uspr}) = 990.107$	**Data Set Mean**

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APPENDIX D

WASTE PACKAGE FILLING PROBABILITY (OUTPUT FROM MATHCAD FILE)

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Fault Displacement Damage due to Seismic Event

This calculation is to evaluate drip shield and waste package damage due to a fault displacement due to seismic events that has the potential to allow advective flow to reach the waste package.

Latin Hypercube Sampling Routine for Evaluation of Fault Displacement

The PGV values and damaged areas are all obtained using Latin Hypercube Sampling.

$n_s := 50000$ **sample size**

$i := 1..n_s$ $\quad$ $\mathrm{Seed}(1)$

$RD_{i-1,0} := i \qquad RD_{i-1,1} := \mathrm{rnd}(1.0) \qquad RD_{i-1,2} := \mathrm{rnd}(1.0)$

RK# are matrixes whose first column contain a permutation on the integers on the interval [1,n $_s$].

$RK1 := \mathrm{csort}(RD,1) \qquad RK2 := \mathrm{csort}(RD,2)$

Define sets of random values. Each random value is selected within one of the equiprobable n $_s$ intervals that partition [0,1]. One set for each random variable.

$$X^{\langle 0\rangle} := \frac{RK1^{\langle 0\rangle} - 1 + \mathrm{runif}(n_s,0,1)}{n_s} \qquad X^{\langle 1\rangle} := \frac{RK2^{\langle 0\rangle} - 1 + \mathrm{runif}(n_s,0,1)}{n_s}$$

1E-8 to 2E-7 Exceedance Frequency Range

Seismic exceedance frequencies and time to first occurrance of seismic event follow uniform distributions (BSC 2004 [DIRS 169183], Section 6.9.2).

$IE_l := 1\cdot 10^{-8} \qquad IE_u := 2\cdot 10^{-7}$ **The upper and lower bounds are from BSC 2004 ([DIRS 169183], Section 6.9.2).**

$T_l := 1 \qquad T_u := 10000$ **The lower bound is 1 year based on closure of repository and the upper bound is 10,000 years based on regulatory period (BSC 2004 [DIRS 169183], Section 6.9.2).**

Calculate a set of sample values for each of the random variables (i.e., seismic exceedance frequency and time to first seismic event).

$i := 0..n_s - 1$

$IE_{s_i} := \mathrm{qunif}(X_{i,0}, IE_l, IE_u)$ **Sample mean annual seismic exceedance frequency**

$T_{s_i} := \mathrm{qunif}(X_{i,1}, T_l, T_u)$ **Sample time (when first seismic event occurred)**

Waste Package Damage due to Fault Displacement

$$WP_{21AP_i} := \mathrm{if}\left(IE_{s_i} \le 6\times 10^{-8}, 1, 1\cdot 10^{-12}\right)$$

$$WP_{12AP_i} := \mathrm{if}\left(IE_{s_i} \le 4\times 10^{-8}, 1, 1\cdot 10^{-12}\right)$$

$$WP_{44AP_i} := \mathrm{if}\left(IE_{s_i} \le 6\times 10^{-8}, 1, 1\cdot 10^{-12}\right)$$

$$WP_{24AP_i} := \mathrm{if}\left(IE_{s_i} \le 4\times 10^{-8}, 1, 1\cdot 10^{-12}\right)$$

$$WP_{DOEs_i} := \mathrm{if}\left(IE_{s_i} \le 2\times 10^{-7}, 1, 1\cdot 10^{-12}\right)$$

$$WP_{DOEL_i} := \mathrm{if}\left(IE_{s_i} \le 2\times 10^{-7}, 1, 1\cdot 10^{-12}\right)$$

$$WP_{DOEmco_i} := \mathrm{if}\left(IE_{s_i} \le 1\times 10^{-7}, 1, 1\cdot 10^{-12}\right)$$

License Application Seepage Flux Rates

The seepage distributions are based on the License Application (LA) seepage abstraction model *Abstraction of Drift Seepage* (BSC 2004 [DIRS 169131]). The outputs were fit to Weibull distributions based on the sampling process developed to obtain the seepage rates for the low, mean, and upper glacial transition climate cases. The distributions are for both the Tptpll and Tptpmn zones (see Appendix C). The Tptpll zone uses the collapsed drift seepage rates, while the Tptpmn zone increases the nominal seepage rates by 20%.

Tptpll Seepage (m ^{3}/yr) (Drift Collapse)

$$STl_{ptl}(r) := 1 - \exp\left[-\left(\frac{r}{9.303}\right)^{0.495}\right]$$

$$STm_{ptl}(r) := 1 - \exp\left[-\left(\frac{r}{145.5}\right)^{0.4561}\right]$$

$$STu_{ptl}(r) := 1 - \exp\left[-\left(\frac{r}{381}\right)^{0.4858}\right]$$

Tptpmn Seepage (m ^{3}/yr) (Drift Degraded {1.2})

$$STl_{ptn}(r) := 1 - \exp\left[-\left(\frac{r}{5.099}\right)^{0.5135}\right]$$

$$STm_{ptn}(r) := 1 - \exp\left[-\left(\frac{r}{84.14}\right)^{0.4619}\right]$$

$$STu_{ptn}(r) := 1 - \exp\left[-\left(\frac{r}{223.2}\right)^{0.4932}\right]$$

Free volume input parameters for the Commercial waste packages in order to calculate the flow rate required to fill the waste package within the regulatory period of 10,000 years.

$Vr_{21pwr} := 4685$ $Vr_{12pwr} := 3280$

$Vr_{44bwr} := 4850$ $Vr_{24bwr} := 2700$

Free volume of a Commercial WPs (liters) *Boron Loss from CSNF Waste Packages* (BSC 2003 [DIRS 165890], Sections 4 and 6).

$Vr_{DOEs} := 4411$

$Vr_{DOEmco} := 4638$

$Vr_{DOEL} := 6320$

Free volume of a DOE Short WP (liters) *Impacts of Updated Design and Rates on EQ6 Calculations for Chemical Degradation of Fermi and TRIGA Codisposal Waste Packages* (BSC 2004 [DIRS 171809], Section 5.1.1). VrDOEMCO and VrDOEL derived in DOE MCO.04.xls and DOE long.04.xls

Time to fill waste package is based on time of seismic event (i.e., 10,000 years minus time seismic event occurred.

$$t1_i := 10000 - T_{s_i}$$

Seepage rate (l/yr) required to fill the waste package types within regulatory period

$$V21pwr_{dr_i} := \frac{Vr_{21pwr}}{t1_i} \quad V12pwr_{dr_i} := \frac{Vr_{12pwr}}{t1_i} \quad V44bwr_{dr_i} := \frac{Vr_{44bwr}}{t1_i} \quad V24bwr_{dr_i} := \frac{Vr_{24bwr}}{t1_i}$$

$$VDOEmco_{dr_i} := \frac{Vr_{DOEmco}}{t1_i} \quad VDOEL_{dr_i} := \frac{Vr_{DOEL}}{t1_i} \quad VDOEs_{dr_i} := \frac{Vr_{DOEs}}{t1_i}$$

$$reqdr_{21pwr_i} := V21pwr_{dr_i} \quad reqdr_{12pwr_i} := V12pwr_{dr_i} \quad reqdr_{44bwr_i} := V44bwr_{dr_i}$$

$$reqdr_{DOEs_i} := VDOEs_{dr_i} \quad reqdr_{DOEmco_i} := VDOEmco_{dr_i} \quad reqdr_{DOEL_i} := VDOEL_{dr_i}$$

$$reqdr_{24bwr_i} := V24bwr_{dr_i}$$

Seepage Filling based on Waste Package Damage from Faulting

Seepage flux at the drift required to fill waste package based on damage to drip shield and waste package in Lithophysal Zone (Localized Corrosion Seepage only).

$$dr21pwr_{ptl_i} := \frac{reqdr_{21pwr_i}}{\left(WP_{21AP_i}\right)}$$

$$dr12pwr_{ptl_i} := \frac{reqdr_{12pwr_i}}{\left(WP_{12AP_i}\right)}$$

Seepage flux at the drift required to fill waste package based on damage to drip shield and waste package in Nonlithophysal Zone (Localized Corrosion Seepage only) .

$$dr21pwr_{ptn_i} := \frac{reqdr_{21pwr_i}}{\left(WP_{21AP_i}\right)}$$ **21-PWR**

$$dr12pwr_{ptn_i} := \frac{reqdr_{12pwr_i}}{\left(WP_{12AP_i}\right)}$$ **12-PWR**

$$dr44bwr_{ptl_i} := \frac{reqdr_{44bwr_i}}{\left(WP_{44AP_i}\right)} \qquad dr44bwr_{ptn_i} := \frac{reqdr_{44bwr_i}}{\left(WP_{44AP_i}\right)}$$

44-BWR

$$dr24bwr_{ptl_i} := \frac{reqdr_{24bwr_i}}{\left(WP_{24AP_i}\right)} \qquad dr24bwr_{ptn_i} := \frac{reqdr_{24bwr_i}}{\left(WP_{24AP_i}\right)}$$

24-BWR

$$drDOEs_{ptl_i} := \frac{reqdr_{DOEs_i}}{\left(WP_{DOEs_i}\right)} \qquad drDOEs_{ptn_i} := \frac{reqdr_{DOEs_i}}{\left(WP_{DOEs_i}\right)}$$

DOE Short

$$drDOEmco_{ptl_i} := \frac{reqdr_{DOEmco_i}}{\left(WP_{DOEmco_i}\right)} \qquad drDOEmco_{ptn_i} := \frac{reqdr_{DOEmco_i}}{\left(WP_{DOEmco_i}\right)}$$

DOE MCO

$$drDOEL_{ptl_i} := \frac{reqdr_{DOEL_i}}{\left(WP_{DOEL_i}\right)} \qquad drDOEL_{ptn_i} := \frac{reqdr_{DOEL_i}}{\left(WP_{DOEL_i}\right)}$$

DOE Long

Using the seepage flux calculated above, the probability of having at least, x, seepage flux or greater flowing into the damaged waste package are calculated using the developed Weibull distributions.

Lithophysal Zone **Nonlithophysal Zone**

$$P21pwrptl_{l_i} := 1 - STl_{ptl}\left(dr21pwr_{ptl_i}\right) \qquad P21pwrpnl_{l_i} := 1 - STl_{ptn}\left(dr21pwr_{ptn_i}\right)$$

$$P21pwrptl_{m_i} := 1 - STm_{ptl}\left(dr21pwr_{ptl_i}\right) \qquad P21pwrpnl_{m_i} := 1 - STm_{ptn}\left(dr21pwr_{ptn_i}\right)$$

$$P21pwrptl_{u_i} := 1 - STu_{ptl}\left(dr21pwr_{ptl_i}\right) \qquad P21pwrpnl_{u_i} := 1 - STu_{ptn}\left(dr21pwr_{ptn_i}\right)$$

21-PWR

$$P12pwrptl_{l_i} := 1 - STl_{ptl}\left(dr12pwr_{ptl_i}\right) \qquad P12pwrpnl_{l_i} := 1 - STl_{ptn}\left(dr12pwr_{ptn_i}\right)$$

$$P12pwrptl_{m_i} := 1 - STm_{ptl}\left(dr12pwr_{ptl_i}\right) \qquad P12pwrpnl_{m_i} := 1 - STm_{ptn}\left(dr12pwr_{ptn_i}\right)$$

$$P12pwrptl_{u_i} := 1 - STu_{ptl}\left(dr12pwr_{ptl_i}\right) \qquad P12pwrpnl_{u_i} := 1 - STu_{ptn}\left(dr12pwr_{ptn_i}\right)$$

12-PWR

$$P44bwrptl_{l_i} := 1 - STl_{ptl}\left(dr44bwr_{ptl_i}\right) \qquad P44bwrpnl_{l_i} := 1 - STl_{ptn}\left(dr44bwr_{ptn_i}\right)$$

$$P44bwrptl_{m_i} := 1 - STm_{ptl}\left(dr44bwr_{ptl_i}\right) \qquad P44bwrpnl_{m_i} := 1 - STm_{ptn}\left(dr44bwr_{ptn_i}\right)$$

$$P44bwrptl_{u_i} := 1 - STu_{ptl}\left(dr44bwr_{ptl_i}\right) \qquad P44bwrpnl_{u_i} := 1 - STu_{ptn}\left(dr44bwr_{ptn_i}\right)$$

44-BWR

$$P24bwrptl_{l_i} := 1 - STl_{ptl}\left(dr24bwr_{ptl_i}\right)$$
$$P24bwrptl_{m_i} := 1 - STm_{ptl}\left(dr24bwr_{ptl_i}\right)$$
$$P24bwrptl_{u_i} := 1 - STu_{ptl}\left(dr24bwr_{ptl_i}\right)$$

$$P24bwrpnl_{l_i} := 1 - STl_{ptn}\left(dr24bwr_{ptn_i}\right)$$
$$P24bwrpnl_{m_i} := 1 - STm_{ptn}\left(dr24bwr_{ptn_i}\right)$$
$$P24bwrpnl_{u_i} := 1 - STu_{ptn}\left(dr24bwr_{ptn_i}\right)$$

24-BWR

$$PDOEsptl_{l_i} := 1 - STl_{ptl}\left(drDOEs_{ptl_i}\right)$$
$$PDOEsptl_{m_i} := 1 - STm_{ptl}\left(drDOEs_{ptl_i}\right)$$
$$PDOEsptl_{u_i} := 1 - STu_{ptl}\left(drDOEs_{ptl_i}\right)$$

$$PDOEspnl_{l_i} := 1 - STl_{ptn}\left(drDOEs_{ptn_i}\right)$$
$$PDOEspnl_{m_i} := 1 - STm_{ptn}\left(drDOEs_{ptn_i}\right)$$
$$PDOEspnl_{u_i} := 1 - STu_{ptn}\left(drDOEs_{ptn_i}\right)$$

DOE Short

$$PDOEmcoptl_{l_i} := 1 - STl_{ptl}\left(drDOEmco_{ptl_i}\right)$$
$$PDOEmcoptl_{m_i} := 1 - STm_{ptl}\left(drDOEmco_{ptl_i}\right)$$
$$PDOEmcoptl_{u_i} := 1 - STu_{ptl}\left(drDOEmco_{ptl_i}\right)$$

$$PDOEmcopnl_{l_i} := 1 - STl_{ptn}\left(drDOEmco_{ptn_i}\right)$$
$$PDOEmcopnl_{m_i} := 1 - STm_{ptn}\left(drDOEmco_{ptn_i}\right)$$
$$PDOEmcopnl_{u_i} := 1 - STu_{ptn}\left(drDOEmco_{ptn_i}\right)$$

DOE MCO

$$PDOELptl_{l_i} := 1 - STl_{ptl}\left(drDOEL_{ptl_i}\right)$$
$$PDOELptl_{m_i} := 1 - STm_{ptl}\left(drDOEL_{ptl_i}\right)$$
$$PDOELptl_{u_i} := 1 - STu_{ptl}\left(drDOEL_{ptl_i}\right)$$

$$PDOELpnl_{l_i} := 1 - STl_{ptn}\left(drDOEL_{ptn_i}\right)$$
$$PDOELpnl_{m_i} := 1 - STm_{ptn}\left(drDOEL_{ptn_i}\right)$$
$$PDOELpnl_{u_i} := 1 - STu_{ptn}\left(drDOEL_{ptn_i}\right)$$

DOE Long

The mean probability of at least, x, seepage flux or greater entering a damaged waste package due to localized corrosion (seepage only) in order to fill the free volume within 10,000 years is listed below.

per 21-PWR WP
(Lithophysal Zone)

$$\mathrm{mean}\left(P21pwrptl_l\right) = 1.771 \times 10^{-1}$$
$$\mathrm{mean}\left(P21pwrptl_m\right) = 2.314 \times 10^{-1}$$
$$\mathrm{mean}\left(P21pwrptl_u\right) = 2.447 \times 10^{-1}$$

per 21-PWR WP
(Nonlithophysal Zone)

$$\mathrm{mean}\left(P21pwrpnl_l\right) = 1.581 \times 10^{-1}$$
$$\mathrm{mean}\left(P21pwrpnl_m\right) = 2.242 \times 10^{-1}$$
$$\mathrm{mean}\left(P21pwrpnl_u\right) = 2.404 \times 10^{-1}$$

per 12-PWR WP
(Lithophysal Zone)

$$\mathrm{mean}\left(P12pwrptl_l\right) = 1.129 \times 10^{-1}$$
$$\mathrm{mean}\left(P12pwrptl_m\right) = 1.415 \times 10^{-1}$$
$$\mathrm{mean}\left(P12pwrptl_u\right) = 1.486 \times 10^{-1}$$

per 12-PWR WP
(Nonlithophysal Zone)

$$\mathrm{mean}\left(P12pwrpnl_l\right) = 1.027 \times 10^{-1}$$
$$\mathrm{mean}\left(P12pwrpnl_m\right) = 1.378 \times 10^{-1}$$
$$\mathrm{mean}\left(P12pwrpnl_u\right) = 1.464 \times 10^{-1}$$

per 44-BWR WP
(Lithophysal Zone)

$\mathrm{mean}\left(\mathrm{P44bwrptl}_{\mathrm{l}}\right) = 1.76 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P44bwrptl}_{\mathrm{m}}\right) = 2.31 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P44bwrptl}_{\mathrm{u}}\right) = 2.445 \times 10^{-1}$

per 24-BWR WP
(Lithophysal Zone)

$\mathrm{mean}\left(\mathrm{P24bwrptl}_{\mathrm{l}}\right) = 1.162 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P24bwrptl}_{\mathrm{m}}\right) = 1.428 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P24bwrptl}_{\mathrm{u}}\right) = 1.494 \times 10^{-1}$

per DOE Short WP
(Lithophysal Zone)

$\mathrm{mean}\left(\mathrm{PDOEsptl}_{\mathrm{l}}\right) = 6.816 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEsptl}_{\mathrm{m}}\right) = 8.83 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEsptl}_{\mathrm{u}}\right) = 9.325 \times 10^{-1}$

per DOE MCO WP
(Lithophysal Zone)

$\mathrm{mean}\left(\mathrm{PDOEmcoptl}_{\mathrm{l}}\right) = 3.191 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEmcoptl}_{\mathrm{m}}\right) = 4.167 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEmcoptl}_{\mathrm{u}}\right) = 4.407 \times 10^{-1}$

per DOE Long WP
(Lithophysal Zone)

$\mathrm{mean}\left(\mathrm{PDOELptl}_{\mathrm{l}}\right) = 6.364 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOELptl}_{\mathrm{m}}\right) = 8.644 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOELptl}_{\mathrm{u}}\right) = 9.205 \times 10^{-1}$

per 44-BWR WP
(Nonlithophysal Zone)

$\mathrm{mean}\left(\mathrm{P44bwrpnl}_{\mathrm{l}}\right) = 1.568 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P44bwrpnl}_{\mathrm{m}}\right) = 2.237 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P44bwrpnl}_{\mathrm{u}}\right) = 2.401 \times 10^{-1}$

per 24-BWR WP
(Nonlithophysal Zone)

$\mathrm{mean}\left(\mathrm{P24bwrpnl}_{\mathrm{l}}\right) = 1.066 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P24bwrpnl}_{\mathrm{m}}\right) = 1.394 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{P24bwrpnl}_{\mathrm{u}}\right) = 1.474 \times 10^{-1}$

per DOE Short WP
(Nonlithophysal Zone)

$\mathrm{mean}\left(\mathrm{PDOEspnl}_{\mathrm{l}}\right) = 6.108 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEspnl}_{\mathrm{m}}\right) = 8.565 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEspnl}_{\mathrm{u}}\right) = 9.167 \times 10^{-1}$

per DOE MCO WP
(Nonlithophysal Zone)

$\mathrm{mean}\left(\mathrm{PDOEmcopnl}_{\mathrm{l}}\right) = 2.849 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEmcopnl}_{\mathrm{m}}\right) = 4.038 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOEmcopnl}_{\mathrm{u}}\right) = 4.33 \times 10^{-1}$

per DOE Long WP
(Nonlithophysal Zone)

$\mathrm{mean}\left(\mathrm{PDOELpnl}_{\mathrm{l}}\right) = 5.579 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOELpnl}_{\mathrm{m}}\right) = 8.339 \times 10^{-1}$

$\mathrm{mean}\left(\mathrm{PDOELpnl}_{\mathrm{u}}\right) = 9.019 \times 10^{-1}$

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APPENDIX E

DESCRIPTION OF EVENT TREE TOP EVENTS

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APPENDIX E - DESCRIPTION OF EVENT TREE TOP EVENTS

The first event tree (Appendix B, Figure B-1) defines the fractional breakdown of the waste forms and waste package types proposed for disposal in the repository. This event tree is a stand-alone tree (i.e., none of its end states transfer to a sub-event tree). Its purpose is to graphically identify the fraction of total waste package inventory for each waste form and waste package type, including naval waste package types.

The 22 commercial and DOE SNF waste package types listed in Figure B-1 are utilized as the initiating event in 22 separate event trees. The sole purpose of these event trees is to transfer to the event tree that initiates the evaluation of the four criticality FEPs cases. The “YMP-INIT-EVENTS” end state name in the “END-STATE” column of Figure B-2 indicates the name of the event tree to which the transfer occurs.

The “YMP-INIT-EVENTS” event tree is presented in (Appendix B, Figure B-3. This event tree directs the evaluation of the four criticality FEPs cases — (1) Base Case, (2) Seismic Disruptive Event, (3) Rock Fall Disruptive Event, and (4) Igneous Disruptive Event. These cases are respectively represented by the four branches of the first top event — INIT-EVENT.

As indicated by the top event SEIS-RANGE, the seismic disruptive event has been divided into four sub-events, each representing a seismic frequency range. Top event SEIS-DAMAGE further subdivides the top three seismic frequency ranges based on whether the seismic induced damage results from ground motion or faulting.

The top three branches of top event SEIS-RANGE are further subdivided to account for the waste package failure dependency on seismic induced ground motions and faulting. The lower branch of top event SEIS-RANGE is not subdivided because seismic faulting is not predicted to result in any waste package failures for this annual exceedance frequency range. The event GROUND MOTION defines the upper branch of the SEIS-DAMAGE top event and is used to evaluate the potential of waste package failure due to seismic induced ground motions. The event FAULTING represents the lower branch of the SEIS-DAMAGE top event and is used to evaluate the potential of waste package failure due to seismic induced faulting.

The rock fall disruptive event is represented by the third branch of top event INIT-EVENT. The basic event for this criticality FEPs case is ROCKFALL-EVENT. Rock fall is the result of natural drift degradation phenomena and is expected to occur throughout the postclosure period without any predictable frequency. The rock fall disruptive event is differentiated from rock fall that may occur during a seismic disruptive event.

The igneous disruptive event case is represented by the fourth branch of the INIT-EVENT top event. Its basic event is IGNEOUS-EVENT.

The DRIFT top event of the “YMP-INIT-EVENTS” event tree is used to split the criticality FEP evaluations between the two geological zones of the drifts – lithophysal and nonlithophysal. It is important to distinguish between the two geological units to account for their different impacts on seepage, drip shield damage, and waste package damage.

The sequences of the “YMP-INIT-EVENTS” event tree of Figure B-3 automatically transfer to another event tree. An event tree transfer is indicated by the “T” after the sequence numbers in the “#” column. The “MSL-ET” end state name in the “END-STATE” column for the first ten sequences indicates the name of the event tree to which the transfer occurs. The “MSL-ET” event tree (shown in Figure B-4) performs the probability evaluation for availability of seepage, drip shield and waste package failure, availability of condensation, seepage accumulation in the waste package (i.e., formation of a bathtub or flow-through configuration), and neutron absorber material misload.

The end state names for the remaining two sequences indicates a transfer to the “IGNEOUS” event tree. The “IGNEOUS” event tree directs the probability evaluation of potentially critical configurations during an igneous event.

As presented in the “MSL-ET” event tree and its continuation event tree “MSL-ET2”, nine top events are used to define the events and processes necessary for the formation of a waste package bathtub or flow-through configuration. The purpose of the first top event, MS-IC-1A, is to evaluate the probability of infiltration water or seepage reaching the drift. This top event is separated into four branches. The first branch represents the no seepage case. The second through fourth branches represent lower-bound, mean, and upper-bound seepage rates, respectively.

If seepage is predicted to occur (i.e., one of the bottom three branches), then top event MS-NF-T is queried. The purpose of this top event is to account for the availability of water in the drift invert, or near-field. Water in the invert provides a transport mechanism of fissile material to the far-field in the event of waste package breach and its release of the waste form. Water in the invert may also provide a reducing environment that causes the deposition and accumulation of fissile material in the near-field. The upper branch, of this top event accounts for the availability of water to enter a failed waste package. The lower branch accounts for seepage water in the invert. The lower branch transfers directly to the near-field event tree “CONFIG-NF4” for further evaluation.

Top event MS-IC-2 evaluates the probability that, given seepage in the drift, the drip shield is failed in such a manner to allow water to pass through to the waste package. Regardless of whether the drip shield is failed (i.e., branching goes down) or not (i.e., branching goes up), top event MS-IC-1B is queried. If the drip shield is failed, the query of top event MS-IC-1B is performed to determine if, in addition to seepage, condensation water flux is available to enter a waste package. If the drip shield is not failed, the query of the condensation top event is performed to determine if any water flux is available to enter a waste package.

Other than those sequences of top event MS-NF-T that transfer to the “CONFIG-NF4” event tree, all sequences of the MSL-ET” event tree transfer to its continuation event tree “MSL-ET2”.

There are six top events in the “MSL-ET2 event tree to complete the master scenario list initiation. The first top event to be queried is MS-IC-3A. Top event MS-IC-3A evaluates the probability of a waste package failure. The branching of this top event allows for both advective and diffusive failures of the waste package as well as no waste package failures. The middle branch of this top event represents a diffusive failure of the waste package. The bottom branch of this top event represents a waste package failure that allows advective flow of water to enter and support the generation of a potentially critical configuration. If the waste package is not failed (i.e., branching goes up), then the analysis is terminated. Termination of sequence evaluation is indicated by the @END-ANALYSIS end state name (the @ symbol prefixing an end state name indicates to SAPHIRE to stop processing).

Top event MS-IC-3B evaluates the probability that, given an advective flow path into the waste package (bottom branch of top event MS-IC-3A), either a flow-through or a bathtub configuration is formed. A flow-through configuration results from a failure of both the top and bottom of the waste package, allowing the water to flow in through the top of the waste package and out through the bottom. This configuration is represented by the upper branch of this top event. A bathtub configuration is formed when only a top failure of the waste package occurs. The bathtub waste package configuration is represented by the bottom branch of this top event. If a flow-through waste package configuration is formed, the next top event queried is NA-MISLOAD. If a bathtub waste package configuration is formed, then top event MS-IC-4 is queried.

Top event MS-IC-4 evaluates the probability that, given its availability to enter a failed waste package, water accumulates in and fills the waste package creating a potentially critical configuration. The probability value for water accumulation and waste package filling is dependent on the seepage scenario of top event MS-IC-1A of event “MSL-ET”. Therefore, separate branches are provided in top event MS-IC-4 that reflect the branching of MS-IC-1A for the lower-bound, mean, and upper-bound seepage scenarios. The second through fourth branches from the top of this top event respectively represents these seepage scenarios. The upper branch of this top event represents the probability that water does not accumulate in sufficient quantity to fill the waste package.

The accumulation and retention of water in the waste package is referred to as a bathtub configuration and is represented on the event tree as a downward branch for top event MS-IC-3B. It is also possible for water to enter the waste package, but does not accumulate due to a breach in the waste package bottom. This condition is referred to as a flow-through configuration and is represented on the event tree as an upward branch for top event MS-IC-3B. Potentially critical configurations could result from either condition through the degradation of the waste package internals and the separation or removal of neutron absorber and/or fissile materials.

Another possible configuration is one in which a breach in the top and bottom of the waste package exists, but that the bottom hole is much smaller than the top hole so more water could enter the waste package through the top than could exit through the bottom. This configuration is not explicitly considered in this analysis because the low seepage rates predicted in the repository would preclude this configuration from occurring. In addition, this waste package configuration can be considered a subset of the bathtub configuration.

The next top event evaluated for the "MSL-ET2"event tree is NA-MISLOAD. This top event is queried for either waste package diffusive or advective (both bathtub and flow-through configurations) failure branches of the all branches of the MS-IC-3A and MS-IC-3B top events. The NA-MISLOAD top event evaluates the probability that neutron absorber material is not loaded as designed into the waste package or waste form. Evaluation of neutron absorber material misload is an important consideration for the determination of a configurations criticality potential. Dependent on the top event MS-IC-4 branching, both misload and no misload branches transfer to the appropriate "CONFIG-BATH" and "CONFIG-NOBATH" event trees for further criticality potential evaluation.

If the NA-MISLOAD top event is queried following a diffusive failure of the waste package (middle branch of top event MS-IC-3A), then the processing of these sequences proceeds to the evaluation of top events WF-MISLOAD and CRIT-POT-WF. The WF-MISLOAD misload top event queries the potential for misloading the waste package's waste form and top event CRIT-POT-WF evaluates the criticality potential of the resulting configuration. The upper branch of the CRIT-POT-WF top event indicates that this configuration does not have any criticality potential and processing of this sequence is terminated. The lower branch of this top event indicates that the configuration has a criticality potential and the probability associated with that potential is assigned to end state IP-DRY.

E.1 DISCRIPTION OF EVENT TREES "MSL-ET" AND "MSL-ET2"

The following subsections provide description of the top events of the event tree "MSL-ET" event tree (Appendix B, Figure B-4) and its continuation event tree "MSL-ET2" (Appendix B, Figure B-5). This event tree consists of 10 top events.

Six events and processes are required to define the formation of a waste package bathtub or flow-through configuration. These events are listed as top events of the "MSL-ET" event tree and its continuation event tree "MSL-ET2". These events are:

(1) The probability that seepage flux is available to enter a waste package (top event MS-IC-1A)

(2) The probability of drip shield failure (top event MS-IC-2)

(3) The probability that condensation flux is available to enter a waste package (top event MS-IC-1B)

(4) The probability of waste package failure (top event MS-IC-3A)

(5) The probability that the waste package failure will allow for the formation of a bathtub configuration (top event MS-IC-3B)

For bathtub configurations only:

(6) The probability of sufficient seepage to fill and overflow the waste package during the regulatory period (top event MS-IC-4).

In addition, event trees "MSL-ET" and "MSL-ET2" contain four other top events necessary to define the internal and external configuration classes. The first of these is top event MS-NF-T that defines whether seepage that reaches the drift flows directly to the invert and is available to influence the formation of near-field configuration classes. The second top event, NA-MISLOAD, helps define the internal waste package conditions by querying whether the waste package's or waste form's neutron absorber material was misloaded. The third top event, WF-MISLOAD, defines the probability that a waste form has been misloaded into a waste package. Finally, the fourth top event determines the criticality potential for failed waste packages under dry diffusion conditions.

The following subsections provide descriptions of event trees "MSL-ET" and "MSL-ET2" for the base case criticality FEPs analysis. This event tree consists of 10 top events.

E.1.1 Top Event MS–IC–1A

Seepage reaching the drift is an important factor in waste package degradation and criticality potential. Two parameters characterize the seepage into the emplacement drifts – the seepage fraction (location within the drifts that see seepage) and the seepage rate (the volume of water entering the drift on an annual basis). The purpose of top event MS-IC-1A is to represent the possibility that seepage is available in a drift to enter a breached waste package. The upper branch of this top event indicates that seepage does not occur and the bottom three branches indicates that seepage does occur: branch 1 – lower-bound seepage scenario, branch 2 – mean seepage scenario and branch 3 – upper-bound seepage scenario.

The appropriate seepage probability is then substituted into the SAPHIRE analysis based on the sequence branching of top event DRIFT-ZONE of the "YMP-INIT-EVENT" event tree

E.1.2 Top Event MS–NF-T

The branching of top event MS-NF-T represents the availability of seepage to flow directly into the invert. The upper branch indicates that seepage does not flow into the invert and the lower branch indicates that it is available. If seepage is available to flow directly into the invert, the sequence transfers to the "CONFIG-NF4" event tree for the evaluation of near-field configuration class NF-4.

E.1.3 Top Event MS–IC–2

The probability of water passing through the drip shield to a failed waste package is an important factor in waste package degradation and criticality. This event is associated with top event MS–IC–2 of the "MSL–ET" event tree (Appendix B, Figure B-4). The upper branch represents no drip shield failure and the lower branch represents that the drip shield has failed.

Water pathways through the drip shield can be created by corrosion and/or gaps caused by the drip shield response to events such as seismic activity and emplacement errors. Drip shield failures can be categorized as being caused by either time-dependent or time-independent mechanisms. Corrosion failure mechanisms are time-dependent and may be active or inactive during the performance evaluation period.

Time-independent drip shield failure mechanisms are defined as those failure mechanisms that can occur randomly from the time of initial emplacement. Drip shield emplacement errors, rock fall, or seismic events are types of time-independent failure mechanisms that can potentially result in immediate creation of an advective pathway through the drip shield. In certain cases, such as fabrication errors, the failure mechanism is an initiator that exacerbates corrosion (a time-dependent mechanism).

E.1.4 Top Event MS–IC–1B

The availability of condensation water to enter a failed waste package is an important factor in waste package degradation and criticality and is associated with top event MS–IC–1B of the "MSL–ET" event tree (Appendix B, Figure B-4). The upper branch of this top event represents the unavailability of condensation to enter a failed waste package. The lower branch represents that condensation is available to enter a failed waste package.

E.1.5 Top Event MS–IC–3A

The ability for water to enter a waste package is an important factor in waste package degradation and criticality and is associated with top event MS–IC–3A of the "MSL–ET2" event tree. Water pathways into the waste package can be created by corrosion and/or failures caused by the waste package response to events such as seismic activity and fabrication errors. Waste package failures can be categorized as being caused by either time-dependent or time-independent mechanisms. Corrosion failure mechanisms are time-dependent and may be active or inactive during the performance evaluation period.

Time-independent waste package failure mechanisms are defined as those failure mechanisms that can occur randomly from the time of initial emplacement. A seismic event is a type of time-independent failure mechanism that can potentially result in immediate creation of an advective pathway into the waste package. In certain cases, such as fabrication errors, the failure mechanism is an initiator that exacerbates corrosion (a time-dependent mechanism).

Waste package failure is defined as those waste package damage mechanisms that can result in either a diffusive or advective flow path into the waste package. The upper branch of this top event represents the probability of no waste package failures. The second and third branches respectively represent the probability of a diffusive or advective waste package failure. Waste package failure could be the result of a crack in the waste package surface or from the catastrophic failure of the complete waste package. As will be discussed, not all waste package damage mechanisms results in an advective failure of the waste package.

E.1.6 Top Event MS–IC–3B

The branching of top event MS-IC-3B represents the probability that waste package failure will result in the formation of a bathtub or flow-through configuration. The upper branch indicates the formation of a flow-through waste package configuration and the lower branch indicates that a bathtub configuration is formed.

E.1.7 Top Event MS-IC-4

The availability of sufficient water to fill and overflow a waste package in a bathtub configuration is associated with top event MS-IC-4 of the "MSL-ET2" event tree. The upper branch of this top event represents that there is insufficient seepage to fill and overflow a failed waste package during the regulatory period. The second, third, and fourth branches represent the probability of sufficient seepage to fill and overflow a failed waste package for the lower-bound, mean, and upper-bound seepage scenarios, respectively.

E.1.8 Top Event NA–MISLOAD

The presence of neutron absorber materials in a waste package is important to criticality control during the regulatory period for the majority of the waste forms proposed for disposal in the repository. Misload of the neutron absorber materials is associated with top event NA–MISLOAD of the "MSL–ET2" event tree. The upper branch of this top event indicates that there is no neutron absorber material misload and the lower branch indicates that there is a misload.

Neutron absorber material misload can occur as the result of several mechanisms during the waste package fabrication and loading processes. These processes include the use of wrong materials, failure to load the neutron absorber materials into the waste package or waste form, and selection of the wrong waste package type.

Assessment of the neutron absorber material misload event only accounts for the potential to load no or less than the designed mass of neutron absorber material. No penalty is assigned for loading additional neutron absorber materials into a waste package or waste form.

E.1.9 Top Event WF–MISLOAD

The WF–MISLOAD top event represent the probability that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.1.10 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of a waste package with a diffusive failure. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.2 DESCRIPTION OF EVENT TREE "CONFIG–BATH"

The following subsections provide description of the top events of the event tree "CONFIG–BATH" (Appendix B, Figure B-6). This event tree consists of 11 top events.

E.2.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN is used to configure the in-package, bathtub configuration classes IP-1, IP-2, and IP-3 for evaluation. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The three in-package, bathtub configuration classes are represented by the second through fourth branches from the top of this top event. These three branches direct the evaluation of configuration subclass IP-1, IP-2, and IP-3, respectively.

E.2.2 Top Event MS-IC-6

The branching of top event MS-IC-6 initiates the evaluation of in-package configuration class IP-1 defined as the scenario in which the waste package internal structures degrade at a slower rate than the waste form. This top event has five branches that are accessed by the second branch of top event CONFIG-SCEN. The upper branch indicates that waste package internal structures do not degrade slower than the waste form and the lower four branches indicate that they do.

E.2.3 Top Event MS-IC-7

The branching of top event MS-IC-7 represents the in-package scenario of the waste package internal structures degrading at the same rate as the waste form and the subsequent transfer of the SAPHIRE evaluation to event tree "CONFIG-IP2-D". This top event is queried by the third branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade at the same rate as the waste form and the lower branch indicates that they do.

E.2.4 Top Event MS-IC-8

The branching of top event MS-IC-8 represents the in-package scenario of the waste package internal structures degrading faster than the waste form and the subsequent transfer of the SAPHIRE evaluation to event tree "CONFIG-IP3". This top event is queried by the fourth branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade faster than the waste form and the lower branch indicates that they do.

E.2.5 Top Event MS-IC-9

The branching of top event MS-IC-9 represents the waste form degrading in-place for the evaluation of configuration subclass IP-1A. This top event is queried by the second branch of top event MS-IC-6. The upper branch indicates that the waste form does not degrade in-place and the lower branch indicates that it does.

E.2.6 Top Event MS-IC-10

The branching of top event MS-IC-10 evaluates whether waste package internal structures degrade at some point during the regulatory period thereby transforming configuration class IP-1 into IP-2. This top event is queried by the third branch of top event MS–IC–6. The upper branch indicates that the waste package internal components do not degrade and the lower branch indicates that they do.

E.2.7 Top Event MS-IC-11

The branching of top event MS-IC-11 represents the mobilization of the degraded waste form and its separation from any intact neutron absorber material. The upper branch indicates that the degraded waste form is not separated from any intact neutron absorber materials and the lower two branches indicate that it does. The second branch of this top event evaluates configuration subclass IP-1B. The third, or bottom, branch of this top event represents the flushing of the mobilized waste form into the near-field environment via this sequence's immediate transfer to the "CONFIG-NF-F" event tree.

E.2.8 Top Event MS-IC-12

The branching of top event MS-IC-12 evaluates whether waste package bottom fails at some point during the regulatory period thereby transforming configuration class IP-1 into IP-4. This top event is queried by the fourth branch of top event MS-IC-6. The upper branch indicates that the waste package bottom does not fail and the lower branch indicates that they do.

E.2.9 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probabilty that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.2.10 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.3 DESCRIPTION OF EVENT TREE "CONFIG–NOBATH"

The following subsections provide description of the top events of the event tree "CONFIG–NOBATH" (Appendix B, Figure B-7). This event tree consists of four top events.

E.3.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN is used to configure the in-package, flow through configuration classes IP-4, IP-5, and IP-6 for evaluation. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The three in-package, flow through configuration classes are represented by the second through fourth branches from the top of this top event. These three branches direct the evaluation of configuration subclass IP-4, IP-5, and IP-6, respectively.

E.3.2 Top Event MC-IC-29

The branching of top event MS-IC-31 represents the in-package scenario of the waste package internal structures degrading slower than the waste form and the subsequent transfer of the SAPHIRE evaluation to event tree "CONFIG-IP4-A". This top event is queried by the second branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade slower than the waste form and the lower branch indicates that they do.

E.3.3 Top Event MS-IC-30

The branching of top event MS-IC-30 represents the in-package scenario of the waste package internal structures degrading at the same rate as the waste form and the subsequent transfer of the SAPHIRE evaluation to event tree "CONFIG-IP5-B". This top event is queried by the third branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade at the same rate as the waste form and the lower branch indicates that they do.

E.3.4 Top Event MS-IC-31

The branching of top event "MS-IC-31" represents the in-package scenario of the waste package internal structures degrading faster than the waste form and the subsequent transfer of the SAPHIRE evaluation to event tree "CONFIG-IP6-C". This top event is queried by the fourth branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade faster than the waste form and the lower branch indicates that they do.

E.4 DESCRIPTION OF EVENT TREE "CONFIG–IP2-D"

The following subsections provide description of the top events of the event tree "CONFIG–IP2-D". This event tree consists of four top events.

E.4.1 Top Event MS-IC-13

The branching of top event “MS-IC-13” determines whether the degraded waste form and waste package components collect at the bottom of the waste package. The upper branch indicates that the waste form and waste package components do not collect at bottom of waste package and bottom two branches indicate that they do.

E.4.2 Top Event MS-IC-14

Top event “MS-IC-14” is queried as part of configuration IP-2 to determine whether soluble neutron absorbers are flushed from waste package. The upper branch indicates that soluble neutron absorbers are not flushed from waste package and the bottom branch indicates that they are.

E.4.3 Top Event MS-IC-15

Top event “MS-IC-15” is queried as part of configuration class IP-5 to determine whether waste package bottom fails draining liquid. The upper branch indicates that waste package bottom does not fail draining liquid and the bottom branch indicates that it does.

E.4.4 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probabilty that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.4.5 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.5 DESCRIPTION OF EVENT TREE “CONFIG–IP3”

The following subsections provide a description of the top events of the event tree “CONFIG–IP3” Appendix B, Figure B-9). This event tree consists of nine top events.

E.5.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN is used to configure the in-package, bathtub configuration classes IP-3. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The two in-package, bathtub configuration classes are represented by the second through fourth branches from the top of this top event. These three branches direct the evaluation of configuration subclass IP-3, IP-5, and IP-6.

E.5.2 Top Event MS-IC-16

The branching of top event “MS-IC-16” determines whether the basket structure supports mechanically collapse. The top branch indicates that they do not the bottom three branches indicate that they do.

E.5.3 Top Event MS-IC-17

Top event “MS-IC-17” is queried as part of IP-3 to determine whether structures containing neutron absorbers fully degrade. The top branch indicates that they do not and the bottom branch indicates that they do.

E.5.4 Top Event MS-IC-18

Top event “MS-IC-18” is queried as part of IP-3 to determine whether soluble neutron absorbers are flushed from degraded portion of basket. The top branch indicates that they are not and the bottom branch indicates that they are.

E.5.5 Top Event MS-IC-22

The branching of top event “MS-IC-22” determines whether significant neutron absorber degradation occurs before structural collapse. The top branch indicates that it does not and the bottom three branches indicate that it does.

E.5.6 Top Event MS-IC-23

Top event “MS-IC-23” is queried as part of IP-3 to determine whether waste package internal structures mechanically collapse and degrade. The top branch indicates that they do not and the bottom branch indicates that they do.

E.5.7 Top Event MS-IC-24

Top event “MS-IC-24” is queried as part of IP-6 to determine whether waste package bottom fails and drains liquid. The top branch indicates that it does not and the bottom branch indicates that it does.

E.5.8 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probabilty that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.5.9 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.6 DESCRIPTION OF EVENT TREE “CONFIG–IP3-G”

The following subsections provide description of the top events of the event tree “CONFIG–IP3-G” (Appendix B, Figure B-10). This event tree consists of six top events.

E.6.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN is used to configure the in-package, bathtub configuration classes IP3-G for evaluation. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The three in-package, bathtub configuration classes are represented by the second through fourth branches from the top of this top event. These three branches direct the evaluation of configuration subclass IP3-G.

E.6.2 Top Event MS-IC-19

Top event “MS-IC-19” is queried as part of IP-3 to determine whether soluble neutron absorbers are flushed from waste package. The top branch indicates they are not and the bottom branch indicates they are.

E.6.3 Top Event MS-IC-20

Top event “MS-IC-20” is queried as part of IP-2 to determine whether waste form degrades mobilizing fissile material. The top branch indicates it does not and the bottom branch indicates it does.

E.6.4 Top Event MS-IC-21

Top event “MS-IC-21” is queried as part of IP-6 to determine whether waste package bottom fails and drains liquid. The top branch indicates it does not and the bottom branch indicates it does.

E.6.5 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probabilty that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.6.6 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.7 DESCRIPTION OF EVENT TREE "CONFIG–IP4-A"

The following subsections provide description of the top events of the event tree "CONFIG–IP4-A" (Appendix B, Figure B-11). This event tree initiates the evaluation of the internal waste package configuration subclasses IP-4A and IP-4B. This event tree consists of six top events.

E.7.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN is used to configure the in-package, flow-through configuration subclasses IP-4A and IP-4B. The upper branch is not utilized in these analyses and is included only for modeling convienence. The three in-package, flow-through configuration subclasses are represented by the second and third branches from the top of this top event. These two branches direct the evaluation of configuration subclass IP-4A and IP-4B, respectively. The bottom, or fourth, branch initiates a transfer to the processing of configuration class IP-5.

E.7.2 Top Event MS-IC-32

The branching of top event MS-IC-32 initiates the evaluation of in-package configuration subclass IP-4A defined as the scenario in which the waste form degradation products hydrate in their initial location. This top event is queried by the second branch of top event CONFIG-SCEN. The upper branch indicates that waste form degradation products do not hydrate in their initial location and the lower branch indicates that they do.

E.7.3 Top Event MS-IC-33

The branching of top event MS-IC-33 represents the degradation of the waste package internal structures. This top event is queried by the third branch of top event CONFIG-SCEN. The upper branch indicates that the waste package internal structures do not degrade and the lower branch indicates that they do. Activation of the lower branch of this top event initiates a transfer to the "CONFIG-IP5-B" event tree.

E.7.4 Top Event MS-IC-34

The branching of top event MS-IC-34 represents the mobilization and hydration of the degraded waste form and its separation from the neutron absorber materials of the waste package. This top event is queried by the third branch of top event CONFIG-SCEN. The upper branch of this top event indicates that the waste form is not mobilized and separated from the neutron absorber materials and the bottom two branches indicate that it is. The second branch represents the waste form mobilization and separation internal to the waste package to initiate the evaluation of configuration subclass IP-4B. The bottom, or third, branch represent the transport of the mobilized waste form to the near-field environment as indicated by the transfer to the "CONFIG-NF-F" event tree.

E.7.5 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probabilty that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.7.6 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.8 DESCRIPTION OF EVENT TREE “CONFIG–IP5-B”

The following subsections provide description of the top events of the event tree “CONFIG–IP5-B” (Appendix B, Figure B-12). This event tree initiates the evaluation of the internal waste package configuration subclass IP-5B. This event tree consists of four top events.

E.8.1 Top Event MS-IC-35

The branching of top event MS-IC-35 represents the accumulation of the hydrated waste form and waste package degraded internal components at the bottom of the waste package. The upper branch of this top event indicates that the waste form and degraded components do not collect on the bottom of the waste package and the bottom two branches indicate that it does. The second branch initiates the evaluation of configuration subclass IP-5B. The bottom, or third, branch represent the transport of the hydrated waste form and degraded internal components to the near-field environment as indicated by the transfer to the “CONFIG-NF-F” event tree.

E.8.2 Top Event MS-IC-36

Top event “MS-IC-36” is queried as part of IP-5 to determine whether flow through flushing removes soluble neutron absorbers. The top branch indicates it does not and the bottom branch indicates it does.

E.8.3 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probabilty that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.8.4 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.9 DESCRIPTION OF EVENT TREE “CONFIG–IP6-C”

The following subsections provide description of the top events of the event tree “CONFIG–IP6-C” (Appendix B, Figure B-13). This event tree initiates the evaluation of the internal waste package configuration subclass IP-6C. This event tree consists of six top events.

E.9.1 Top Event MS-IC-37

The branching of top event “MS-IC-37” determines whether the intact waste form settles in the bottom of the waste package and mixes with hydrated waste package corrosion products. The top branch indicates it does not and the bottom four branches indicate that it does.

E.9.2 Top Event MS-IC-38

Top event “MS-IC-38” is queried as part of IP-6 to determine whether flow through flushing removes soluble neutron absorbers. The top branch indicates it does not and the bottom branch indicates it does.

E.9.3 Top Event MS-IC-39

Top event “MS-IC-39” is queried as part of IP-5 to determine whether waste form degrades mobilizing fissile material. The top branch indicates it does not and the bottom branch indicates it does.

E.9.4 Top Event MS-IC-40

Top event “MS-IC-40” is queried as part of near-field configuration classes to determine whether waste package mostly degrades while waste form stays largely intact. The top branch indicates it does not and the bottom branch indicates it does.

E.9.5 Top Event WF-MISLOAD

The WF-MISLOAD top event represents the probabilty that a waste form was incorrectly placed into a waste package or DOE standardized SNF canister during the preclosure loading process. The lower branch of this top event indicates the occurrence of a waste form misload and the upper branch indicates that no misload occurred.

E.9.6 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.10 DESCRIPTION OF EVENT TREE “CONFIG-NF-F”

The following subsections provide description of the top events of the event tree “CONFIG–NF-F” (Appendix B, Figure B-14). This event tree initiates the evaluation of the near-field configurations for the formation of potentially critical configurations. This event tree consists of four top events.

E.10.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of three of the five near-field configuration classes – NF-1, NF-2, and NF-3. These configuration classes are represented by the second, third and fourth branches from the top of this top event. The top branch is not utilized in these analyses and is included as a modeling convenience.

E.10.2 Top Event MS-NF-6

The branching of top event MS-NF-6 directs the evaluation of near-field configuration class NF-1. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class will be evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF1 event tree. This near-field configuration class represents the transport of fissile material bearing solutes from the waste package to the near-field environment. The NF-1 configuration class is to be evaluated for either a waste package overflow or bottom breach scenario.

E.10.3 Top Event MS-NF-7

The branching of top event MS-NF-7 directs the evaluation of near-field configuration class NF-2. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class will be evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF2 event tree. Configuration class NF-2 represents the transport of fissile material bearing slurry effluent from the waste package into the near-field environment. A slurry effluent can only result from a bottom breach of the waste package.

E.10.4 Top Event MS-NF-8

The branching of top event MS-NF-8 directs the evaluation of near-field configuration class NF-3. The upper branch of this top event indicates that this configuration class is not to be evaluated and the lower branch indicates that this configuration class will be evaluated. Selection of the lower branch results in a transfer to the CONFIG-NF3 event tree. This near-field configuration class represents the transport of fissile material bearing colloids from the waste package to the near-field environment. The NF-3 configuration class is to be evaluated either for a waste package overflow or bottom breach scenario.

E.11 DESCRIPTION OF EVENT TREE “CONFIG-NF1”

The following subsections provide description of the top events of the event tree “CONFIG–NF1” (Appendix B, Figure B-15). This event tree initiates the evaluation of the near-field configuration class NF-1 representing the near-field accumulation of fissile materials into potentially critical configurations resulting from solution effluent discharges from the waste package. This event tree consists of five top events.

E.11.1 Top Event MS-NF-9

The branching of top event MS-NF-9 directs the evaluation of the three configuration subclasses of configuration class NF-1 – NF-1A, NF-1B, and NF-1C. These configuration classes are represented by the second, third and fourth branches from the top of this top event. The upper branch is not utilized in these analyses and is included for modeling convenience. The lower branch of this top event represents the transport of fissile material from the near-field to the far-field. This branch immediately transfers to the CONFIG-FF-J event tree for far-field evaluation.

E.11.2 Top Event MS-NF-10

The branching of top event MS-NF-10 directs the evaluation of near-field configuration class NF-1A. The upper branch of this top event indicates that fissile materials are not sorbed into the invert materials and the lower branch indicates that fissile materials are sorbed in the invert materials. The criticality potential of near-field configuration class NF-1A will be evaluated for the seismic disruptive event.

E.11.3 Top Event MS-NF-11

The branching of top event MS-NF-11 directs the evaluation of near-field configuration class NF-1B. The upper branch of this top event indicates that fissile materials do not precipitate in the invert and the lower branch indicates that fissile materials do precipitate in the invert. The criticality potential of near-field configuration class NF-1B will be evaluated for the seismic disruptive event.

E.11.4 Top Event MS-NF-12

The branching of top event MS-NF-12 directs the evaluation of near-field configuration class NF-1C. The upper branch of this top event indicates that fissile materials are not transported from one or more waste packages and deposited at an invert low point. The lower branch indicates that fissile materials are transported and deposited at an invert low point. The criticality potential of near-field configuration class NF-1C will be evaluated for the seismic disruptive event.

E.11.5 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of a waste package with an advective failure. The cladding of a waste form in such a waste package is assumed to have breached and the waste form converted (degraded) into a more reactive configuration that has been flushed from the breached waste package. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does. This top event is queried for this event tree only for waste package advective failure conditions.

E.12 DESCRIPTION OF EVENT TREE “CONFIG-NF2”

The following subsections provide description of the top events of the event tree “CONFIG–NF2” (Appendix B, Figure B-16). This event tree initiates the evaluation of the near-field configuration class NF-2 representing the near-field accumulation of fissile materials into potentially critical configurations resulting from slurry effluent discharging from the waste package. This event tree consists of three top events.

E.12.1 Top Event MS-NF-13

The branching of top event MS-NF-13 directs the evaluation of near-field configuration class NF-2A. The upper branch of this top event indicates that fissile material contained in the slurry effluent does not flow and conform to the invert surface. The lower branch indicates that the slurry effluent does flow to conform to the invert surface. In order to evaluate near-field configuration subclass NF-2A, only the lower branch of this top event will be evaluated – slurry effluent does flow to conform to the invert surface.

E.12.2 Top Event MS-NF-14

The branching of top event MS-NF-14 evaluates whether the neutron absorber and fissile materials separate as the slurry effluent flows to conform to the invert surface. The upper branch of this top event indicates that the neutron absorber and fissile materials do not separate and the lower branch indicates that they do. Both branches of this top event will be evaluated in order to assess the criticality potential of the slurry effluent with and without neutron absorber materials.

E.12.3 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclass NF-2A - a slurry effluent from the waste package is assumed to flow and conform to the invert surface with and without neutron absorber material separation. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.13 DESCRIPTION OF EVENT TREE “CONFIG-NF3”

The following subsections provide description of the top events of the event tree “CONFIG–NF3” (Appendix B, Figure B-17). This event tree initiates the evaluation of the near-field configuration class NF-3 representing the near-field accumulation of fissile material bearing colloids into potentially critical configurations. This event tree consists of seven top events.

E.13.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of the three subclasses of near-field configuration class NF-3 and the transport of fissile material containing colloids from the near-field to the far-field environments. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The three near-field configuration subclasses are represented by the second and third branches from the top of this top event. The second branch directs the evaluation of configuration subclass NF-3A and the third branch directs the evaluation of subclasses NF-3B and NF-3C. The fourth, or bottom, branch of this top event represents the transport of fissile material through the near-field environment to the far-field environment. The fourth branch immediately transfers to the “CONFIG-FF-K” event tree for far-field configuration evaluation.

E.13.2 Top Event MS-NF-15

The branching of top event MS-NF-15 directs the evaluation of near-field configuration subclass NF-3A. The upper branch of this top event indicates that fissile material containing colloids are not filtered and concentrated on top of the invert, trapped by corrosion products. The lower branch indicates that the colloids are trapped on the invert surface. In order to evaluate near-field configuration subclass NF-3A, only the lower branch of this top event will be evaluated.

E.13.3 Top Event MS-NF-16

The branching of top event MS-NF-16 determines whether fissile material containing colloids are transported into the invert. Activation of the upper branch of this top event indicates that fissile material containing colloids are not transported into the invert. The activation of the second branch indicates that fissile material containing colloids are transported into the invert. In order to evaluate near-field configuration subclasses NF-3B and NF-3C, the second branch of this event is activated. The third branch is activated, which allows the fissile material colloids to be transported into the far-field.

E.13.4 Top Event MS-NF-19

The branching of top event MS-NF-19 directs the evaluation of near-field configuration subclasses NF-3B and NF-3C. The upper branch of this top event evaluates configuration subclass NF-3B and indicates that the invert materials have not degraded prior to the release of the waste form materials following a seismic event. The lower branch evaluates near-field configuration subclass NF-3C and indicates that the invert materials have degraded prior to the release of waste form materials following a seismic event.

E.13.5 Top Event MS-NF-17

The branching of top event MS-NF-17 evaluates the likelihood of hydrodynamic or chromatographic separation of fissile material containing colloids from the neutron absorber materials for both near-field configuration subclasses NF-3B and NF-3C. The upper branch of this top event indicates that fissile material containing colloids are not separated from the neutron absorber materials and the lower branch indicates that they are. Although no known mechanism exists to separate the fissile materials from the neutron absorber materials, both branches of this top event will be evaluated.

E.13.6 Top Event MS-NF-18

The branching of top event MS-NF-18 represents the filtration and concentration of the fissile material containing colloids in the invert for both configuration subclasses NF-3B and NF-3C. The upper branch of this top event indicates that fissile material containing colloids are not filtered and concentrated in the invert and the lower branch indicates that they are. In order to evaluate both configuration classes, only the lower branch of this top event will be activated.

E.13.7 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclasses NF-3A, NF-3B, and NF-3C. – scenarios for the filtration and concentration of fissile material containing colloids in the near-field. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.14 DESCRIPTION OF EVENT TREE “CONFIG-NF4”

The following subsections provide description of the top events of the event tree “CONFIG–NF4” (Appendix B, Figure B-18). This event tree initiates the evaluation of the near-field configuration class NF-4. This event tree consists of six top events.

E.14.1 Top Event MS-NF-2

The branching of top event MS-NF-2 determines whether seepage water ponds on the drift floor due to sealing or damming. The upper branch of this top event indicates that ponding does not occur and the lower branch indicates that it does.

E.14.2 Top Event MS-NF-3

Top event “MS-NF-3” is queried to determine whether aqueous corrosion of waste package occurs. The top branch indicates it does not and the bottom branch indicates it does.

E.14.3 Top Event MS-NF-4

Top event “MS-NF-4” is queried to determine whether container bottom breaches. The top branch indicates it does not and the bottom branch indicates it does.

E.14.4 Top Event MS-NF-5

Top event “MS-NF-5” is queried to determine whether waste form and basket degradation mobilizes fissile material and neutron absorber. The top branch indicates it does not and the bottom branch indicates it does.

E.14.5 Top Event MS-NF-DD

The branching of top event MS-NF-DD determines whether fissile material can accumulate on the invert surface due to dry transport mechanisms from a failed waste package that does not experience advective flow. The upper branch of this top event indicates that fissile material does not accumulate on the invert surface and the lower branch indicates that it does.

E.14.6 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclasses NF-3A, NF-3B, and NF-3C (scenarios for the filtration and concentration of fissile material containing colloids in the near-field.) The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.15 DESCRIPTION OF EVENT TREE “CONFIG-NF4-E”

The following subsections provide description of the top events of the event tree “CONFIG–NF4-E” (Appendix B, Figure B-19). This event tree initiates the evaluation of the near-field configuration class NF-4. This event tree consists of five top events.

E.15.1 Top Event MS-NF-22

Top event “MS-NF-22” is queried to determine whether fissile material and absorbers accumulate in pond. The top branch indicates they do not and the bottom branch indicates they do.

E.15.2 Top Event MS-NF-23

Top event “MS-NF-23” is queried to determine whether the basin is effectively sealed. The top branch indicates it is not and the bottom branch indicates it is.

E.15.3 Top Event MS-NF-24

Top event “MS-NF-24” is queried to determine whether fissile material accumulates in clays at the bottom of the pool. The top branch indicates it does not and the bottom branch indicates it does.

E.15.4 Top Event MS-NF-25

Top event “MS-NF-25” is queried to determine whether non-fissile bearing water flushes neutron absorbers. The top branch indicates it does not and the bottom branch indicates it does.

E.15.5 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclass NF-5A. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.16 DESCRIPTION OF EVENT TREE “CONFIG-NF5-I”

The following subsections provide description of the top events of the event tree “CONFIG–NF5-I” (Appendix B, Figure B-20). This event tree initiates the evaluation of the near-field configuration class NF-5. This event tree consists of two top events.

E.16.1 Top Event MS-NF-26

Top event “MS-NF-26” is queried to determine whether intact waste form sits in pond on drift floor. The top branch indicates it does not and the bottom branch indicates it does.

E.16.2 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclass NF-5 (scenario for intact waste form to sit in a pond on drift floor.) The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.17 DESCRIPTION OF EVENT TREE “CONFIG-FF-J”

The following subsections provide description of the top events of the event tree “CONFIG–FF-J” (Appendix B, Figure B-21). This event tree initiates the evaluation of the far-field configuration class FF-1 representing the far-field accumulation of fissile material bearing solutes into potentially critical configurations. This event tree consists of nine top events.

E.17.1 Top Event MS-FF-1

The branching of top event MS-FF-1 initiates the evaluation of far-field configuration class FF-1 representing the transport of fissile material containing solutes into the far-field’s saturated and unsaturated zones. The upper branch represents that the fissile material bearing solutes are not transported to the far-field and the lower branch represents that they are. Only the lower branch of this top event is activated to initiate the evaluation of this far-field configuration class.

E.17.2 Top Event MS-FF-2

The branching of top event MS-FF-2 determines whether the fissile materials entering the far-field environment are separated from the neutron absorber materials of the waste package or waste form. The upper branch indicates that the fissile material is not separated from the neutron absorber materials by the far-field environment. The remaining three branches evaluate far-field configuration classes for the separation of the fissile materials from the neutron absorber materials. The second branch from the top directs the evaluation of configuration subclass FF-1A and the third branch directs the evaluation of subclasses FF-1B and FF-1C. The fourth, or bottom, branch of this top event represents the transport of fissile material through the unsaturated zone and into the water table for the evaluation of configuration class FF-3. The fourth branch immediately transfers to the “CONFIG-FF3” event tree.

E.17.3 Top Event MS-FF-3

The branching of top event MS-FF-3 represents the transport of fissile materials through the unsaturated zone to the water table. The upper branch of this top event indicates that fissile material is not transported to the water table. The lower branch of this top event indicates that fissile materials are transported directly to the water table.

E.17.4 Top Event MS-FF-11

The branching of top event MS-FF-11 represents the precipitation of fissile material as the chemistry of the fissile material containing carrier plume is altered by the unsaturated zone host rock. This scenario represents far-field configuration subclass FF-1A. The upper branch of this top event indicates that fissile material is not precipitated and the lower branch of this top event indicates that it is.

E.17.5 Top Event MS-FF-12

The branching of top event MS-FF-12 represents the transport of fissile material containing solutes to altered TSbv. The upper branch of this top event indicates that the fissile material is not transported to the altered TSbv. The second and third branches of this top event indicate that fissile materials are transported to the altered TSbv and initiate the evaluation of far-field configuration subclasses FF-1B and FF-1C, respectively.

E.17.6 Top Event MS-FF-13

The branching of top event MS-FF-13 represents formation of the far-field configuration subclass FF-1B, which is defined as the sorption of fissile material in clays and zeolites in the altered TSbv. The upper branch of this top event indicates that fissile materials are not sorbed and the lower branch of this top event indicates that they are.

E.17.7 Top Event MS-FF-14

The branching of top event MS-FF-14 represents the formation of far-field configuration subclass FF-1C, which is defined as the accumulation of fissile material containing solutes in topographical lows above altered TSbv. The upper branch of this top event indicates that fissile material containing solutes are not accumulated and the lower branch of this top event indicates that they are accumulated.

E.17.8 Top Event MS-FF-15

The branching of top event MS-FF-14 represents the formation of far-field configuration subclass FF-1C, which is defined as the chemical changes in perched water precipitating fissile material. The upper branch of this top event indicates that there are no chemical changes and the lower branch of this top event indicates that there are.

E.17.9 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclass FF-1 (scenario representing the far-field accumulation of fissile material bearing solutes into potentially critical configurations.) The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.18 DESCRIPTION OF EVENT TREE “CONFIG-FF-K”

The following subsections provide description of the top events of the event tree “CONFIG–FF-K” (Appendix B, Figure B-22). This event tree initiates the evaluation of the far-field configuration class FF-2 representing the far-field accumulation of fissile material bearing colloids into potentially critical configurations. This event tree consists of seven top events.

E.18.1 Top Event MS-FF-16

The branching of top event MS-FF-16 initiates the evaluation of far-field configuration class FF-2 representing the transport of fissile material bearing colloids into the far-field’s unsaturated zone. The upper branch represents that fissile material bearing colloids are not transported to the far-field and the lower branch represents that they are.

E.18.2 Top Event MS-FF-17

The branching of top event MS-FF-17 determines whether the fissile material bearing colloids entering the unsaturated zone environment are hydrodynamically or chromatographically separated from the neutron absorber materials of the waste package or waste form. The upper branch indicates that the fissile material is not separated from the neutron absorber materials by the unsaturated zone environment. The remaining two branches represent the separation of the fissile materials from the neutron absorber materials and initiate the evaluation of the FF-2 configuration subclasses. The second branch from the top directs the evaluation of configuration subclass FF-2A and the third branch directs the evaluation of configuration subclasses FF-2B and FF-2C.

E.18.3 Top Event MS-FF-18

The branching of top event MS-FF-18 represents far-field configuration subclass FF-2A that is defined as the trapping of fissile material bearing colloids in altered TSbv. The upper branch of this top event indicates that fissile material bearing colloids are not trapped and the lower branch indicates that they are.

E.18.4 Top Event MS-FF-19

The branching of top event MS-FF-19 represents the transport of fissile material containing colloids to altered TSbv. The upper branch of this top event indicates that fissile material containing colloids are not transported and the lower two branches indicate that they are. The second and third branches of this top event initiate the evaluation of far-field configuration subclasses FF-2B and FF-2C, respectively.

E.18.5 Top Event MS-FF-20

The branching of top event MS-FF-20 represents formation of the far-field configuration subclass FF-2B, which is defined as the sorption of fissile material containing colloids on clays and zeolites in the altered TSbv. The upper branch of this top event indicates that fissile materials are not sorbed and the lower branch of this top event indicates that they are.

E.18.6 Top Event MS-FF-21

The branching of top event MS-FF-21 represents the formation of far-field configuration subclass FF-2C, which is defined as the filtration and accumulation of fissile material containing colloids in topographical low above altered TSbv. The upper branch of this top event indicates that fissile material containing colloids are not filtered and accumulated and the lower branch of this top event indicates that they are.

E.18.7 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclass FF-2 (scenario representing the far-field accumulation of fissile material bearing colloids into potentially critical configurations.) The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

E.19 DESCRIPTION OF EVENT TREE “CONFIG-FF3”

The following subsections provide description of the top events of the event tree “CONFIG–FF3” (Appendix B, Figure B-23). This event tree initiates the evaluation of the far-field configuration class FF-3 representing the accumulation of fissile material into potentially critical configurations in the far-field saturated zone. This event tree consists of nine top events.

E.19.1 Top Event CONFIG-SCEN

The branching of top event CONFIG-SCEN establishes the evaluation of the five subclasses of far-field configuration class FF-3 defined as the transport of fissile material into the saturated zone. The upper branch is not utilized in these analyses and is included only as a modeling convenience. The five far-field configuration subclasses are represented by the second through sixth branches from the top of this top event. These five branches direct the evaluation of configuration subclass FF-3A, FF-3B, FF-3C, FF-3D, and FF-3E, respectively.

E.19.2 Top Event MS-FF-4

The branching of top event MS-FF-4 initiates the evaluation of far-field configuration subclass FF-3A defined as the precipitation of fissile material in the upwell zone of hydrothermal fluids at faults or in fractures. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that they are.

E.19.3 Top Event MS-FF-5

The branching of top event MS-FF-5 represents the mixing of the fissile material containing contaminant plume below the redox front. The upper branch indicates that mixing does not occur and the lower branch indicates that it does.

E.19.4 Top Event MS-FF-6

The branching of top event MS-FF-6 initiates the evaluation of far-field configuration subclass FF-3B defined as the precipitation of fissile material as the contaminant plume mixes below the redox front. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that they are.

E.19.5 Top Event MS-FF-7

The branching of top event MS-FF-7 initiates the evaluation of far-field configuration subclass FF-3C defined as the precipitation of fissile materials at the reducing zone (i.e., the remains of organic materials). The upper branch indicates that fissile material is not precipitated and the lower branch indicates that it is.

E.19.6 Top Event MS-FF-8

The branching of top event MS-FF-8 initiates the evaluation of far-field configuration subclass FF-3D defined as the precipitation of fissile materials at the reducing zone of a pinchout of the tuff aquifer. The upper branch indicates that fissile material is not precipitated and the lower branch indicates that it is.

E.19.7 Top Event MS-FF-9

The branching of top event MS-FF-9 represents the transport of fissile material containing solutes to Franklin Lake Playa. The upper branch indicates that transport does not occur and the lower branch indicates that it does.

E.19.8 Top Event MS-FF-10

The branching of top event MS-FF-10 represents the precipitation of fissile material containing solutes in organic-rich zones of Franklin Lake. The upper branch indicates that precipitation does not occur and the lower branch indicates that it does.

E.19.9 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of the precipitated fissile material in the organic-rich zones of Franklin Lake. The upper branch indicates that precipitated material does not have a criticality potential and the lower branch indicates that it does.

E.20 DESCRIPTION OF EVENT TREE “IGNEOUS”

The following subsections provide description of the top events of the event tree “IGNEOUS” (Appendix B, Figure B-24). This event tree is accessed as part of the igneous disruptive event and directs the evaluation of the eruptive and intrusive igneous scenarios. This event tree consists of four top events.

E.20.1 Top Event IG-EVENT-TYPE

The upper branch of the IG-EVENT-TYPE top event represents the eruptive igneous scenario. The lower branch of the IG-EVENT-TYPE top event represents the intrusive igneous scenario. Given an igneous event, an intrusive scenario is expected to occur.

E.20.2 Top Event IG-WP-LOC

The branches of the IG-WP-LOC top event directs the evaluation of waste packages at the dike (intrusive event) or conduit (eruptive event) intersection point. The upper branch of this top event directs the evaluation of a waste package at the dike or conduit intersection points. The lower branch of this top event directs the evaluation of waste packages beyond the dike or conduit intersection points.

E.20.3 Top Event IG-WP-RELOC

The purpose of this top event is to represent the possibility that, for an eruptive igneous scenario, waste packages initially beyond the conduit intersection point may at some point may get pulled into the conduit.

E.20.4 Top Event NA–MISLOAD

The presence of neutron absorber materials in a waste package is important to criticality control during the regulatory period for the majority of the waste forms proposed for disposal in the repository. Misload of the neutron absorber materials is associated with top event NA–MISLOAD of the "MSL–ET2" event tree (Appendix B, Figure B-5). The lower branch of this top event indicates the occurrence of a misload of neutron absorber materials in the waste package or waste form and the upper branch indicates that no misload occurred.

E.21 DESCRIPTION OF EVENT TREE "IG-ERUPTIVE"

The following subsections provide description of the top events of the event tree "IG-ERUPTIVE" (Appendix B, Figure B-25). This event tree is accessed as part of the evaluation of an eruptive igneous scenario for those waste packages intersected by the eruptive conduit or those waste packages that are initially beyond the conduit, but are subsequently pulled into the conduit. This event tree consists of seven top events.

E.21.1 Top Event IG-CONFIG

The IG-CONFIG top event establishes the configuration of the waste packages ejected from the repository during an eruptive igneous event. Waste packages in the eruptive conduit can be either destroyed and the waste form pulverized during the eruptive process and the remains ejected and dispersed across the surface (the branch of this top event) or it can be ejected breached, but relatively intact and lying on the surface (the failure branch of this top event).

E.21.2 Top Event IG-RAINFALL

The purpose of top event IG-RAINFALL is to determine the probability that rainfall occurs at some point in time after an eruptive event. The upper branch of this top event indicates that rainfall does not occur and the lower branch indicates that it does.

E.21.3 Top Event IG-BATHTUB

Top event "IG-BATHTUB" is queried to determine whether waste package bathtub configuration forms. The top branch indicates that a flow-through configuration forms and the bottom branch indicates that a bathtub configuration occurs.

E.21.4 Top Event IG-FM-TRANS

Top event "IG-FM-TRANS" is queried to determine whether fissile material is transported from the waste package. The top branch indicates it is not and the bottom branch indicates it is.

E.21.5 Top Event IG-FM-ACCUM

The purpose of this top event is to represent the possibility that, after an eruptive igneous event disperses the waste form on the surface, subsequent rainfall mobilizes the waste form and it accumulates into a potentially critical configuration.

E.21.6 Top Event WF-MISLOAD

The WF-MISLOAD top event represent the probability that a waste form was incorrectly placed into a waste packaged during the preclosure loading process.

E.21.7 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.22 DESCRIPTION OF EVENT TREE “IG-INTRUSIVE”

The following subsections provide description of the top events of the event tree “IG-INTRUSIVE” (Appendix B, Figure B-26). This event tree is accessed as part of the eruptive and intrusive igneous scenario evaluations for those waste packages that are in the drift beyond the eruptive conduit or for those waste packages that are at or beyond the dike intersection point. This event tree consists of eight top events.

E.22.1 Top Event IG-WP-DESTRYD

This top event quantifies the probability that the waste package is destroyed as a result of the entry force of intrusive material. Separate consideration is given for those waste packages at the dike intersection point where the forces would be greatest versus those waste packages lying beyond the dike or conduit intersection points.

E.22.2 Top Event IG-WP-SLUMP

The IG-WP-SLUMP top event evaluates whether the waste package will remain intact (upper branch), partially slump (middle branch), or completely slump (lower branch) as a result of the high temperatures of the intruding materials.

E.22.3 Top Event IG-MAGMA-INT

The purpose of this top event is to quantify the possibility that, because of waste package breach following an intrusive igneous event, intrusive material can enter the breached waste package. The upper branch represents that magma does not intrude into the waste package upon its failure and the lower branch represents that it does.

E.22.4 Top Event IG-MAGMA-COOL

Top event “IG-MAGMA-COOL” is queried to determine whether the magma has cooled. The top branch indicates it has not and the bottom branch indicates it has.

E.22.5 Top Event IG-MAGMA-FRAC

Top event “IG-MAGMA-FRAC” is queried to determine whether the magma fractures after cooling. The top branch indicates it does not and the bottom branch indicates it does.

E.22.6 Top Event IG-MAGMA-SEEPAGE

The purpose of top event IG-MAGMA-SEEPAGE is to represent the possibility that, after the cooling and fracturing of the intrusive material, seepage returns and enters the breached waste package. The upper branch of this top event indicates that seepage does not occur and the bottom three branches indicates that seepage does occur for the lower-bound, mean and upper-bound seepage scenarios, respectively.

E.22.7 Top Event IG-FM-TRASPT

Top event “IG-FM-TRASPT” is queried to determine whether fissile material transports to the near-field. The top branch indicates it does not and the bottom branch indicates it does.

E.22.7 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of configuration. The upper branch indicates that configuration does not have a criticality potential and the lower branch indicates that it does.

E.23 DESCRIPTION OF EVENT TREE “IG-INTRUSIVE2”

The following subsections provide description of the top events of the event tree “IG-INTRUSIVE2” (Appendix B, Figure B-27). This event tree is a continuation of the evaluation of an intrusive igneous event for those waste packages not destroyed by the force of the intrusive event. This event tree consists of seven top events.

E.23.1 Top Event IG-MAGMA-COOL

The branching of top event IG-MAGMA-COOL establishes the temperature of the intrusive material. The upper branch indicates that the temperature is above 100°C. The lower branch indicates that the temperature is below 100°C. Both branches of this top event are processed for the determination of the waste package's pre- and post-cooling criticality potential.

E.23.2 Top Event IG-MAGMA-FRAC

The branching of top event IG-MAGMA-FRAC indicates whether or not the intrusive material fractures upon cooling. The upper branch of this top event indicates that no fracturing of the intrusive material occurs and the bottom branch indicates that fracturing does occur.

E.23.3 Top Event IG-SEEPAGE

The purpose of top event IG-SEEPAGE is to represent the possibility that, after the cooling and fracturing of the intrusive material, seepage returns and enters the breached waste package. The upper branch of this top event indicates that seepage does not occur and the bottom three branches indicates that seepage does occur for the lower-bound, mean and upper-bound seepage scenarios, respectively.

E.23.4 Top Event IG-BATHTUB

The purpose of top event IG-BATHTUB is to represent the possibility that, after the cooling and fracturing of the intrusive material and seepage returns and enters the breached waste package, a bathtub configuration is formed within the waste package. The upper branch of this top event indicates that a bathtub configuration does not form and the lower branch indicates that it does.

E.23.5 Top Event IG-FM-TRANSPT

The branching of top event IG-FM-TRANSPT establishes whether fissile material remains internal to the waste package or is transported external to the waste package to the near-field environment. The upper branch indicates the evaluation of fissile material remaining in the waste package. The lower branch indicates that the fissile material is transported external to the waste package.

E.23.6 Top Event WF-MISLOAD

The WF-MISLOAD top event represent the probability that a waste form was incorrectly placed into a waste packaged during the preclosure loading process.

E.23.7 Top Event CRIT-POT-WF

Quantification of the CRIT-POT-WF top event establishes the criticality potential of a given igneous configuration. Activation of the upper branch indicates that the configuration has no criticality potential and activation of the lower branch indicates that there is criticality potential.

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APPENDIX F

LISTING OF FILES ON CD-ROM

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The directory of files on the electronic media (compact disk, Appendix G) for this analysis report is given in the following table. File names, their size in bytes, and the date and time of last update as given in the directory on the originating PC hardware are listed in the table. Files identified with a ".xls" suffix are all in Excel spreadsheet format and files identified with a ".mcd" suffix are Mathcad® output files. Files in the SAPHIRE directory must be copied to a local drive unit, unzipped, and converted to a read/write status before using them with the SAPHIRE software.

EXCEL Directory

File Name	Date	Time	Size (bytes)
SAPHIRE Event Probability Files			
Probability of Seepage.xls	08/23/2004	10:22p	20,480
Probability of Seepage-R1.xls	08/21/2004	12:55p	18,944
Probability of Waste Package Filling.xls	06/19/2004	04:28p	19,456
waste package percentages.xls	06/22/2004	09:32a	29,696
endstate.xls	07/21/2004	11:45a	31,744
endstate-2.xls	09/30/2004	10:20a	31,744
per waste package type criticality probabilities.xls	08/27/2004	11:12a	27,648
probability of criticality.xls	08/27/2004	10:53a	29,184
FEP Results Binomial Distribution Files			
Binom Dist.xls	08/05/2004	08:51a	62,464
Waste Package Void Volume			
DOE long.04.xls	10/13/2004	01:22p	31,744
DOE MCO.04.xls	10/13/2004	01:22p	32,256

MATHCAD Directory

File Name	Date	Time	Size (bytes)
Probability of Seepage			
LA seepage glacTptpll collapse-seismic.mcd	10/13/2004	10:54p	300,534
LA seepage glac Tptpll weibull.mcd	10/13/2004	10:53p	300,505
LA seepage glac Tptpmn collapse-igneous.mcd	10/13/2004	11:02p	300,003
LA seepage glac Tptpmn seismic 1_2.mcd	10/13/2004	11:05p	299,981
LA seepage glac Tptpmn weibull.mcd	10/13/2004	10:24p	299,849
Waste Package Filling Probability			
Localizedcorrosion_seismic_commercial_updated.mcd	08/26/2004	08:59a	119,153
Localizedcorrosion_seismic_commercial.mcd	08/26/2004	07:22a	99,509
Fault Displacement Probability			
Fault_displacement_commercial.mcd	10/13/2004	04:47p	62,344

SAPHIRE Directory

File Name	**Date**	**Time**	**Size (bytes)**
criticality-feps-rev01c-model.zip	08/27/2004	10:18a	389,985
criticality-feps-rev01-model.zip	06/30/2004	09:34a	558,369

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