OCRWM	**DESIGN CALCULATION OR ANALYSIS COVER SHEET**	1. QA: QA 2. Page 1 of 50

3. System DOE and Commercial Waste Package	4. Document Identifier CAL-DS0-NU-000002 REV 00B
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8. Notes/Comments	

Attachments	Number of Pages
I: Configuration Generator Model Event Tree and SAPHIRE RULES	36
II: Description of Event Tree Tops	34
III: List of the Electronic Files in Attachment IV	4
IV: Compact Disk with CGM Data Files	CDROM

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. QER (Print/Sign/Date)	16. Approved/Accepted (Print/Sign)	17. Date
00A	Initial Issue Supersedes MDL-EBS-NU-000001 REV 01 ICN 01. Add DOE SNF, Igneous and External configurations and event trees. Changes are too extensive to use change bars.	124	III-4	Abdelhalim Alsaed	Cheng T. Hsu (Entire document except Attachment IV) William Galyean (Attachment IV only)	William Dockery	William Hutchins	
00B	The purpose of this revision is make editorial corrections on pages 1, 7, 9, 11, 13, 14, 15, 20, 32, 34, 35, 36, 46, 47, 48, 49, II-4, I-16, II-11, II-14, II-18, and II-33. The changed lines are marked with vertical change bars on the right side of the page. Attachment IV was copied over from previous revision (00A) but had no modifications.	124	III-4	Abdelhalim Alsaed aalsaed 11/18/04	Cheng T. Hsu ChengTsing Hsu 11/18/04	William Dockery William Dockery 18 NOV 2004	William Hutchins [signature] FOR WH	11/18/2004

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EXECUTIVE SUMMARY

The Disposal Criticality Analysis Methodology Topical Report[a] prescribes an approach to the methodology for performing postclosure criticality analyses within the monitored geologic repository at Yucca Mountain, Nevada. An essential component of the methodology is the *Configuration Generator Model for In-Package Criticality* that provides a tool to evaluate the probabilities of degraded configurations achieving a critical state. The configuration generator model is a risk-informed, performance-based process for evaluating the criticality potential of degraded configurations in the monitored geologic repository. The method uses event tree methods to define configuration classes derived from criticality scenarios and to identify configuration class characteristics (parameters, ranges, etc.). The probabilities of achieving the various configuration classes are derived in part from probability density functions for degradation parameters.

The NRC has issued *Safety Evaluation Report for Disposal Criticality Analysis Methodology Topical Report, Revision 0*[b]. That report contained 28 open items that required resolution through additional documentation. Of the 28 open items, numbers 5, 6, 9, 10, 18, and 19 were concerned with a previously proposed software approach to the configuration generator methodology and, in particular, the k_{eff} regression analysis associated with the methodology. However, the use of a k_{eff} regression analysis is not part of the current configuration generator methodology and, thus, the referenced open items are no longer considered applicable and will not be further addressed.

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

[b] Reamer, C.W. 2000. "Safety Evaluation Report for Disposal Criticality Analysis Methodology Topical Report, Revision 0." Letter from C.W. Reamer (NRC) to S.J. Brocoum (DOE/YMSCO), June 26, 2000, with enclosure. ACC: MOL.20000919.0157.

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CONTENTS

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FIGURES

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TABLES

Page

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ACRONYMS AND ABBREVIATIONS

BWR	boiling water reactor
CGC	Configuration Generator Code
CGM	Configuration Generator Model
CRWMS	Civilian Radioactive Waste Management System
CSNF	commercial spent nuclear fuel
DHLW	Defense High Level Waste
DOE	U.S. Department of Energy
DTN	data tracking number
EBS	engineered barrier system
FEPs	features, events, and processes
HLW	high-level radioactive waste
IP	inside the waste package
MCO	Multi-Canister Overpack
M&O	Management and Operating Contractor
MTHM	metric tons of heavy metal
NRC	U.S. Nuclear Regulatory Commission
OCRWM	Office of Civilian Radioactive Waste Management
PWR	pressurized water reactor
SAPHIRE	Systems Analysis Programs for Hands-on Integrated Reliability Evaluations
SCC	stress corrosion cracking
SNF	Spent Nuclear Fuel
STN	Software Tracking Number
TSPA	Total System Performance Assessment
TSbv	Topopah Spring basal vitrophyre
TSw	Topopah Spring welded hydrogeologic
YMP	Yucca Mountain Project

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1. PURPOSE

The *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003) presents an approach to the methodology for evaluating potential criticality situations in the monitored geologic repository. As stated in the referenced Topical Report, the detailed methodology for performing the disposal criticality analyses will be documented in model reports. Many of the models developed in support of the Topical Report differ from the definition of models as given in the Office of Civilian Radioactive Waste Management (OCRWM) procedure AP-SIII.10Q, *Models*, in that they are procedural, rather than mathematical. These model reports document the detailed methodology necessary to implement the approach presented in the *Disposal Criticality Analysis Methodology Topical Report* and provide calculations utilizing the methodology. Thus, the governing procedure for this type of report is AP-3.12Q, *Design Calculations and Analyses*. The *Configuration Generator Model* is of this latter type, providing a procedure to evaluate the probability of achieving potentially critical in-package and external configurations.

An overview of the approach to the methodology for evaluating potential criticality situations in the monitored geologic repository from the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003) is provided in Figure 1-1 that illustrates the flow process of the major analysis components. Figure 1-1 shows the input required for the methodology as well as the decision points that include tests against performance and design criteria imposed on the methodology. These criteria are intended to ensure sufficient measures are implemented to satisfy the 10 CFR Part 63 acceptance criteria applicable to the postclosure performance assessment for the Yucca Mountain site (Section 4.2). These measures include examining the significant factors contributing to the probability of criticality in the repository and implementing additional criticality consequence analyses or design enhancements to reduce the overall criticality risk if the respective criteria are exceeded.

The configuration generator model (CGM) can be used to identify configuration classes for the various waste forms expected for disposal in the proposed monitored geologic repository that have potential for criticality and to evaluate their probability of criticality. The CGM is an integral part of the disposal criticality analysis methodology (Figure 1-1) where the CGM components are indicated by shaded blocks. The CGM will not provide direct input to the total system performance assessment (TSPA) but, rather, it is used to evaluate the overall probability of criticality for the repository based upon the probabilities of potentially critical configuration classes. These latter classes may require additional criticality consequence assessments depending on the calculated total probability of criticality. Any such criticality consequence results would, in turn, be input to the total system performance assessment for the license application (YMP 2003, Section 3.8).

The scope of this analysis is to document the process for evaluating the overall probability of criticality for the monitored geologic repository. The CGM provides a systematic process to address the standard criticality scenarios (identified in the *Disposal Criticality Analysis Methodology Topical Report* [YMP 2003, Section 3.3]) having the potential to increase the reactivity of the in-package system and the parameters associated with these identified scenarios. The approach is to use an event tree method to define end states of configuration classes derived from criticality scenarios. Note that multiple configuration classes can result from a criticality scenario. Furthermore, the event tree structure is flexible, permitting the event trees to be tailored to specific requirements. The probabilities of achieving the various configuration classes are derived in part from probability density functions for the configuration parameters. A configuration class is considered to have *potential for criticality* if the probability of achieving the class does not satisfy the probability screening criterion as shown in Figure 1-1. The *probability of criticality*, derived from the probability values of the configuration class parameters, is evaluated only for classes that exceed the criticality potential criterion, i.e., have a k_{eff} range exceeding the critical limit for the waste form.

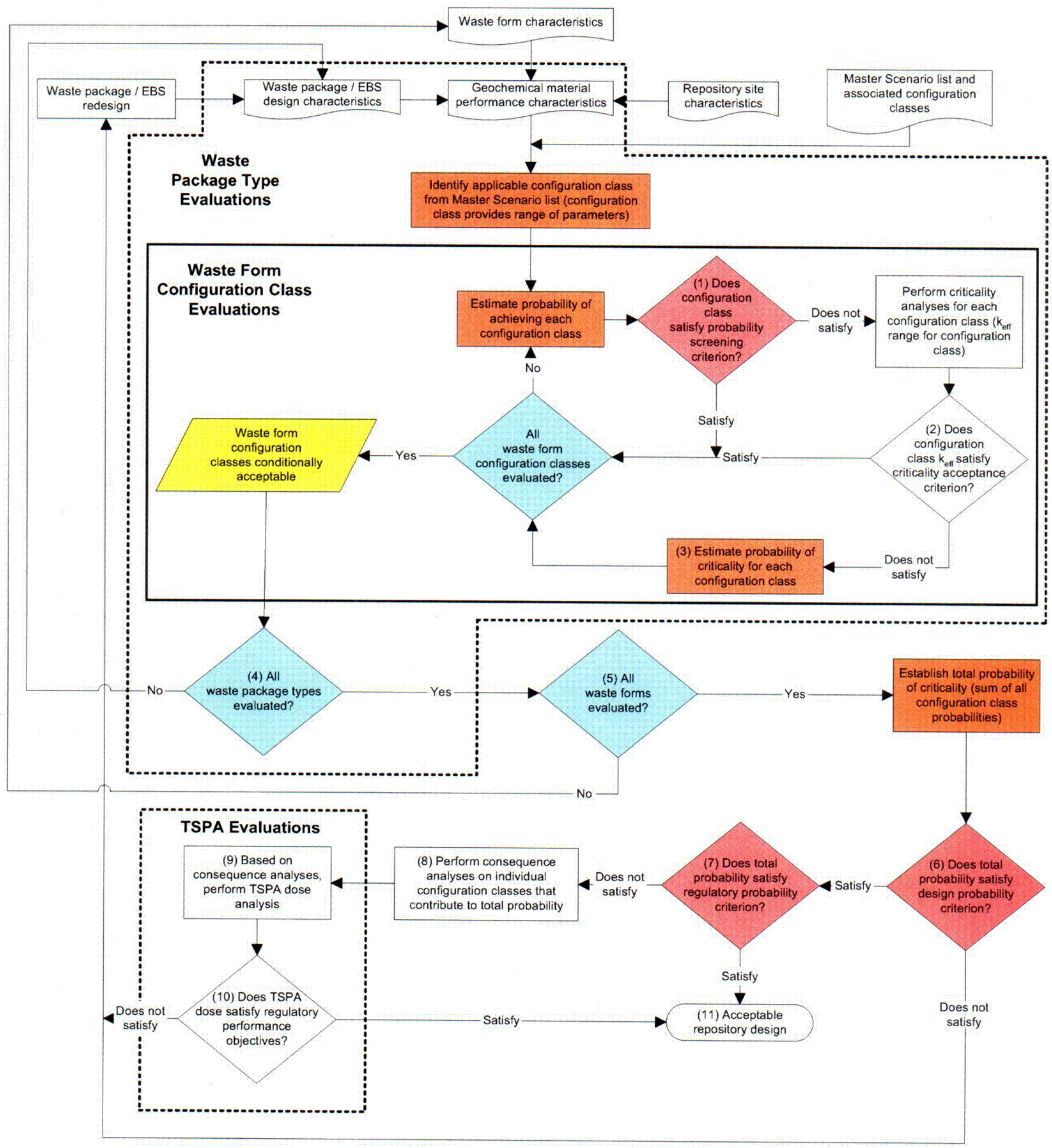

Figure 1-1. Overview of Approach to the Disposal Criticality Analysis Methodology

The purpose of the CGM can be summarized as follows:

- Identify the various possible sequences of top events required for the development of event trees and their various end states for configuration classes
- Provide configuration classes and their associated parameter ranges to the criticality model to identify configuration classes with potential for criticality.

Limitations of the configuration generator model include the requirement that probability density functions be specified for the set of basic parameters that are themselves derived from abstractions.

The NRC has issued *Safety Evaluation Report for Disposal Criticality Analysis Methodology Topical Report, Revision 0* (Reamer 2000). That report contained 28 open items (Reamer 2000, pp. 77 to 79) that required resolution through additional documentation. The strategy for resolution of these open items included, but was not restricted to, the development of model reports (such as the CGM report) that addressed open item issues. In particular, Open Items 5, 6, 9, 10, 18, and 19 were concerned with a previously proposed software approach to the configuration generator methodology and, in particular, the k_{eff} regression analysis associated with the methodology (Section 6.1). However, the use of a k_{eff} regression analysis is not part of the current configuration generator and, thus, the referenced open items are no longer considered applicable and will not be further addressed.

The development of this analysis is consistent with the specifications included in *Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002* (BSC 2004a).

2. QUALITY ASSURANCE

Development of this analysis and the supporting activities have been determined to be subject to the Yucca Mountain Project's quality assurance program in Section 8 of *Technical Work Plan for: Criticality Department Work Packages ACRM01 and NSN002* (BSC 2004a). Approved quality assurance procedures identified in the technical work plan (BSC 2004a, Section 4) have been used to conduct and document the activities described in this analysis. The technical work plan also identifies the methods used to control the electronic management of data (BSC 2004a, Section 8) during the analysis and documentation activities.

3. USE OF SOFTWARE

The software used in the analysis includes SAPHIRE.

3.1 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 (SAPHIRE V7.18, STN: 10325-7.18-00) was used to develop and quantify event 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 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 as a result of the use of this software.

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

4. INPUTS

4.1 INPUT DATA AND PARAMETERS

The configuration generator model is a systematic process for identifying configurations that have potential for criticality in the postclosure period of the repository and for estimating the probability of occurrence for such identified configurations. The CGM addresses the standard criticality scenarios, identified in Sections 6.2.2 and 6.2.3, as having the potential to increase the reactivity of the in-package and external configurations. The analysis provides a systematic process to evaluate the outcome of the various scenarios. The input for the process is criticality scenarios as listed in Table 4-1.

Table 4-1. Scenario Input Source

Scenarios and Top Events	Input	Section Used in	Reference Document
Degradation scenarios IP-1 – IP-6, NF-1 – NF-5 FF-1 – FF-5	Scenarios leading to in-package criticality	6.2.2	*Disposal Criticality Analysis Methodology Topical Report* (YMP 2003)
	Scenarios leading to external criticality	6.2.3	
	Generic degradation configuration classes	6.2.3.2	

4.2 CRITERIA

The acceptance criteria applicable to the Yucca Mountain site are identified in the requirements for postclosure performance assessment specified in the NRC rule 10 CFR Part 63. The following requirements extracted from 10 CFR Part 63 are applicable to the development of this CGM analysis:

- "...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 on radionuclide sorption; potentially adverse effects of fracture flow or a criticality event)..." (10 CFR 63.102(j))

- "The engineered barrier system must be designed so that, working in combination with natural barriers, radiological exposures to the reasonably maximally exposed individual are within the limits specified at §63.311 of subpart L of this part. Compliance with this paragraph must be demonstrated through a performance assessment that meets the requirements specified at §63.114 of this subpart..." (10 CFR 63.113(b))
- "Account for uncertainties and variabilities in parameter values and provide for the technical basis for parameter ranges, probability distributions, or bounding values used in the performance assessment." (10 CFR 63.114(b))
- "Consider only events that have at least one chance in 10,000 of occurring over 10,000 years." (10 CFR 63.114(d)).

4.3 CODES AND STANDARDS

The following code was used to develop criteria for the Configuration Generator Model:

> 10 CFR 63. *Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada.*

5. ASSUMPTIONS

None.

6. METHODOLOGY

The waste packages in the monitored geologic repository can, over time, undergo various degradation processes. These processes have major effects on the isotopic content and spatial distribution of the waste form within the waste packages as well as for the waste packages themselves. Potential effects of the degradation processes are separation of neutron absorbers from fissile material and rearrangement of the degraded waste package components into a (possibly) more reactive geometry that may increase the chance for criticality. Another potential effect of waste degradation is releasing the fissile material from the waste package in solution and reconcentrating it in the invert or the far field into a (possibly) more reactive geometry that may increase the chance for criticality. Note that a critical system for the repository is defined as one having an effective neutron multiplication factor, k_{eff}, larger than the critical limit (YMP 2003, Subsection 3.2.1). The critical limit is the value of k_{eff} at which a system configuration is considered potentially critical as characterized by statistical tolerance limits. The methodology for evaluating waste form-dependent critical limit values has been documented in *Criticality Model* (BSC 2004b) that is part of the analysis methodology.

The degradation processes of interest for criticality are related to a combination of features, events, and processes (FEPs) that result in configurations that have the potential for criticality requiring further evaluation of this potential. Generic degradation scenarios and potential critical configuration classes have been identified in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.3) by considering the features of the site and the characteristics of the waste form and other waste package internal components. Potential critical configuration classes are states of a degraded waste package defined by a set of parameters characterizing the quantity and physical arrangement of the materials that have a significant effect on criticality. There are various uncertainties associated with these parameters depending on the particular scenario sequences that result in degraded configurations. These uncertainties need to be accounted for in the criticality evaluations.

An important component of the approach in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003) shown in Figure 1-1 is a process for identifying degraded configurations and evaluating the probability of these configurations achieving a critical state. In order to address parameter uncertainty, analyses will use an approach that is part of a risk-informed methodology to evaluate the range and physical arrangement of parameters associated with waste package configurations. The method uses event trees to define configuration class characteristics (e.g., range of parameters) associated with the various end states. Since the probability functions required for analyses with this process will normally have upper and lower bounds, sensitivity studies provide a means to evaluate the effects of these bounds on analysis results. An overview of the CGM is given in this section with a detailed description of the process provided in Sections 6.2 through 6.4 and Attachments I and II.

The CGM methodology is a probability based analysis tool that, in accordance with the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003), specifies use of such methodology to demonstrate how the potential for postclosure criticality will be evaluated. The use of risk-informed, performance-based analyses in regulatory matters is likewise consistent with the U.S. Nuclear Regulatory Commission (NRC) policy statement "Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities" (60 FR 42622).

The CGM is a consistent methodology to follow and document in-package and external criticality scenarios through possible degradation sequences to identify potential critical configurations and to provide the basis for evaluating the probability of achieving any such configurations. These processes and their connections with the overall methodology (Figure 1-1) are illustrated in more detail in Figure 6-1. The CGM provides a systematic process to address the standard degradation scenarios, identified in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.3), as having the potential to increase the reactivity of the in-package or external system, and the parameters associated with potentially critical waste package and external configuration classes. The approach is to use event tree method to define end states of the possible configuration classes. The probabilities of the end states that have potential for criticality are derived from the evaluation of probability density functions for degradation parameters and probability values.

In order to determine what parameters are required for the CGM, the various degradation sequences of a configuration class need to be established which is accomplished through a graphical representation in the form of an event tree structure. The event tree representation provides the processes and sequences required to achieve the configuration classes discussed in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figures 3-2a and 3-

2b). These processes are time dependent, which must be considered when performing analyses to evaluate both the criticality potential and probability of criticality. All of the intermediate and end-state configurations identified in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.3) and "believed to be comprehensive with respect to the spectrum of scenarios that might occur in the repository and might affect criticality risk" (YMP 2003, Section 3.1) are addressed in the event tree.

The CGM event tree lists the different waste forms that are expected for disposal in the monitored geologic repository. Waste forms described in this report refer to high-level radioactive waste and spent nuclear fuel[1]. The procedure for generating the configurations using the CGM event tree is partially waste form independent. However during an analysis, the waste form type must be defined for bookkeeping purposes and to determine the configuration class parameter ranges for criticality evaluations if a configuration class cannot be screened out on the basis of a low probability of occurrence. The CGM event tree provides the basis for identifying the degraded configuration parameters and provides assistance in the probability calculation.

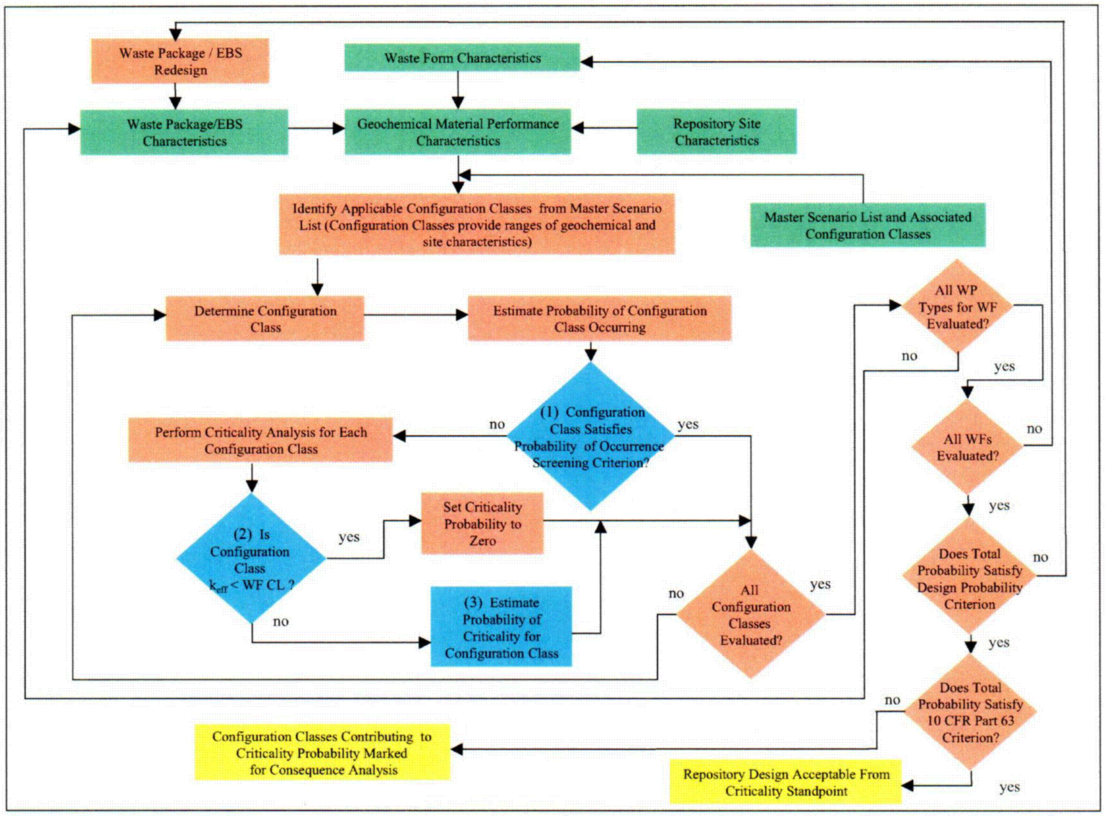

Figure 6-1. Block Diagram of the Configuration Generator Process

[1] The process described in this report will be applied to commercial SNF (including PWR, BWR, and mixed oxide fuels), DOE SNF (including degraded Naval Nuclear Propulsion Program SNF outside the waste package), and vitrified HLW. The methodology used to address intact Naval Nuclear Propulsion Program SNF and degraded naval SNF within the waste package is described in NNPP's Technical Support Document for the License Application (McKenzie 2004).

C02

Preclosure events that can adversely impact postclosure criticality evaluations are included in the event tree models. These events are limited to mechanisms contributing to early waste package failures (e.g., improper heat treatment), early drip shield failures (e.g., emplacement errors), and waste package misloads. These events result from undetected situations during the preclosure period.

The CGM, illustrated in Figure 6-1, uses two screening levels in determining the total probability of criticality of the repository to minimize calculations. The first screening level [box (1), Figure 6-1] tests the estimated probability of occurrence for a configuration class (evaluated over all end states) against a probability screening criterion. This criterion is set well below the 10 CFR 63.114(d) criterion of one chance in 10,000 of an event occurring over 10,000 years (Section 4.2). If the probability of occurrence for the class is below the probability screening level, then no criticality evaluation is performed for this configuration class and the probability of potential criticality for the configuration class is set to zero. The second screening level [box (2)] tests the criticality potential criterion for those configuration classes where the estimated probability of occurrence exceeds the probability screening criterion. The criticality potential of the configuration classes, which includes the uncertainty in the requisite parameters, is evaluated using the CGM to determine the range of parameters and the *Criticality Model* (BSC 2004b) to determine the k_{eff} range for the classes. If the k_{eff} from the criticality analysis is less than the critical limit over the range of parameters for the configuration class (criticality potential criterion), then the probability of criticality for the class is set to zero. However, if the criticality analysis shows that the criticality potential criterion is exceeded over some range of the configuration class parameters, then an evaluation of the probability of criticality [box (3)] is performed. This evaluation is a detailed analysis of the probability of criticality of the waste form configuration class utilizing the probability values for the range of waste form parameters required to obtain a k_{eff} greater than the critical limit.

All of the configuration classes identified for the waste form are evaluated using the two screening levels. This process is continued until the waste package and waste form configuration classes have all been analyzed. Since configuration classes are mutually exclusive entities, the probabilities from all the configuration classes that have potential for criticality are summed to obtain the total probability of criticality for the repository. This total probability is compared to the 10 CFR 63.114(d) criterion (Section 4.2)[2]. If the total probability of criticality is less than that criterion, then the repository design is acceptable with respect to criticality concerns. However, if the total probability is above the 10 CFR Part 63 criterion, then all of the waste package and waste form configuration classes that contributed to the total criticality probability are marked for consequence analysis with results to be included in the TSPA as appropriate.

The potential for criticality is based on the configuration class waste form parameters and waste package internal parameters. The probability of achieving a critical configuration class is based on the probabilities and the probability density functions for the independent variables associated with the configuration class. A detailed description of the CGM process and event tree is

[2] The total probability of all analyzed waste forms is also checked against the design probability criterion (Figure I-1), and if the total probability is above the design probability criterion of 10^{-4}, then implementation of criticality mitigation strategies would be necessary.

provided in the Sections 6.2 through 6.4 and Attachments I and II of this report. The sections are summarized as follows:

- Section 6.1 addresses an alternate model proposed in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2000).
- Section 6.2 discusses internal waste package and external criticality and degradation scenarios.
- Section 6.3 discusses the mathematical concepts of probability used in the CGM.
- Section 6.4 discusses information required to perform analyses using the CGM.

6.1 ALTERNATIVE SOFTWARE BASED MODEL TO THE PROCESS BASED MODEL

A proposed outline for a Configuration Generator Code (CGC), an alternative approach given in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2000) for evaluating the probability of criticality of waste forms, was based upon both deterministic and probabilistic methods. Coupled differential equations for tracking isotopic concentrations were proposed as the deterministic method and Monte Carlo sampling was proposed as the probabilistic method. The CGM uses an event tree methodology coupled with probability density functions for parameters to evaluate the probability of criticality. Differences between the CGC and CGM are primarily in the approach to the computational task. The proposed CGC model from the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2000) is described as follows:

> ..."Deterministic analyses are used to evaluate the various long-term processes, the combination of events, and any potential criticality. Similarly, the analysis of any potential consequence resulting from a criticality (e.g., increase in radionuclide inventory) is a deterministic analysis. However, it is not possible to state with certainty what will actually happen, which events will occur, and what actual values the parameters will have, so the individual deterministic calculations must be applied in a probabilistic context. In addition, the potential for criticality is related to various processes and events that take place over long periods and have associated uncertainties that must be considered. Therefore, establishing the likelihood of a criticality occurring involves probabilistic analysis. Hence, the disposal criticality analysis methodology is a blend of deterministic and probabilistic aspects." (YMP 2000, Section 1.1).
>
> "...The purpose for the CGC is to track the concentrations (or amounts) of neutronically significant isotopes (either fissionable or neutron absorbing) and chemical species which can effect the solubility of the neutronically significant elements. The concentrations, or amounts, are tracked by time-dependent first-order differential equations, which are solved by numerical integration. Some of these differential equations represent chemical transformations of elements or compounds. These equations form heuristic model(s) with

coefficients determined by fitting data from the detailed EQ3/6 geochemistry calculations..."

"...the CGC will generally be used for two purposes: (1) to provide bookkeeping for the transport between sites of application of EQ3/6, such as the interior of the waste package where the source term for external criticality is generated, and the external location where a chemistry change might cause significant precipitation, as may be determined by PHREEQC; (2) to provide more rapid calculation of Monte Carlo statistics in situations where the EQ3/6 and PHREEQC results can be used to develop heuristic models for the few most significant ions for a few solution parameters, such as pH..." (YMP 2000, Subsection 3.6.3.3).

The Monte Carlo approach in the CGC would allow random sampling from the input parameters for different degradation processes until some end time was reached. The sampling process results in parameter sets that are input to a criticality evaluation performed to determine the k_{eff} of the sets. The CGC would then continue this process until all configurations had been evaluated up to the termination time. The outcome from the CGC would be a multidimensional surface for k_{eff} as a function of the parameter space variables. The CGC would finally calculate the average criticality probability by dividing the number of critical realizations by the total number of realizations (YMP 1998, p. 4-36).

The CGC model as proposed in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2000) was a single-probability model contained within a software system and assumed to be amenable to numerical integration. Furthermore, the CGC model did not provide a method for determining the probability of any particular critical configuration.

A review of the proposed CGC method for performing the probability calculations indicated that there was an opportunity to improve the manner in which the process handled parameter probabilities and uncertainties. The CGM provides a traceable set of sequences to end-states in each configuration class and identifiable probability and uncertainty values for parameters through the event trees. In addition, the use of event tree logical structures minimizes the computational complexity of the model.

6.2 CRITICALITY SCENARIOS

The Master Scenario List and the companion flow charts presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.3) provide the basis for identifying the degradation processes that define the different degraded configuration classes (defined in Subsections 6.3.2 and 6.3.3). An event tree process, created from the Master Scenario List and flow charts, defines the processes and sequences that lead to the different degraded configuration class end states. The degraded configuration classes identified by the event tree process are evaluated for criticality potential and, if necessary, for the probability of criticality. The evaluations are specific to the waste form and waste package type. The top events of the event tree represent the degradation processes that are required to obtain the different configuration classes.

The degradation processes of interest for criticality are related to a combination of FEPs that result in configurations that have the potential for criticality. 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 2004d, Sections 2.4, 3, and 4) describing the TSPA-LA FEP identification and screening process that led to the development of the LA FEP List documented in DTN: MO0405SEPFEPS6.000. Changes in the FEP list, FEP names, and FEP descriptions can also be traced through that report. The criticality FEPs addressed in this report are a subset of the revised LA FEP List. These FEPs are listed in Table 6-1, including the designation of shared FEPs.

Table 6-1. 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. A breach (or breaches) in the waste package allow(s) water to either accumulate or flow-through the waste package. Criticality then occurs 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 degrade. A critical configuration (sufficient fissile material and neutron moderator, lack of neutron absorbers) develops and criticality occurs 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). In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.1.14.17.0A	Near-field criticality	Near-field criticality occurs when 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). In-package criticality resulting from disruptive events is addressed in separate FEPs.
2.2.14.09.0A	Far-field criticality	Far-field criticality occurs when 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). 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. A breach (or breaches) in the waste package allow(s) water to either accumulate or flow-through the waste package. Criticality then occurs 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 degrade. A critical configuration develops and criticality occurs 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).
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 occurs when 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).
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 occurs when 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).

Table 6-1. Criticality FEPs List to be Utilized in Criticality Screening Analysis (Cont.)

FEP Number	FEP Name	FEP Description
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. A breach (or breaches) in the waste package allow(s) water to either accumulate or flow-through the waste package. Criticality then occurs 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 degrade. A critical configuration develops and criticality occurs 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).
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 occurs when 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).
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 occurs when 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).
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. A breach (or breaches) in the waste package allow(s) water to either accumulate or flow-through the waste package. Criticality then occurs 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 degrade. A critical configuration develops and criticality occurs 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).
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 occurs when 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).
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 occurs when 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).

Source: DTN: MO0405SEPFEPS6.000

6.2.1 Degradation Configuration Definition

Degradation scenarios are related to a combination of FEPs that result in degraded configuration classes to be evaluated for potential criticality. In particular, features may affect the configuration parameters and thereby influence the outcome of the criticality analyses. The principal examples of features applicable to internal criticality analyses are faults that may focus or block the flow of groundwater, thereby affecting the drip rate onto waste packages. Processes are natural or anthropogenic phenomena that have potential to affect a disposal system performance and that operate during all or a significant part of the period of performance. Examples of processes include groundwater flow, corrosion, and precipitation. Events are similar to processes but operate during an interval that is short compared to the period of performance. Examples of events would be a rockfall onto a waste package or a seismic event, either of which could potentially cause the waste package basket to collapse.

A configuration is defined by a set of parameters characterizing the quantity and physical arrangement of materials at a specific location that have a significant effect on criticality (e.g., fissile materials, neutron absorbing materials, reflecting materials, and moderators). The numerous possible configurations are best understood by grouping them into classes. A configuration class is a set of similar configurations whose composition and geometry are defined by specific parameters that distinguish one class from another. Within a class, the configuration parameters may vary over a given range. The in-package configuration classes are discussed in Section 6.2.2. The external configuration classes are discussed in Section 6.2.3.

6.2.2 In-Package Criticality

The internal degradation scenarios identified in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.3) are the basis for deriving the different configuration classes that are related to the consequences of criticality FEPs (Table 6-1) that affect the contents of the waste package. The activities from these FEPs that most directly impact the potential for internal criticality include:

- Rearrangements to a more reactive geometry
- Accumulation/retention of moderator and reflector
- Separation of neutron absorbers from fissile material
- Changes of moderator and reflector.

6.2.2.1 Internal Criticality Master Scenarios

Tracing through the Master Scenario List, six degradation scenario groups internal to the waste package [designated as (IP) - inside the waste package] are identified that have potential for criticality. The six groups are IP-1 through IP-6 (YMP 2003, Section 3.3). The CGM event tree, based on the Master Scenario List, generates all of the various possible sequences of top events that comprise the six in-package degradation scenario groups. These degradation scenarios are dependent on the degradation processes and degradation rates for the waste package and the components inside the waste package, including the waste forms.

Groups IP-1, IP-2, and IP-3 are associated with degradation scenarios representing a bathtub configuration. A bathtub configuration is defined as one having a breach near the top of the waste package allowing the in-flux of water through a breached drip shield to collect and pool in the waste package. Any out-flux of water and degradation products occur through the waste package breach at the same elevation as the breach. This is a conservative approach for internal waste package criticality evaluations; however, for evaluations of other types of waste package events (e.g., external radionuclide accumulation), use of the bathtub geometry may not be a conservative approach. Degradation scenario groups IP-1, IP-2, or IP-3 are described as configurations where the waste form either degrades slower than, equal to, or faster than that of the other internal components, respectively.

Degradation scenario groups IP-4, IP-5, and IP-6 represent flow-through configurations. A flow-through configuration is defined as one having a breach in the waste package bottom either before or after a breach of the top section of the waste package. Consequently, there is no flooding inside the waste package. Flow-through geometry can be obtained from two different event sequences:

1. The bottom of the waste package can breach prior to the top of the waste package.

2. Degradation processes from IP-1 to IP-3 start and then the bottom of the waste package breaches.

Configurations belonging to degradation scenario groups IP-4 through IP-6 would require hydration of degraded waste package components to achieve criticality. Silica may provide some neutron moderation but the critical mass with silica as the only moderator exceeds the fissile loading of a waste package, thus excluding an internal waste package criticality on that basis.

The following descriptions provide additional information about the six in-package degradation scenario groups and configuration classes:

IP-1 Waste form degrades faster than other internal components inside the waste package. Possible generic configuration classes in this scenario include:

(a) Waste form degrades in place and non-soluble neutron absorber remains in place (IP-1a).

(b) Degraded waste form is mobilized and separated from non-soluble neutron absorbers that remain in place (IP-1b).

IP-2 Waste form degrades at the same rate as the other internal components inside the waste package. The possible generic configuration classes in this scenario include:

(a) Degraded waste form and internal components collect at the bottom of waste package and soluble neutron absorbers flushed from waste package (IP-2a).

IP-3 Waste form degrades slower than the other internal components inside the waste package. There are four possible generic configuration classes for this scenario that include:

(a) Carbon steel basket structural supports mechanically collapse, allowing separation of the waste form and neutron absorber that remains in place (IP-3a).

(b) After basket structures collapse, waste form and insoluble degradation products stratified at the bottom of the waste package with soluble neutron absorbers from the degraded portion of structure flushed from the waste package (IP-3b).

(c) Structures containing neutron absorbers fully degrade with stratified waste form and degradation products. Soluble neutron absorbers flushed from waste package (IP-3c).

(d) Significant neutron absorber degradation before structural collapse occurs (IP–3d).

IP-4 Waste form degrades faster than other internal components inside the waste package and the waste package has a flow-through geometry. Possible generic configuration classes for this scenario include:

(a) Waste form degrades in place and degradation products hydrate in initial location (IP–4a).

(b) Degraded waste form is mobilized and separates from the neutron absorber that remains in the initial location. Degradation products are hydrated (IP-4b).

IP-5 Waste form degrades at the same rate as the other internal components inside the waste package. Possible generic configuration classes for this scenario include hydrated waste forms and internal components collecting at the bottom of waste package while flow-through flushing removes soluble neutron absorbers (IP-5a).

IP-6 Waste form degrades slower than the other internal components. Possible generic configuration classes for this scenario include structures containing neutron absorbers fully degrade and the flow-through geometry flush soluble neutron absorbers from the waste package. This scenario also has the waste form collecting on the bottom of the waste package mixed with hydrated corrosion products from waste package internal components (IP-6a).

6.2.2.2 Generic In-Package Degradation Configuration Classes

As stated previously, a configuration class is a set of similar configurations whose composition and geometry are defined by specific parameters that distinguish one class from another. The following paragraphs list and discuss the configuration classes resulting from the standard scenarios presented previously that have potential for criticality with emphasis on their end states

(YMP 2003, Subsection 3.3.1). The configuration classes are intended to comprehensively represent the configurations that can result from physically realizable scenarios, are generic to the waste form, and waste package type.

Configuration class IP-1a: For this configuration class, the fissile material separates from the neutron absorber, which remains in place within the waste package. This configuration class can be reached from the standard scenario IP-1 where the waste form degrades faster than waste package internal structures. In this configuration class, the neutron absorber is not released from its carrier before the waste form degrades and the fissionable material degrades in place. Configuration class IP-1a has potential for criticality only if there is sufficient moderator to permit criticality of the fissile material.

Configuration class IP-1b: This configuration class considers the mobilization of the degraded waste form and its separation from the neutron absorber. The mobilized fissionable material accumulates at the bottom of the waste package. A mechanism to mobilize the degraded waste form is needed. Configuration class IP-1b has potential for criticality only if there is sufficient water present with separation of fissile material from neutron absorber material to permit criticality of the fissile material accumulated at the bottom of the waste package.

Configuration Class IP-2a: Both basket and waste form have degraded to be in this configuration class. The corrosion product composition is a mixture of fissile material and degradation products from internal structures. It is more complex than for degradation scenario IP-3, and is characterized by geochemistry calculations. This configuration class is most directly reached from the standard degradation scenario IP-2, in which all the waste package components degrade at the same time. However, eventually the standard scenarios IP-1 and IP-3, in which the waste form degrades before or after the other components, respectively, can lead to this configuration class when the latter scenario catches up with the former.

The configuration class IP-2a has potential for criticality if the soluble neutron absorber is flushed from the waste package. Solubility of a substance depends on pH, Eh (the electrode potential [in volts] with respect to the standard hydrogen electrode), dissolved species levels, and ionic strength. The quantity of degradation products and the remaining soluble neutron absorber inside the waste package barrier is evaluated as a function of time. The configuration class has potential for criticality only if there is sufficient moderating water with loss of absorber material to permit criticality of the fissile material accumulated at the waste package bottom.

Configuration Class IP-3a: This configuration class has the waste package internal basket degrading but waste form remains relatively intact at the bottom of the waste package surrounded by, and/or beneath, the basket corrosion products. This configuration class has potential for criticality only if the basket structural supports mechanically collapse due to degradation, while the absorber plates and the waste form remain intact. The mechanical collapse of the basket structural support permits geometric rearrangement of the waste form reducing the neutron leakage.

Configuration Class IP-3b: This configuration class has the waste package internal basket structures collapsing with the waste form and degradation corrosion products stratified. Neutron absorbers are flushed from the waste package. This configuration class has potential for criticality only by complete basket structure support degradation and partial neutron absorber degradation.

Configuration Class IP-3c: This configuration is characterized by the complete degradation of the basket structure support and neutron absorber plates. The soluble neutron absorber is flushed from the waste package. Two sequences that lead to this configuration class apply to the waste package design in which either the basket structural support degrades prior to the neutron absorber plates or the neutron absorber plates degrade prior to the waste package internal structures.

Configuration Class IP-3d: The neutron absorbing structure degrades significantly before structural collapse occurs. The absorber separates from the waste form and remains inside the waste package. The waste form and waste package internal structures maintain their integrity.

Configuration Class IP-4a: Fissile material degrades in place faster than the waste package internal structures in a flow through geometry and moves away from the neutron absorber, which remains in the waste package. In this configuration class, the waste form degrades prior to the neutron absorber being released from its carrier. The degraded material hydrates and collects in its initial location. Configuration class IP-4a has potential for criticality only if there is sufficient hydration of the degradation products to permit criticality of the fissile material.

Configuration Class IP-4b: This configuration class considers the mobilization of the degraded waste form and its separation from the neutron absorber. The mobilized fissionable material hydrates and collects with other hydrated corrosion products and most likely accumulates at the waste package bottom. A mechanism to mobilize the degraded waste form is needed. Configuration class IP-4b has potential for criticality only if the hydrated waste form mobilizes in order for it to separate from the neutron absorbing material.

Configuration Class IP-5a: In this configuration class, both the waste package basket and waste form have degraded at similar rates. This configuration class can also be obtained from degradation scenarios IP-1 or IP-3. IP-1 has the waste form degrading faster than basket and IP–3 has the basket degrading faster than waste form, but ultimately both waste form and other internal components degrade and accumulate on the bottom of the waste package. This configuration class can be reached from the IP-5 standard scenarios (i.e., flow-through geometry occurring either prior to or after both waste form and basket degrade and hydrated products collect on the bottom of waste package).

Configuration class IP-5a has potential for criticality if the soluble neutron absorber is flushed from the waste package and there is sufficient hydration of the degradation products to permit criticality of the fissile material. Solubility of a substance depends on pH, Eh (the electrode potential [in volts] with respect to the standard hydrogen electrode), dissolved species levels, and ionic strength.

Configuration Class IP-6a: In this configuration class, the waste package internal basket degrades faster than the waste form. The waste form is relatively intact and sitting at the bottom of the waste package surrounded by, and/or beneath, the basket corrosion products. This configuration class is also obtained from degradation scenario IP-3 where the neutron absorber and waste package basket structure have significantly degraded before the waste package bottom failure. This configuration has potential for criticality only if the basket structural supports mechanically collapse due to degradation, the neutron absorber is flushed from waste package, and there is sufficient hydration of the insoluble degradation products to permit criticality of the fissile material.

6.2.2.3 Parameters Associated with Potential Critical Configurations

The k_{eff} of a nuclear system is a complex function of neutron production, moderation, absorption, and leakage for the system being analyzed. The contents inside a degraded waste package and the relative positioning of those contents continuously change under the degrading factors of drift environments; therefore, there is a large number of possible configurations. However, based on the features of the repository and the characteristics of waste package contents, a finite number of configuration classes has been deemed to have potential for criticality (YMP 2003, Section 3.3). These configuration classes have been presented in Subsection 6.2.2.2. The configuration classes identify states of a degraded waste package that could attain criticality, thus reducing the range for some of the parameters associated with criticality.

Variables that affect k_{eff} for a degraded waste package are the isotopic and elemental contents, volume of moderator, and geometry of the system components. These parameters are based on the waste form and waste package internal structure and materials and are discussed in the next subsections.

The different waste package types have the same characteristics with respect to the outer barrier. The waste package barrier design features two shells, an inner shell of stainless steel for structural strength and an outer shell of Alloy 22 for corrosion resistance. The differences among the waste packages, aside from the contained waste forms, are the different variants on the design of the inner basket structure. The different waste package types are identified in Table 6-2.

Table 6-2. Breakdown of 70,000 MTHM Emplacement Inventory by Waste Package Type

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

Source: [a] *D&E/PA/C IED Typical Waste Package Components Assembly* (BSC 2004c, Table 11)
[b] *Packaging Strategies for Criticality Safety for 'Other' DOE Fuels in the Repository* (DOE 2004, Table A-2)
The number of DOE waste packages given in BSC 2004c (Table 11) is superceded by DOE 2004 (Table A-2).

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-S – Naval Short waste package type
[s] 5-DHLW/DOE Short waste package type
[t] 5-DHLW/DOE Long waste package type
[u] 2-MCO/2-DHLW waste package type
[v] NNPP-L – Naval Long waste package type

The CSNF waste package group is comprised of the following: 21-PWR with Absorber Plates, 21-PWR with Control Rods, 12-PWR, 44-BWR, and 24-BWR. An isometric view representative of the 21-PWR with Absorber Plates Waste Package (with internal basket) is shown in Figure 6-2.

The waste package inner basket structure for the CSNF contains interlocking plates that delimit the locations for assembly loading. There are three types of plates in the intact waste package design for CSNF, each having a different function. Plates made of carbon steel serve as structural support for assemblies. A second type of plate made of aluminum alloy serves as a thermal conductive medium from the assemblies to the waste package outer barrier in design variants for high thermal output. The third type of plate made of B932-04 (Ni-Gd) Alloy used for criticality control in the 21-PWR with Absorber Plates Waste Packages. The 21-PWR with Control Rods Waste Package design variant for PWR CSNF having a high assembly k_{∞} uses zirconium clad boron carbide (B_4C) control rods for reactivity control in place of the absorber plates (CRWMS M&O 1997, Subsection 7.3.2). The waste package internal structure for this latter design variant also contains fuel basket tubes and side guide plates made of carbon steel that are similar to the 21-PWR with Absorber Plates Waste Package (BSC2004g, Section 5.2).

The DOE waste package group is comprised of the following: 5 DHLW/DOE SNF-SHORT, 5 DHLW/DOE SNF-LONG, and 2-MCO/2-DHLW waste packages. The basket structure for the 5 DHLW/DOE SNF-SHORT and 5 DHLW/DOE SNF-LONG waste packages is a web device to be constructed of carbon steel and divided into six separate compartments, five on the periphery and one in the center. The five compartments on the periphery are intended to contain the HLW canisters while the center tube is for the DOE SNF waste form canister. An isometric view representative of a 5 DHLW/DOE SNF waste package with six compartments is shown in Figure 6-4. The long and short design variants are similar except for their length. Another variant on the design of the DOE waste packages, designated as 2-MCO/2-DHLW, has the basket structure divided into four separate compartments. The 2–MCO/2-DHLW waste package is intended to contain two multi-canister overpacks and two defense high-level radioactive waste glass canisters (BSC 2004f, Section 5.2).

The parameters for the different variants of the waste package design and the parameters associated with criticality for the different waste forms can be obtained from many YMP sources. Various YMP reports define the physical characteristics of the waste form along with how the waste form is loaded into its respective waste package type. Figures 6-3 and 6-4 show the various waste forms and waste package configurations.

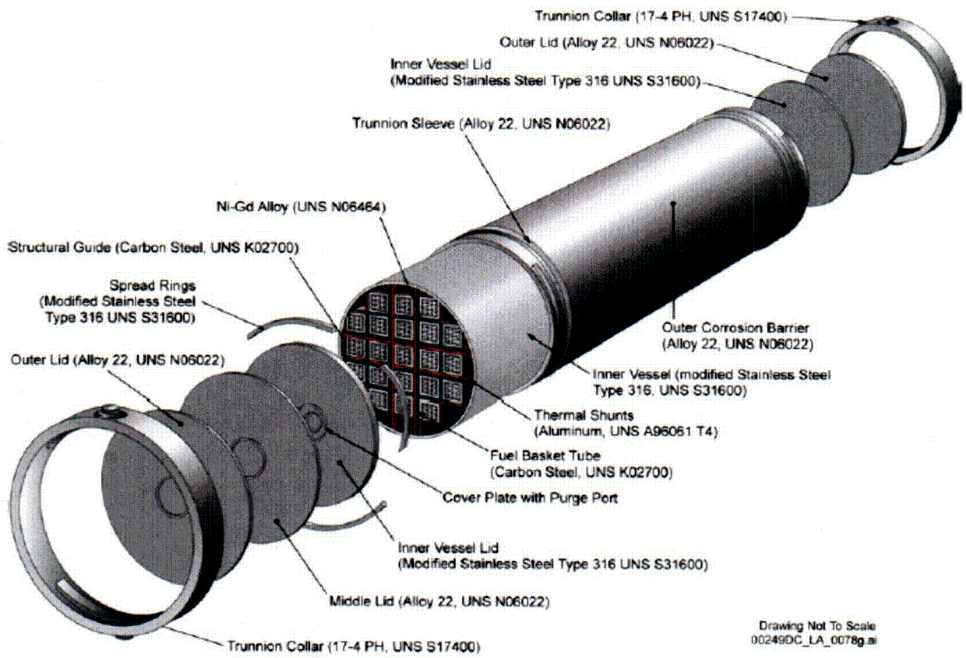

Figure 6-2. 21-PWR With Absorber Plates Waste Package Configuration

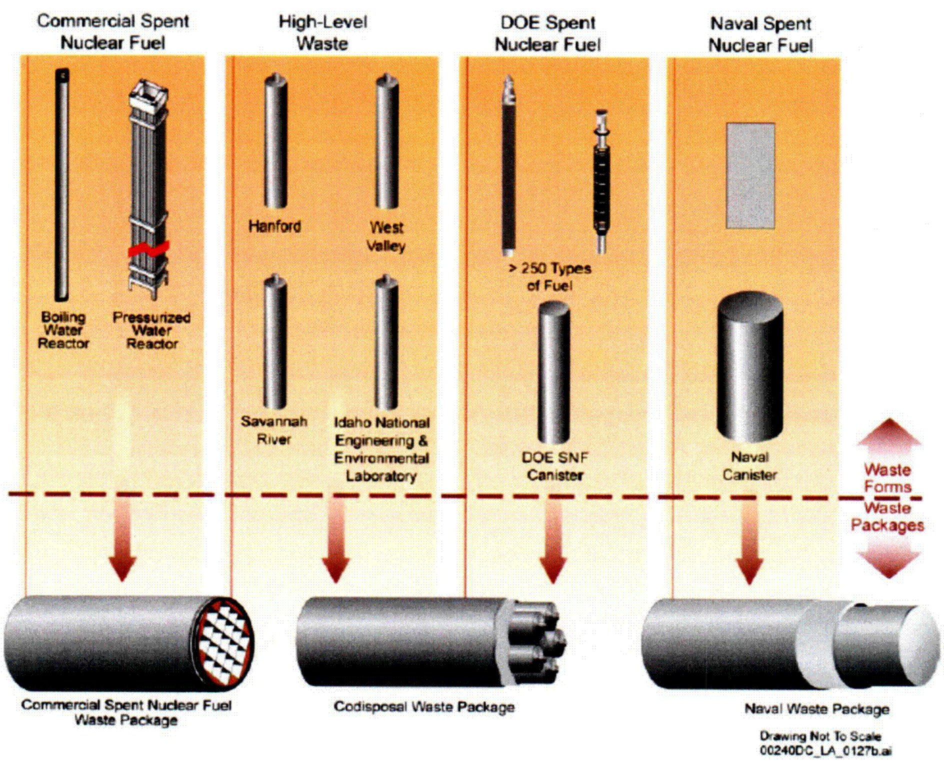

Figure 6-3. Waste Form and Waste Package Configurations

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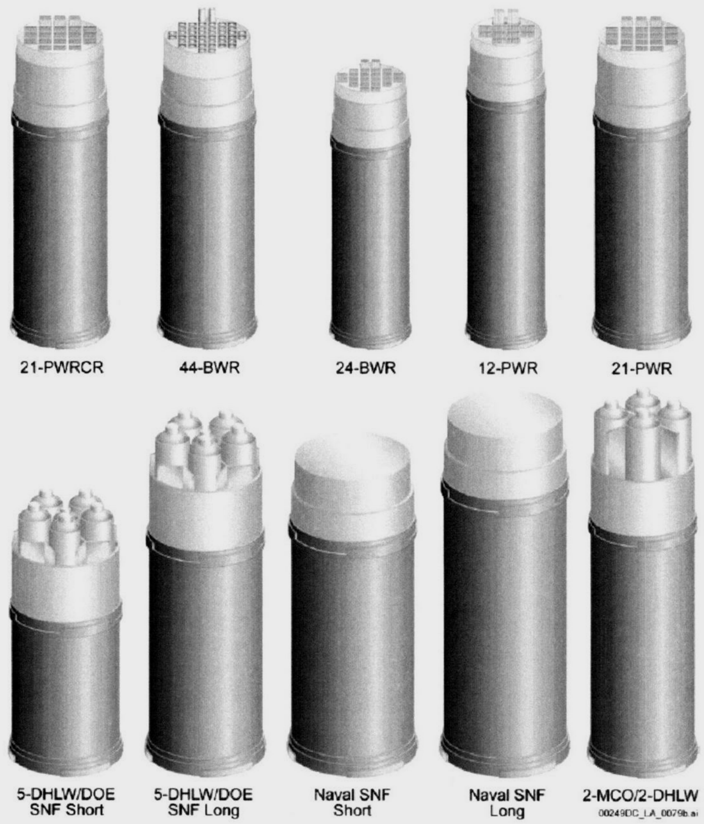

Figure 6-4. Waste Package Configurations

6.2.3 External Criticality

The degradation scenarios identified in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.3) are the basis for deriving the different configuration classes that are related to the consequences of criticality FEPs (Table 6-1) that affect the contents of the waste package and external environment. The activities from these FEPs that most directly impact the potential for external criticality include:

- Release of fissile material out of the waste package
- Accumulation of fissile material in the near-field or far-field
- Changes of moderator and reflector.

6.2.3.1 External Criticality Master Scenarios

Tracing through the Master Scenario List, eight degradation scenario groups external to the waste package are identified that have potential for criticality. The degradation scenarios are designated as external to the waste package in the near field (NF), which is within the drift and external to the waste package in the far field (FF), which is outside the drift, respectively. The eight groups are NF-1 through NF-5 and FF-1 through FF-3 (YMP 2003, Section 3.3). The CGM event tree, based on the Master Scenario List, generates all the various sequences based on the top events that comprise the eight external degradation scenario groups. These degradation scenarios are dependent on the degradation processes and degradation rates for the waste

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package; the components inside the waste package, including the waste forms; and degradation of and reactions within the invert.

The near field scenario groups are based on the waste package bottom breach allowing the waste package internals to flush out and collect in the invert. Groups NF-1, NF-2, and NF-3 are transfers from in-package scenarios where the waste package bottom breaches (i.e., IP-4, IP-5, and IP-6) and the waste package internals are flushed out. Groups NF-5 and NF-6 are associated with degradation scenarios where the waste package bottom is completely degraded and the waste form collects in the bottom of the pool.

The far field scenario groups are based on the fissile material being transported from the invert (near field) into the Topopah Spring welded hydrogeologic (TSw) units. The fissile material is in solution or colloid matrix where it can be precipitated out into clays and rock fractures in sufficient concentrations. FF-1 is based on the fissile material precipitating in clays and fractured rocks. FF-2 is fissile material colloids being collected in dead-end fractures and the Topopah Spring basal vitrophyre (TSbv) zone. FF-3 is based on the fissile material precipitating in organic rich zones.

The following descriptions provide additional information about the five near field and three far field external degradation scenario groups and configuration classes:

NF-1 Waste form and other internal components inside the waste package have been degraded and are flushed from the breached waste package into the invert. The waste form and waste package internal components are in solution as they are being flushed from the breached waste package. Possible generic configuration classes in this scenario are:

(a) The fissile material solutes are sorbed into the invert tuff (NF-1a).

(b) The fissile material solutes precipitate by tuff and then concentrate (NF-1b).

(c) The fissile material solutes from one or more breached waste package are transported to a low point within the drift and concentrate (NF-1c).

NF-2 Waste form and other internal components inside the waste package have been degraded and are flushed from the breached waste package into the invert. The waste form and waste package internal components are in a slurry mixture as they are being flushed from the breached waste package. The possible generic configuration class in this scenario is:

(a) The slurry effluent (waste form and waste package internal components) conforms to the invert surface and the neutron absorber separates from the fissile material (NF-2a).

NF-3 Waste form and other internal components inside the waste package have been degraded and are flushed from the breached waste package into the invert. The fissile material colloids in liquid effluent, which flushed from the breached waste package. Possible generic configuration classes in this scenario are:

(a) The fissile material colloid filter to the top of the invert because of being trapped by the waste package corrosion products and concentrate (NF-3a).

(b) The fissile material colloids are transported into the invert and become separated from the neutron absorber due to hydrodynamic/chromatographic process. The fissile material colloids concentrate in the rock fractures (NF-3b).

(c) The fissile material colloids separate from the neutron absorber material via chromatographic and concentrate in the degraded invert material (NF-3c).

NF-4 Waste form and waste package internals degrade and mobilize fissile material and neutron absorber out of the bottom of the breached waste package. The possible generic configuration class for this scenario is:

(a) Fissile material accumulates in clays on the bottom of the pool while the neutron absorber is flushed by the non-fissile bearing water (IP–4a).

NF-5 Waste form degrades slower than the other internal components given the waste package has been degraded. The possible generic configuration class for this scenario is:

(a) The waste package has mostly degraded and the waste form remains largely intact. The intact waste form sits in a pond of water on the drift floor (NF-5a).

FF-1 Fissile material solutes from the invert are transported to TSw units in a carrier plume. The fissile material is separated from the neutron absorbers. The following are the possible generic configuration class for this scenario.

(a) The fissile material precipitates from the carrier plume as flows through the rock fractures (FF-1a).

(b) The fissile material solutes are transported to the altered TSbv zone where it gets sorbed on clays and zeolites (FF-1b).

(c) The fissile material solutes are transported to the altered TSbv zone where accumulation occurs in the topographic lows. The fissile material begins to precipitate because of the chemical changes in the perched water (FF-1c).

FF-2 Fissile material colloids from the invert are transported to TSw units in a carrier plume. The fissile material colloids are separated from the neutron absorbers via hydrodynamic/chromatographic process. The following are the possible generic configuration class for this scenario.

(a) The fissile material colloids are trapped in dead-end fractures at the boundary of stress-relief zone (FF-2a).

(b) The fissile material colloids are transported to the altered TSbv zone where it gets sorbed on clays and zeolites (FF-2b).

(c) The transported fissile material colloids begin to accumulate due to filtration in the topographic lows above the altered TSbv (FF-2c).

FF-3 Fissile material solutes from the invert are transported to TSw units in a carrier plume. The fissile material is then separated from the neutron absorbers and transported to the water table. The following are the possible generic configuration class for this scenario.

(a) The fissile material precipitates in fractures or faults (FF-3a).

(b) The fissile material mixes below the reduction/oxidation (redox) front where it precipitates (FF-3b).

(c) The fissile material precipitates at the reducing zone in the remains of the organic matter (FF-3c).

(d) The fissile material precipitates at the organic reducing zone at the tuff aquifer located in the alluvial aquifer (FF-3d).

(e) The fissile material is transported to the Franklin Lake Playa where it precipitates in the organic rich zones (FF-3e).

6.2.3.2 Generic External Degradation Configuration Classes

As stated previously, a configuration class is a set of similar configurations whose composition and geometry are defined by specific parameters that distinguish one class from another. The following paragraphs list and discuss the configuration classes resulting from the standard scenarios presented previously that have potential for criticality with emphasis on their end states (YMP 2003, Subsection 3.3.1). The configuration classes are intended to comprehensively represent the configurations that can result from physically realizable scenarios, are generic to the waste form, and waste package type.

Configuration Class NF-1a: For this configuration class, fissionable material accumulates in fractures and other void spaces of the near-field. This configuration class can be reached from scenario NF-1 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a). This configuration is obtained from processes such as adsorption (sorption) of fissile materials in tuff as a result of a reducing reaction.

Configuration Class NF-1b: For this configuration class, fissionable material accumulates in fractures and other void spaces of the near-field. . This configuration class can be reached from scenario NF-1 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a). This configuration is obtained from chemistry changes due to carrier plume interaction with surrounding rock and pore waters that result in precipitation of fissile material by tuff.

Configuration Class NF-1c: For this configuration class, fissionable material accumulates at the low point of the emplacement drift (or any connecting drift). This configuration class can be reached from scenario NF-1 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a). The scenario leading to this configuration class must have a mechanism for sealing the fractures in the drift floor so that the effluent from individual waste packages can flow to, and accumulate at, a low point in the drift or repository, possibly in combination with effluent from other waste packages. Such a pool would be expected to occur only within a short time (weeks or less) following a high infiltration episode.

Configuration Class NF-2a: For this configuration class, fissionable material accumulates at the surface of the invert due to filtration by the degradation products, or remnants, of the waste package and its contents, for the cases in which the fissionable material may be carried as a slurry. This configuration class can be reached from scenario NF-2 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a).

Configuration Class NF-3a: For this configuration class, fissionable material accumulates at the surface of the invert due to filtration by the degradation products, or remnants, of the waste package and its contents, for the cases in which the fissionable material may be carried as a colloid. This configuration class can be reached from scenario NF-3 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a).

Configuration Class NF-3b: For this configuration class, fissionable material accumulates by processes involving the formation, transport, and eventual breakup (or precipitation) of fissionable material containing colloidal particles. This configuration class can be reached from scenario NF-3 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a). This configuration class is characterized by the final accumulation in the invert in open fractures of solid material.

Configuration Class NF-3c: For this configuration class, fissionable material accumulates by processes involving the formation, transport, and eventual breakup (or precipitation) of fissionable material containing colloidal particles. This configuration class can be reached from scenario NF-3 presented in *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a). This configuration class is characterized by the final accumulation in the invert in pore space of granular material.

Configuration Class NF-4a: For this configuration class, fissionable material accumulates in water that has pooled in the drift. This configuration class can be reached from scenario NF-4 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a). This configuration class is reached from the scenario involving waste packages that may not have been directly subjected to dripping water but are located in a local depression so that water from other dripping sites may collect around the bottom of the package during periods of high flow.

Configuration Class NF-5a: This configuration class has the intact or degraded waste form in water that has pooled in the drift. This configuration class can be reached from scenario NF-5 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3a). This configuration class is a variant of NF-4a. Such a configuration class would be evaluated for waste forms that could be demonstrated to be more robust with respect to aqueous corrosion than their waste package materials.

Configuration Class FF-1a: For this configuration class, fissionable material accumulates by precipitation in fractures and other void spaces of the far-field. This configuration class can be reached from scenario FF-1 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b). This configuration is obtained from processes such as adsorption, from a reducing reaction, or from chemistry changes made possible by carrier plume interaction with surrounding rock and pore waters.

Configuration Class FF-1b: For this configuration class, fissionable material accumulates by sorption, onto clay or zeolite. Such material may be encountered beneath the repository. This configuration class can be reached from scenario FF-1 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b).

Configuration Class FF-1c: For this configuration class, fissionable material accumulates by precipitation from encountering perched water (groundwater deposit isolated from the nominal flow and not draining because of impermeable layer beneath) having significantly different chemistry from the fissionable material carrier plume. This configuration class can be reached from scenario FF-1 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b).

Configuration Class FF-2a: For this configuration class, fissionable material accumulates by processes involving the formation, transport, and eventual breakup (or precipitation) of fissionable material containing colloidal particles. This configuration class can be reached from scenario FF-2 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b). It has been suggested that the colloid-forming tendency of plutonium will enhance its transport capability, providing the potential for accumulation at some significant distance from the waste package. This configuration class is characterized by the final accumulation in dead-end fractures.

Configuration Class FF-2b: For this configuration class, fissionable material accumulates by processes involving the formation, transport, and eventual breakup (or precipitation) of fissionable material containing colloidal particles. This configuration class can be reached from scenario FF-2 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b). It has been suggested that the colloid-forming tendency of plutonium will enhance its transport capability, providing the potential for accumulation at some significant distance from the waste package. This configuration class is characterized by the final accumulation in clay or zeolites.

Configuration Class FF-2c: For this configuration class, fissionable material accumulates by processes involving the formation, transport, and eventual breakup (or precipitation) of fissionable material containing colloidal particles. This configuration class can be reached from scenario FF-2 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b). It has been suggested that the colloid-forming tendency of plutonium will enhance its transport capability, providing the potential for accumulation at some significant distance from the waste package. This configuration class is characterized by the final accumulation in topographically low regions.

Configuration Class FF-3a: For this configuration class, fissionable material accumulates by precipitation in the saturated zone at the contact between the waste-package plume and a hypothetical up welling fluid. This configuration class can be reached from scenario FF-3 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b).

Configuration Class FF-3b: For this configuration class, fissionable material accumulates by precipitation in the saturated zone at the contact between the waste-package plume and a redox front (where the plume meets a different groundwater chemistry so that an oxidation-reduction reaction can take place). This configuration class can be reached from scenario FF-3 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b).

Configuration Class FF-3c: For this configuration class, fissionable material accumulates by chemical reduction of fissionable material by a mass of organic material (reducing zone). Such a deposit might be located beneath the repository. This configuration class can be reached from scenario FF-3 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b).

Configuration Class FF-3d: For this configuration class, fissionable material accumulates by chemical reduction of fissionable material by a mass of organic material (reducing zone). Such a deposit might be located at a narrowing of the tuff aquifer. This configuration class can be reached from scenario FF-3 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b).

Configuration Class FF-3e: For this configuration class, fissionable material accumulates by chemical reduction of fissionable material by a mass of organic material (reducing zone). Such a deposit might be located at the surface outfall of the saturated zone flow. This configuration class can be reached from scenario FF-3 presented in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Figure 3-3b).

6.3 CONFIGURATION GENERATOR MODEL

Information on the overall methodology that the CGM must address is given in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.1). The Master Scenarios (YMP 2003, Figures 3-2a, 3-2b, 3-3a, and 3-3b) represent three general degradation groups in the monitored geologic repository having criticality potential. The three general groups are based on locations inside the waste package (IP), outside the waste package in the near-field (NF) environment (emplacement drift outside the waste package), and outside the waste package in the far-field (FF) environment (region outside the emplacement drift). These three different locations are broken down into specific scenarios (i.e., six IP degradation scenarios (Section 6.2.2), five near-field environment degradation scenarios, and three far-field environment degradation scenarios).

The following is a discussion of how the CGM is used with the Master Scenario List. The model uses event tree methodology to express the degradation processes and sequences that lead to the different configuration classes. Note that a configuration class may possess multiple end states. The construction of the event tree captures all of the configuration classes discussed in the Master Scenario List (YMP 2003, Figures 3-2a, 3-2b, 3-3a, and 3-3b).

The event tree (illustrated in Figures I-1 through I-27) starts with the different waste forms expected for disposal in the monitored geologic repository. Listing the different waste forms in the event tree provides a bookkeeping mechanism. However, in an analysis, a specific waste form must be specified in order to quantify the degradation parameters for both the waste form and waste package. The event tree then lists in sequential order the degradation processes required to reach each of the degradation scenarios for the IP, NF and FF degradation groups. The top events on the event tree are the specific processes required for degradation. The branching under the top events (degradation processes) provides a traceable sequence to each configuration class. The different configuration classes are noted on the event tree with their respective end states.

The CGM addresses the calculation of the criticality potential for a given configuration class and ties the criticality analysis together with the probability analysis. The CGM generates the different configuration classes based on the Master Scenario List following the sequences through the event tree to generate the different waste form and waste package configuration classes. Once an end state in a configuration class has been generated, the probability of that state is compared with the screening criterion (Section 6). If the screening criterion is exceeded, the potential for criticality of the state is evaluated (Figure 6-1). A detailed evaluation using the criticality model (BSC 2004b) is performed for those configurations to evaluate their potential for criticality. Then, if the criticality potential criterion for the waste form is not satisfied, a probability analysis of the critical configuration is performed (YMP 2003, Subsection 3.2.1). Since the configuration classes are mutually exclusive entities, the probabilities for a configuration class are summed over the various end states.

In order to perform the probabilistic analysis, probability density functions for the independent variables associated with the potential critical configurations need to be defined. These probability density functions are derived from the functional relationships between drift environment, waste form variables, and waste package variables and are obtained from various sources. The probability analysis uses the range of parameters determined from the criticality analysis. Methods for the criticality analyses are discussed in *Criticality Model Report* (BSC 2004b). Methods for the probability analysis are discussed in the following subsections.

The potential for criticality of a waste form configuration class in the waste package is determined by the material composition and the physical arrangement (or geometry) of this material composition. For a waste package containing CSNF, the initial configuration is the waste package as-loaded with commercial light water reactor fuel assemblies. The fuel assemblies in this initial configuration are intact; thus, the fuel rods within the fuel assembly are expected to have the same geometry as during their operation in the commercial reactor. The fuel rod geometry in the fuel assembly is a square pin matrix optimized with respect to maximizing reactivity in the reactor core (i.e., results in a potentially high k_{eff}). This initial configuration in the waste package is subcritical since a correctly loaded waste package is designed to ensure that condition, even in a flooded state, through inclusion of neutron absorbing materials. Any potential criticality thus can only occur for degraded configurations.

6.3.1 CGM Event Tree

The CGM event tree represents the degradation processes and sequences that lead to the different configurations classes discussed in the Master Scenario List (YMP 2003, Section 3.3). The event tree is developed in a comprehensive manner in order to capture all of the processes and sequences that lead to one of the six in-package degradation scenarios associated with internal waste package processes. Only these six related degradation scenarios are constructed in the CGM event tree using the SAPHIRE software (SAPHIRE V7.18, STN: 10325-7.18-00), a state-of-the-art computer code for performing probabilistic risk assessment evaluations. The CGM event tree, shown in Attachment I, is used to evaluate all of the in-package configuration classes resulting from the scenarios to identify those having potential for criticality and thus require a detailed criticality analysis to determine if the k_{eff} is greater than the critical limit for the waste form.

The CGM 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 CGM event tree with their respective end states. Note that to reach a specific end state, the degradation-related processes in that sequence must occur. Thus, the probability of reaching that end state is evaluated in a reverse manner (i.e., determine first what parameter values are required to allow the end state conditions to occur within the given time period, then evaluate the probability of occurrence for these particular values). This process will normally require an iterative approach to maximize the overall probability.

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 (Figure 6-1). The parameter values essential for criticality are correlated, but the probability distributions for the random variables in the set are independent. Thus, an iterative approach may be necessary to maximize the probability of occurrence based upon the correlated variables. The process is time-dependent so that the assigned probabilities include the additional requirement that the parameter values must be realized within a given time period. The probability of criticality is set to zero for all end states of configuration classes that are not marked as having potential for criticality.

6.4 INFORMATION REQUIRED TO PERFORM ANALYSES USING THE CGM

6.4.1 Steps Required for Analyses

The required steps to use the CGM for analysis are described in the following discussion. The CGM requires considerable information to be obtained and formulated in a manner that allows for its evaluation. All of the important steps required for evaluation are listed below along with the information on how to perform the steps. The steps discussed in the following paragraphs are independent of the waste form being analyzed.

Step 1. The first step is to generate all of the potential in-package and external critical configuration classes. Section 6.2.2 and 6.2.3 discuss all of the configuration classes for in-package and external criticality, respectively. For each configuration class, there are specific degradation sequences. The CGM event tree (Attachment I) is used to obtain these specific degradation sequences for each configuration class as identified in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003). The CGM event tree not only generates the sequence of events required for the waste form to reach a specific configuration class, it also provides a time frame for the analysis. The end states in the analysis may be subdivided into major time intervals that are required for the evaluation. The time steps provided on the event tree are very important for the probabilistic calculation since they govern what the probability is for most of the degradation processes.

Step 2. For each waste form, all of the in-package and external critical configuration classes need to be evaluated. Therefore, the analyst starts with configuration IP-1a and works all the way through to FF-3e. For each configuration class there are two questions that need to be answered as either TRUE (i.e., yes) or FALSE (i.e., no). These questions are:

(1) Can the configuration class be achieved?
(2) Does the configuration class have potential for becoming critical?

and can be answered using engineering judgment or simple calculations. If the answer to either question based on engineering judgment or simple calculations is FALSE, further evaluation of the waste form for that particular configuration class is not required. The engineering judgment or simple calculation requires documentation on why the waste form can not degrade according to the configuration class or the waste form does not have the potential of becoming critical. This process must also take into account each time step listed on the event tree since certain processes may or may not be able to occur within the period being evaluated.

Step 3. If the answer to both of the questions in Step 2 (i.e., waste form configuration and criticality potential) is TRUE, then an estimation of the probability of occurrence for the configuration class is performed. This estimated probability is tested against the probability screening criterion stated in Section 6. If the estimated probability is less than the criterion, then the analysis for the configuration class is complete at this point of the analysis and the analyst moves to Step 5.

If the estimated probability is greater than the criterion, the configuration class has potential for criticality and a more detailed analysis is required. A detailed criticality calculation is performed using the criticality model (BSC 2004b) with the waste form and waste package parameters from the configuration class to determine the k_{eff}. These waste form and waste package parameters have probabilities that are based on degradation and time and, if the k_{eff} goes above the critical limit, a more detailed probability calculation is performed for the configuration class to estimate the probability of criticality. However, if k_{eff} is less than the critical limit over the entire parameter range, then the configuration class can be stopped from further consideration for this waste form.

Step 4. The detailed criticality probability calculation performed for the configuration class of interest uses the range of waste form and waste package parameters that caused k_{eff} to be greater than the critical limit. In order to perform the probability calculation, the probability density functions for the waste form and waste package are extracted. The only probability density functions extracted are those specific to the configuration class being analyzed. The probability calculation takes into account the time after waste package emplacement as noted on the event tree and the probability that the waste form and waste package take on the parameters required for criticality. The calculated probability is added to the probability of the other configuration classes to obtain an overall probability of criticality for the waste form. Note: Probability values for configuration classes are additive since the classes are mutually exclusive.

Step 5. All of the configuration classes need to be evaluated; therefore, the next configuration class (i.e., IP-1b) needs to be evaluated for the same waste form. Steps 1 through 4 are performed until all of the configuration classes generated by the event tree have been analyzed. Once all of the configuration classes have been analyzed, the probabilities from individual configuration classes are then summed together to obtain an overall probability of criticality for the waste form. If the overall probability of criticality does not satisfy the design probability criterion, then a waste package / engineered barrier system (EBS) redesign is required and steps 1 through 4 should be repeated. If the design probability is satisfied, then this overall probability determines if consequence analyses need to be performed. If the total probability of all configuration classes is less than a defined screening probability, e.g., a factor of ten lower than the 10 CFR Part 63.114(d) criterion, then no further analysis is required. However, if the total probability of all configuration classes is greater than the defined screening probability, then consequence analyses are required for all configuration classes that contribute to the overall probability (i.e., non-zero probability configuration classes).

6.4.2 Analysis Input Data and Parameters

The parameters that are required as input to analyses using the CGM consist of waste package design parameters, generic degradation scenarios, and parameters that characterize the emplacement drift environment. The waste form parameters are dependent upon the particular waste form being analyzed. These input parameters are used for two separate but joint evaluations: (1) to determine the potential for criticality, and (2) to determine the probability of those configuration parameters that have the potential for causing criticality. Input to a CGM analysis consists of generic parameters identified by Event Tree Top Events that characterize the degradation sequences applicable to multiple waste forms.

7. CONCLUSIONS

The CGM, as directed by the technical work plan (BSC 2004a), was to provide a method to perform the probability screening analysis of degraded waste form configurations internal and external to waste packages that have potential for criticality. The components in the process were to address the scenarios identified in Section 3.3 of the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003) related to FEPs as having the potential to increase the reactivity of the in-package and ex-package system.

The degradation scenarios from the *Disposal Criticality Analysis Methodology Topical Report* (YMP 2003, Section 3.3) related to FEPs were integrated into an event tree process that forms the central analytical tool for the CGM. The event tree structure is flexible, permitting the event trees to be tailored to specific requirements. Additional information required to perform analyses with the CGM includes probability distributions of fundamental variables, correlations with uncertainties for dependent parameters, and descriptions of both the waste package and waste form. The process discussion includes a subsection describing the steps required to perform an analysis, and configuration parameters required for a CGM analysis.

The CGM, documented in this report, contributes to or meets the acceptance criteria stated in Section 4.2 through:

- Development of degradation scenarios coupled with evaluation methods for identifying configurations that have potential of criticality
- Development of processes to determine potential external radionuclide source terms
- Processes based upon probabilistic risk-informed methods
- Methods permit analyses to span, at the minimum, the period of regulatory concern.

The NRC safety evaluation report (Reamer 2000) for the *Disposal Criticality Analysis Methodology Topical Report* (YMP 1998) contained six open items (Reamer 2000, pp. 77 to 79) that concerned the configuration generator model. These Open Items, numbers 5, 6, 9, 10, 18, and 19, concern the k_{eff} regression analysis associated with the previous approach to the configuration generator model discussed in the *Disposal Criticality Analysis Methodology Topical Report* (YMP 1998). However, use of a k_{eff} regression analysis is not part of the current configuration generator methodology and, thus, the referenced open items are no longer considered applicable and will not be further addressed.

It is recommended that the CGM be an integral part of the disposal criticality methodology for the Yucca Mountain Project subject to the limitation that probability density functions be specified for the set of basic parameters that are themselves derived from model abstractions.

8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

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8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES CITED

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LP-SI.11Q-BSC, Rev. 0, ICN 1. *Software Management.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20041005.0008.

8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

MO0405SEPFEPS6.000. LA FEP List. Submittal date: 05/14/2004.

8.4 SOFTWARE CODES

Software Code: SAPHIRE. V7.18. PC - Windows 2000/NT 4.0. 10325-7.18-00.

Software Code: EQ6. 7.2bLV. PC. 10075-7.2bLV-02. Windows NT, 2000.

Software Code: PHREEQC. V2.3. PC. 10068-2.3-01.

9. ATTACHMENTS

Attachments to this model report are as follows:

Attachment I:	Configuration Generator Model Event Tree and SAPHIRE Rules
Attachment II:	Description of Event Tree Tops
Attachment III:	List of the Electronic Files in Attachment IV
Attachment IV:	Compact Disk with CGM Data Files

ATTACHMENT I

CONFIGURATION GENERATOR MODEL EVENT TREE AND SAPHIRE RULES

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ATTACHMENT I - CONFIGURATION GENERATOR MODEL EVENT TREE AND SAPHIRE RULES

The event trees used in the SAPHIRE CGM are presented and discussed in Section I.1. The logic rules used to assign the basic event probabilities and direct the evaluation of the event trees are presented in Sections I.2 through I.22.

I.1 SAPHIRE EVENT TREES

Figures I-1 through I-27 present the event trees used in the CGM. Figure I-1 presents the "WP–WF" event tree used for determining the waste form and waste package type inventory fraction. Figure I-2 presents the "WP01-21-PWR-AP" event tree used to initiate the 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. Figure I-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 I-4 and I-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, Section 3.3). The event trees of Figures I-6 through I-13 detail the events and processes necessary for the formation and evaluation of in-package configuration classes. The event trees of Figures I-14 through I-20 detail the events and processes necessary for the formation and evaluation of near-field configuration classes. The event trees of Figures I-21 through I-23 detail the events and processes necessary for the formation and evaluation of far-field configuration classes. Finally, Figures I-24 through I-27 present the event trees required for the formation and evaluation of configuration classes resulting from an igneous disruptive event.

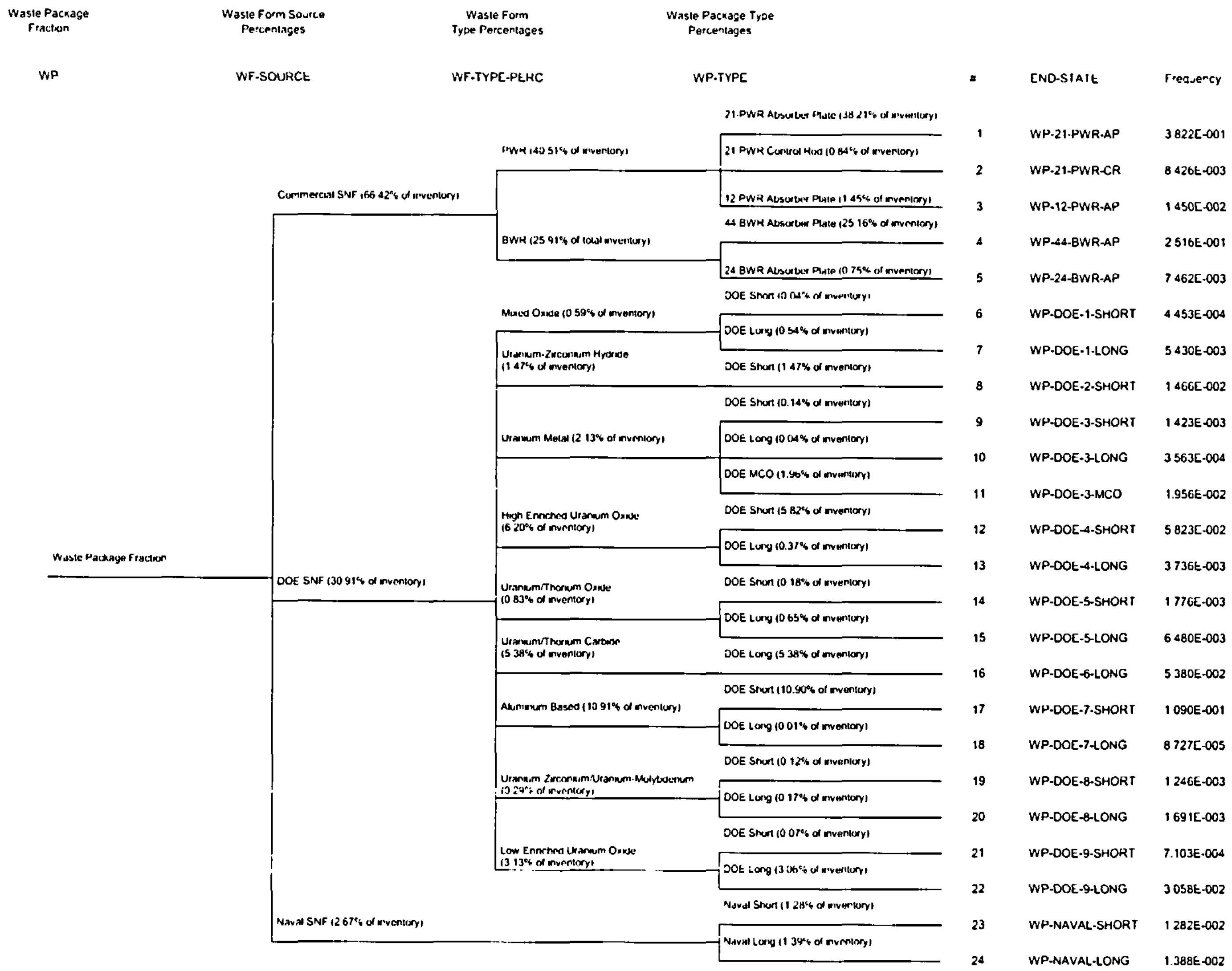

Figure I-1. Waste Form and Waste Package Type Inventory Fraction Event Tree — "WP-WF"

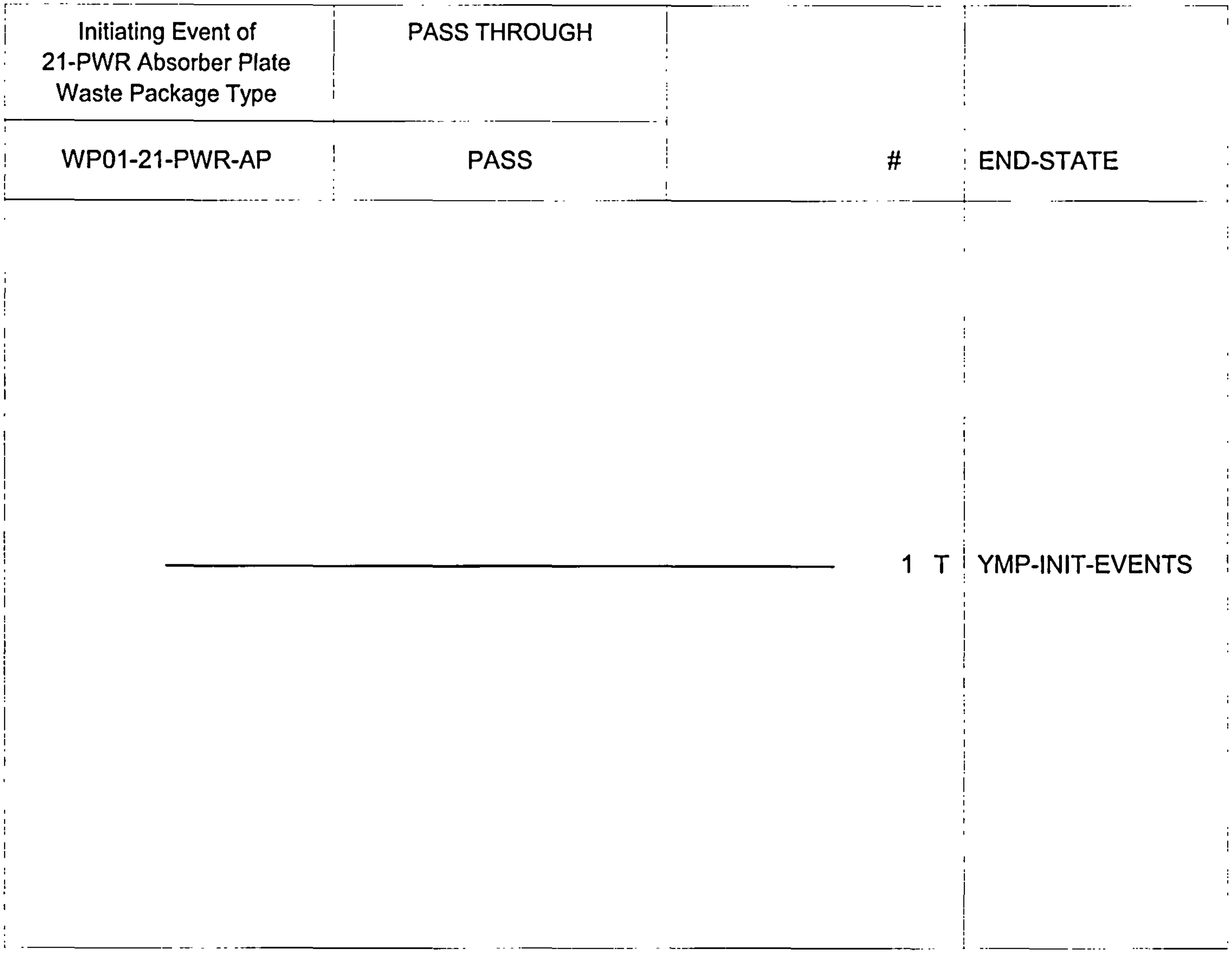

Figure I-2. Example of Waste Package Type Event Tree — "WP01-21-PWR-AP"

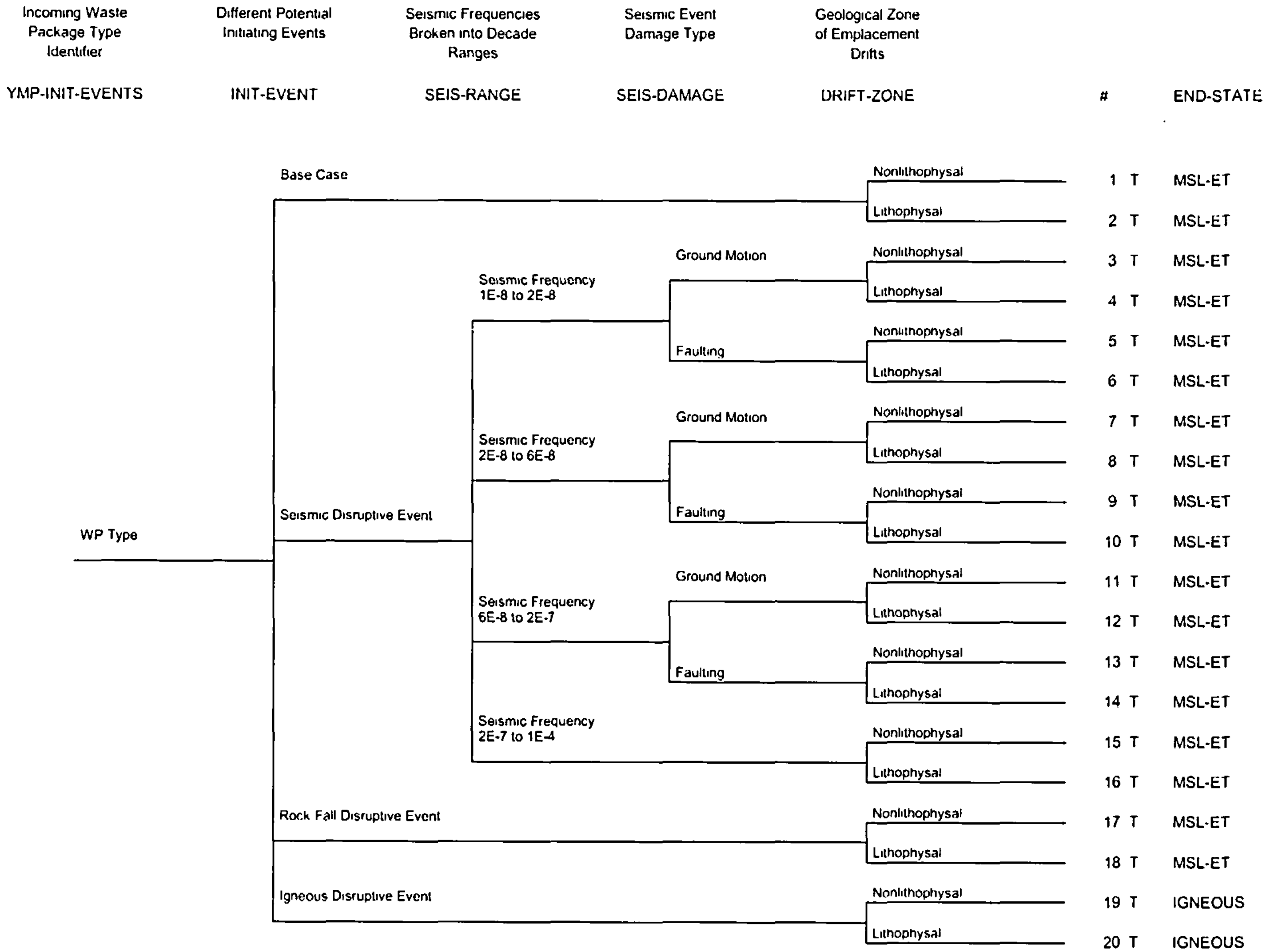

Figure I-3. Criticality FEPs Case Assignment Event Tree — "YMP-INIT-EVENT"

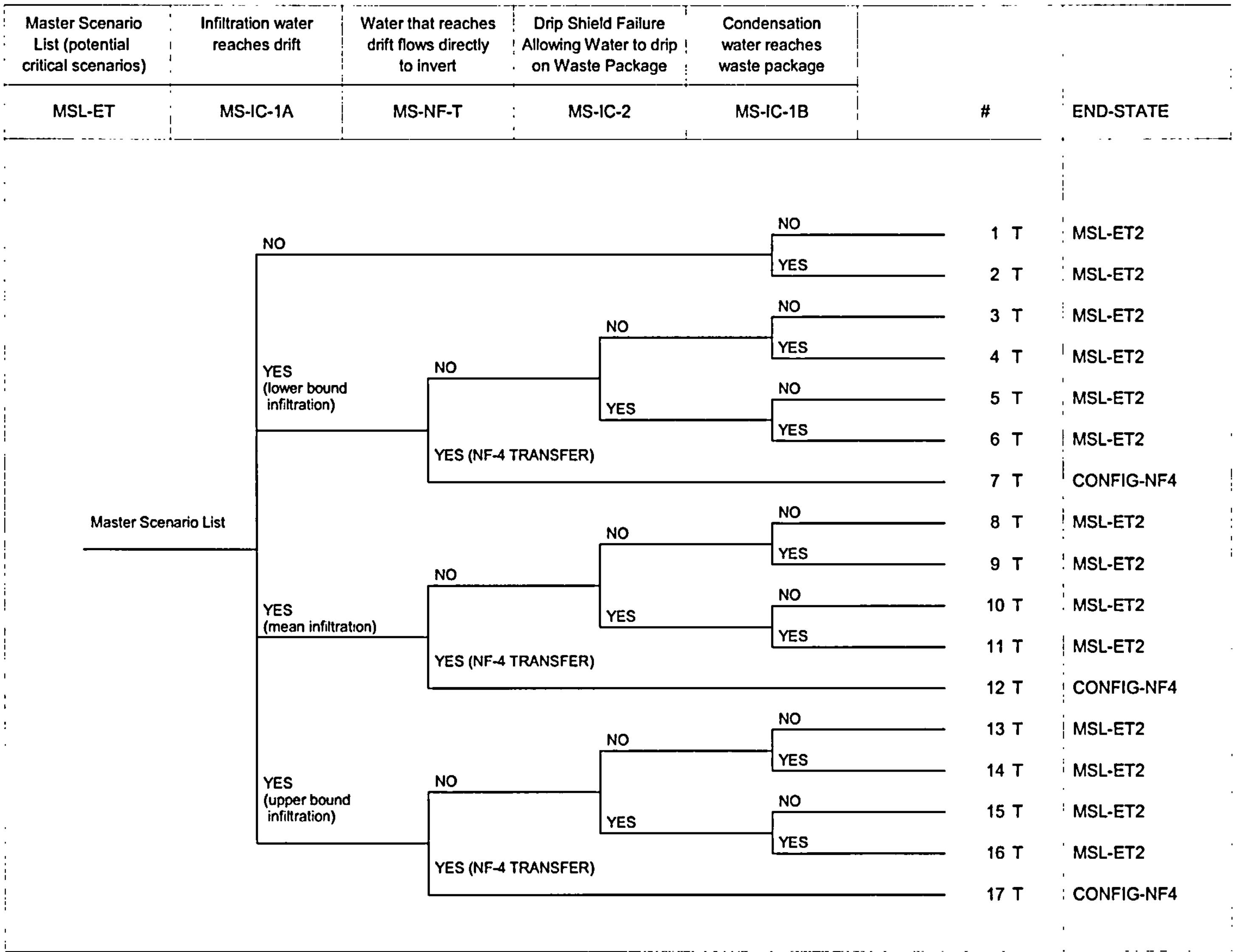

Figure I-4. Master Scenario List Event Tree — "MSL-ET"

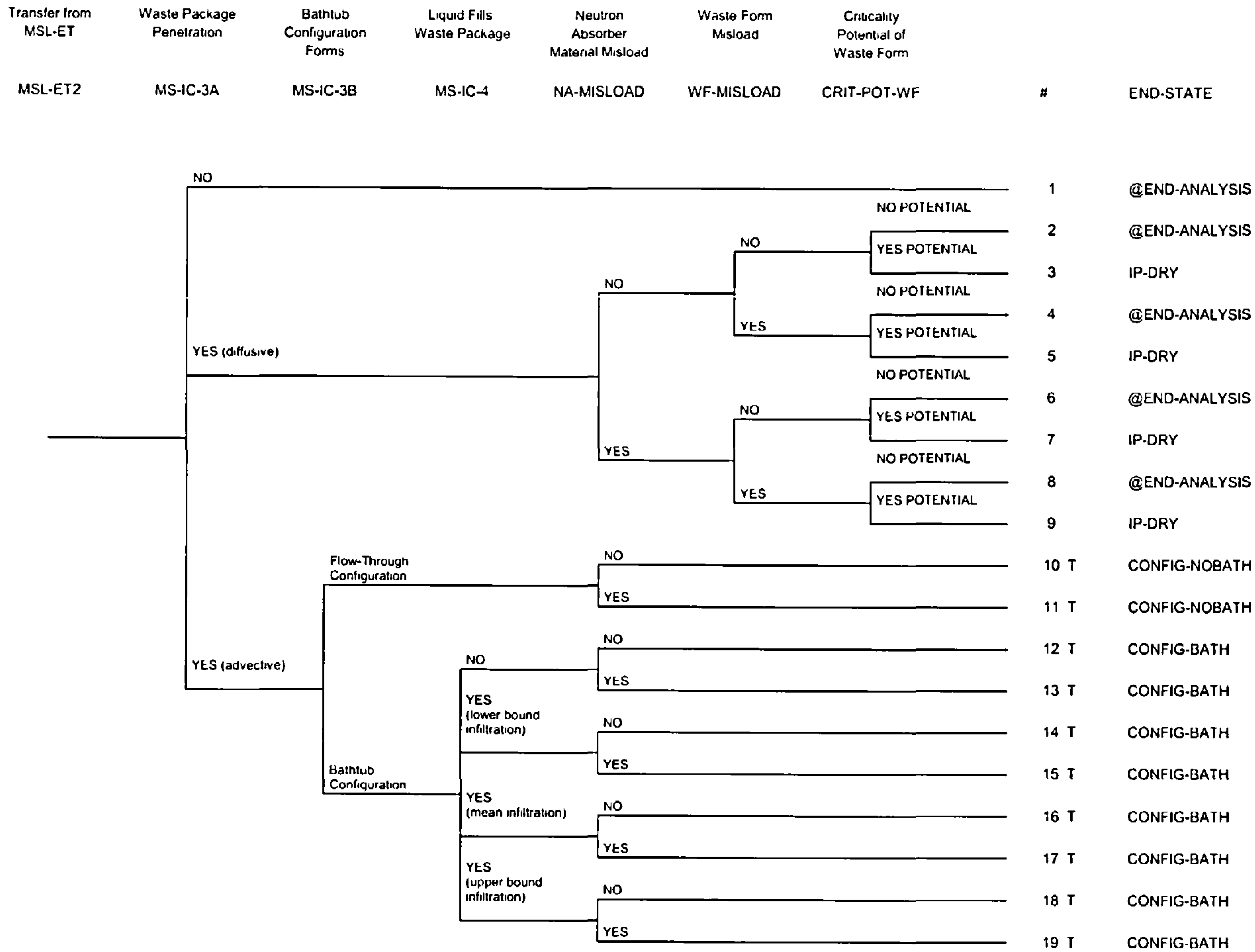

Figure I-5. Master Scenario List Event Tree – Continued — "MSL-ET2"

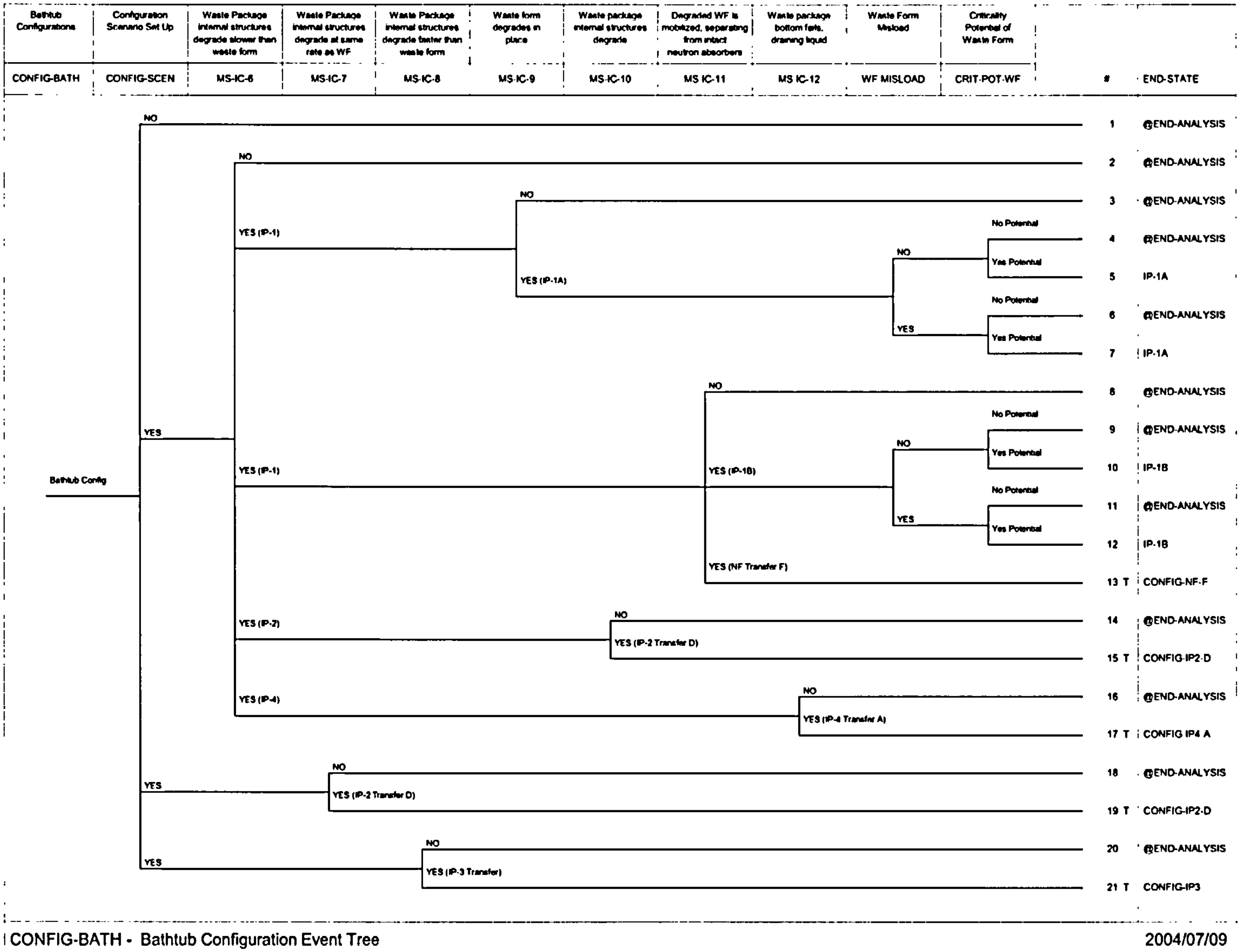

Figure I-6. Bathtub Configuration Event Tree — "CONFIG-BATH"

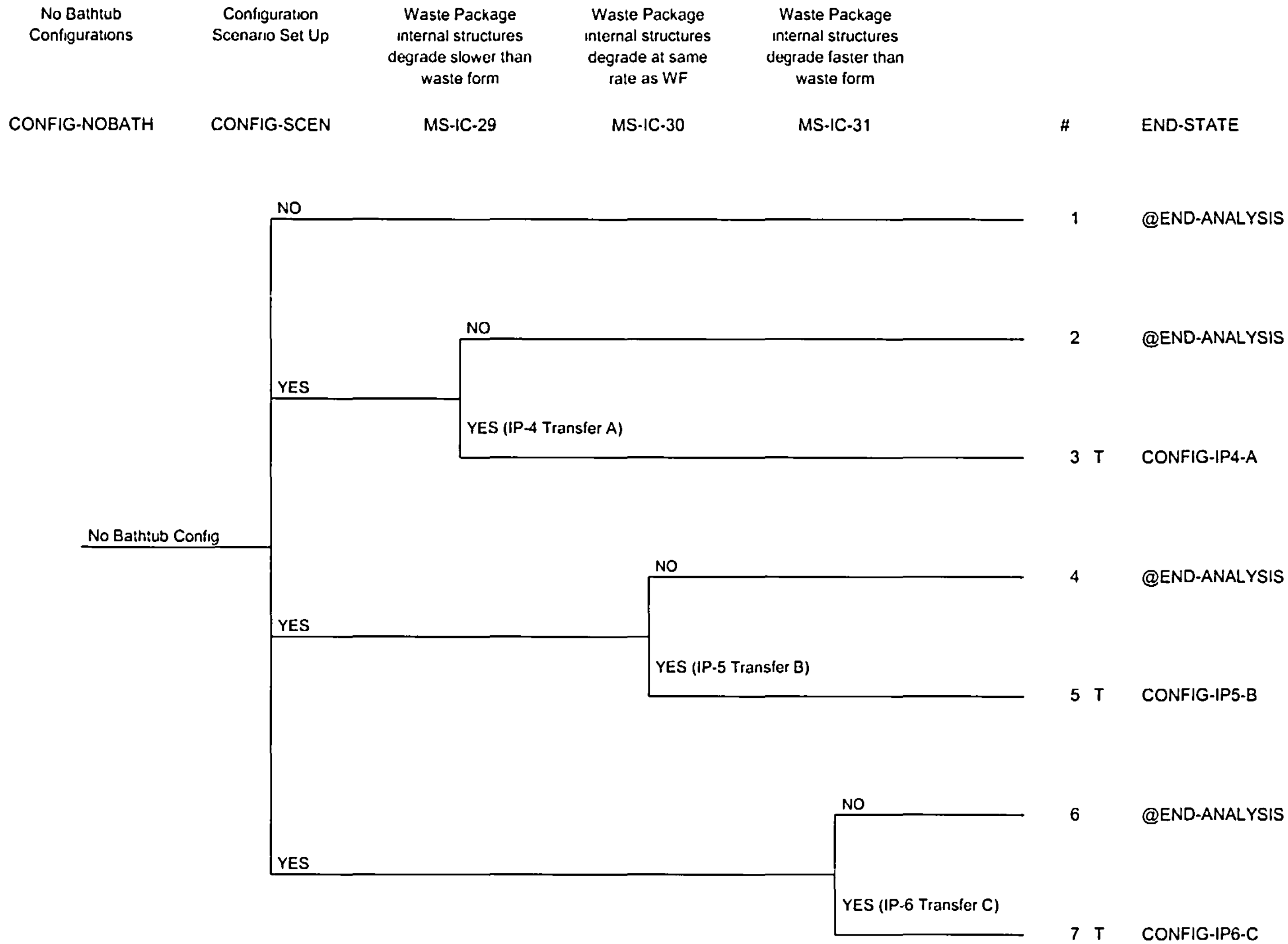

Figure I-7. Flow-Through Configuration Event Tree — "CONFIG-NOBATH"

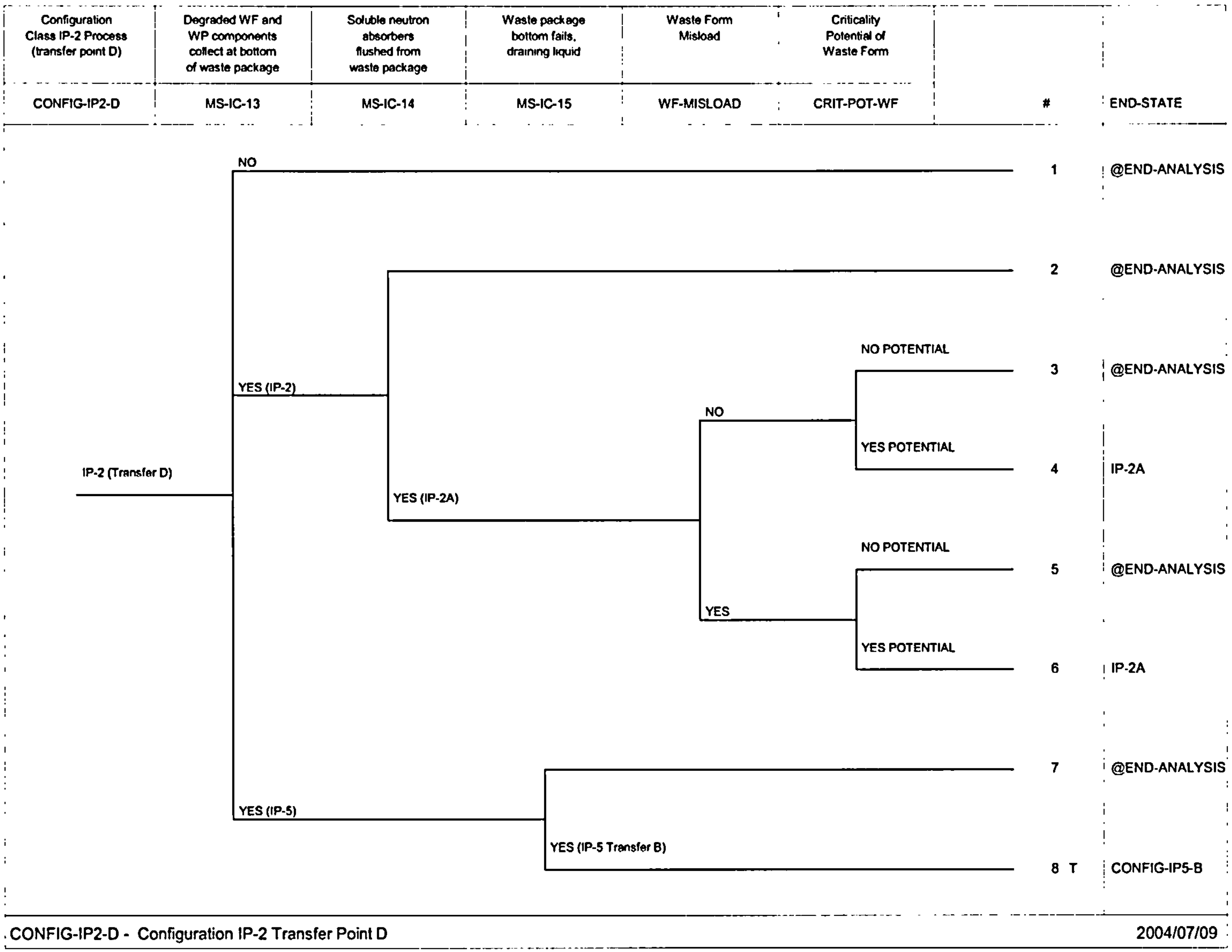

Figure I-8. Configuration Class IP-2 Event Tree — "CONFIG-IP2-D"

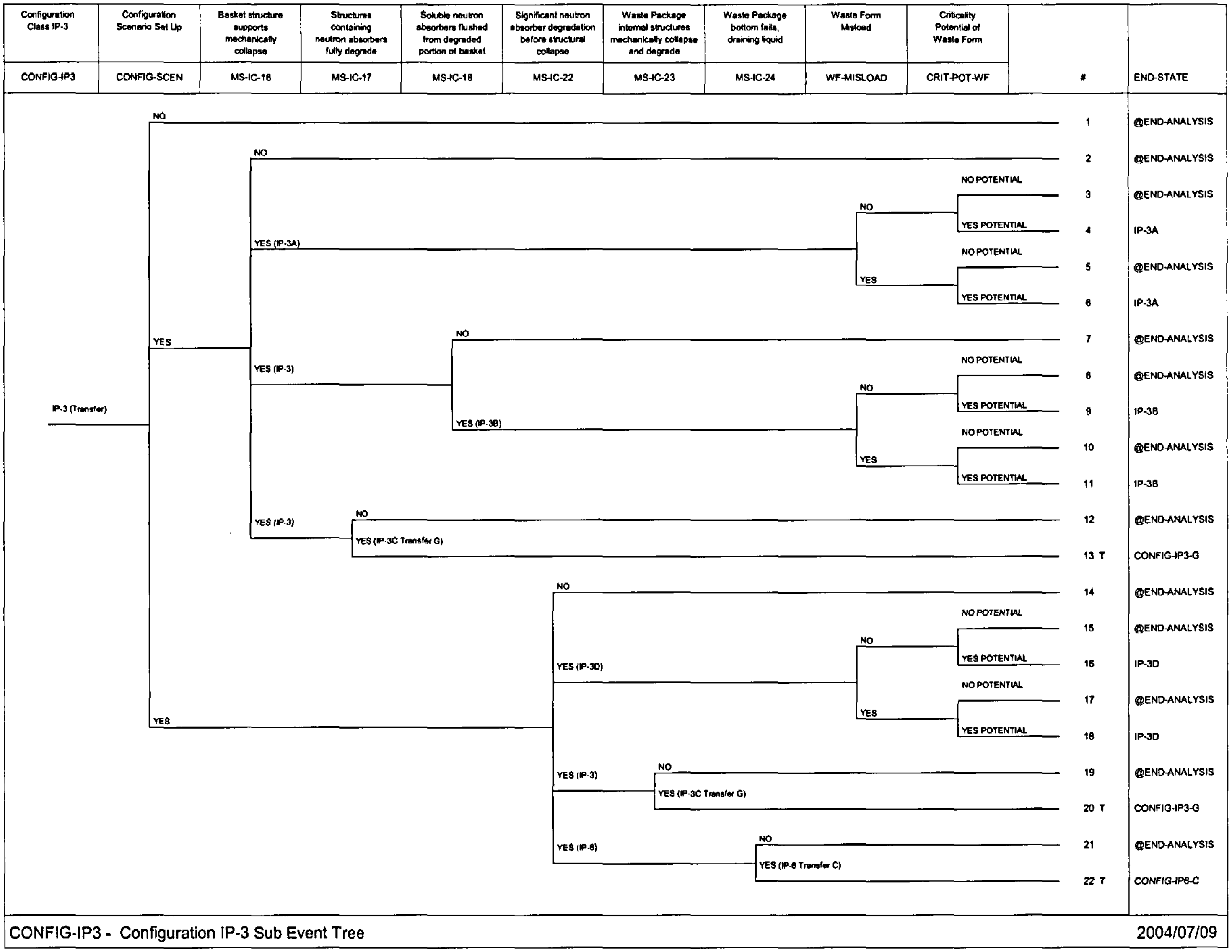

Figure I-9. Configuration Class IP-3 Event Tree — "CONFIG-IP3"

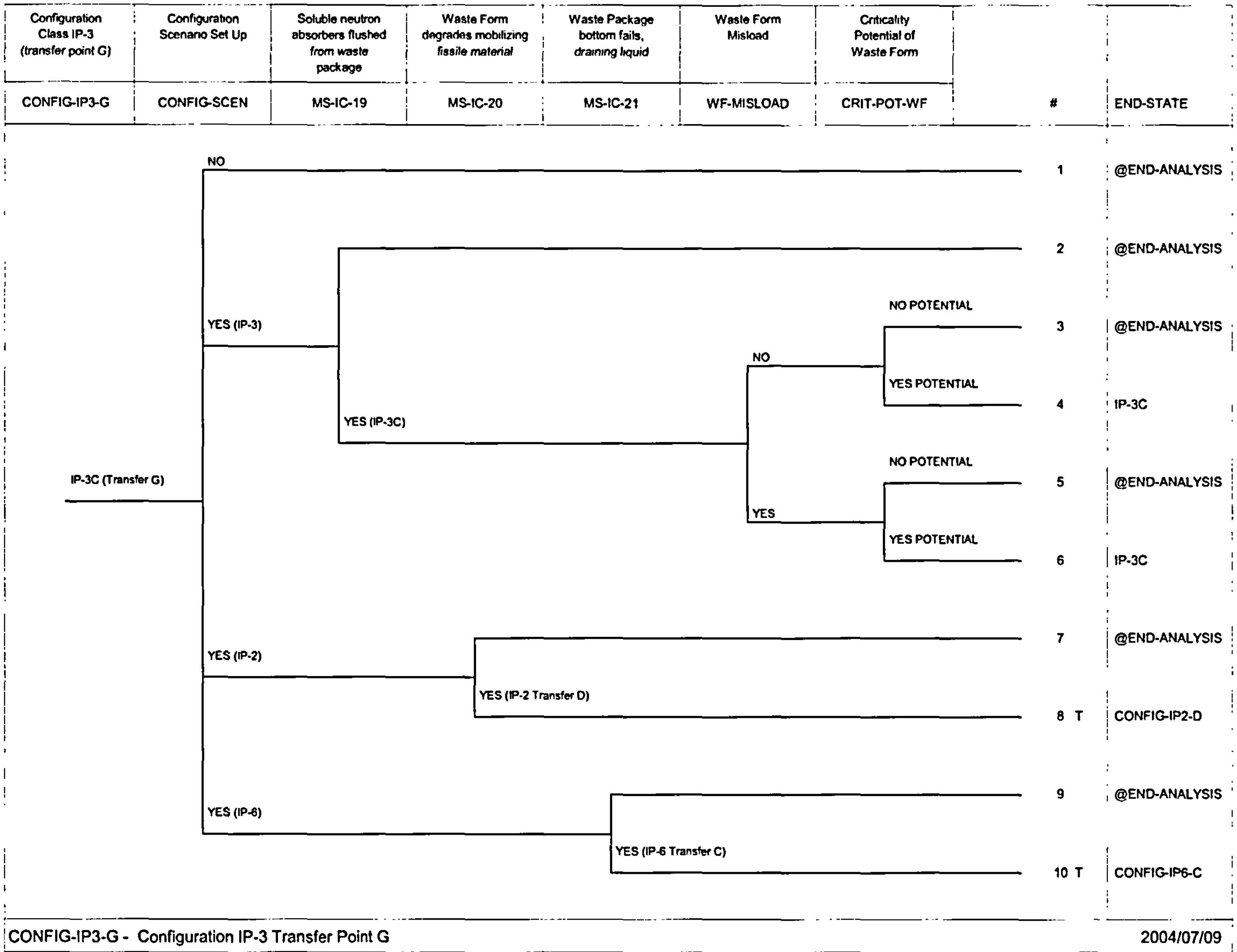

Figure I-10. Continuation of Configuration Class IP-3 Event Tree — "CONFIG-IP3-G"

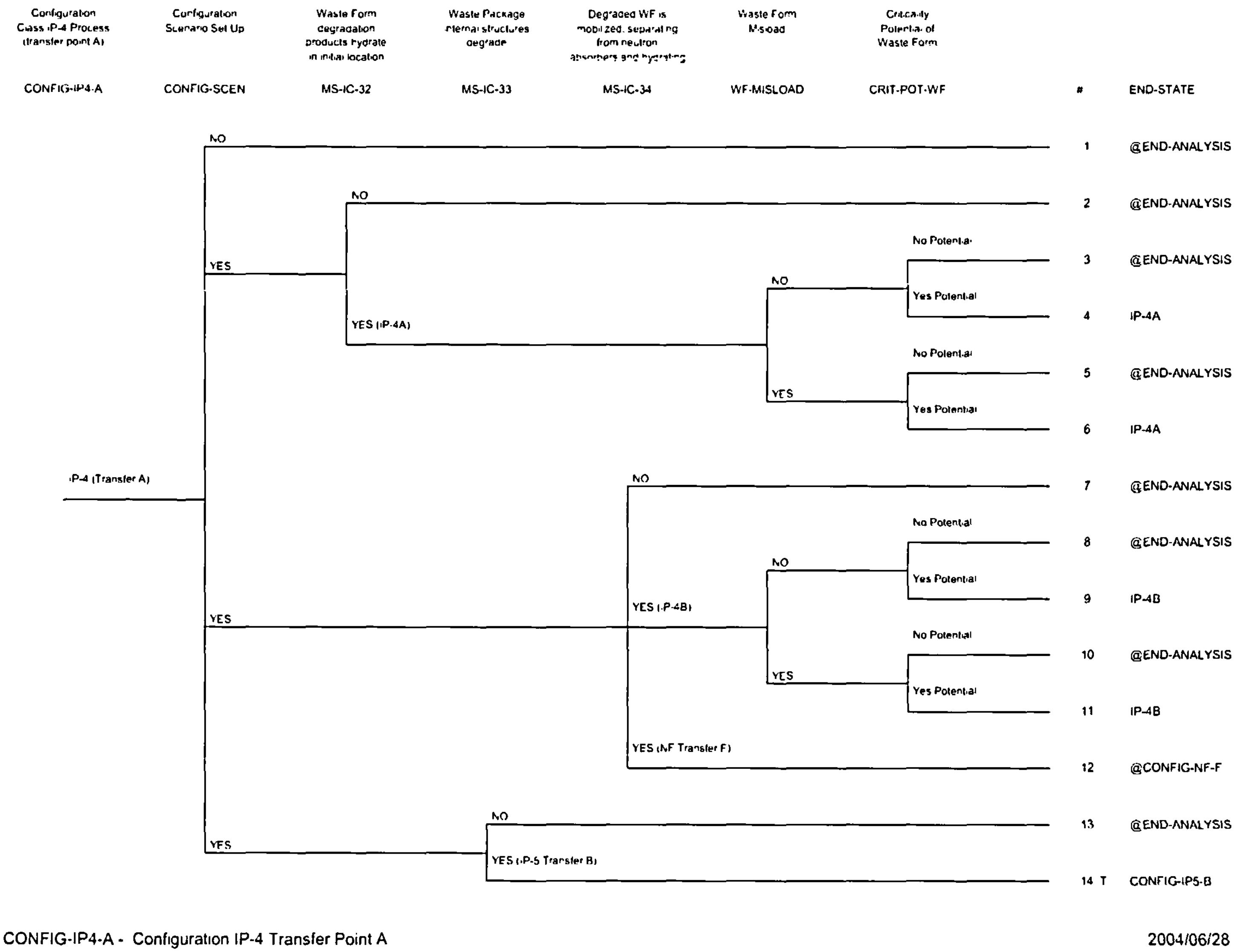

Figure I-11. Configuration Class IP-4 Event Tree — "CONFIG-IP4-A"

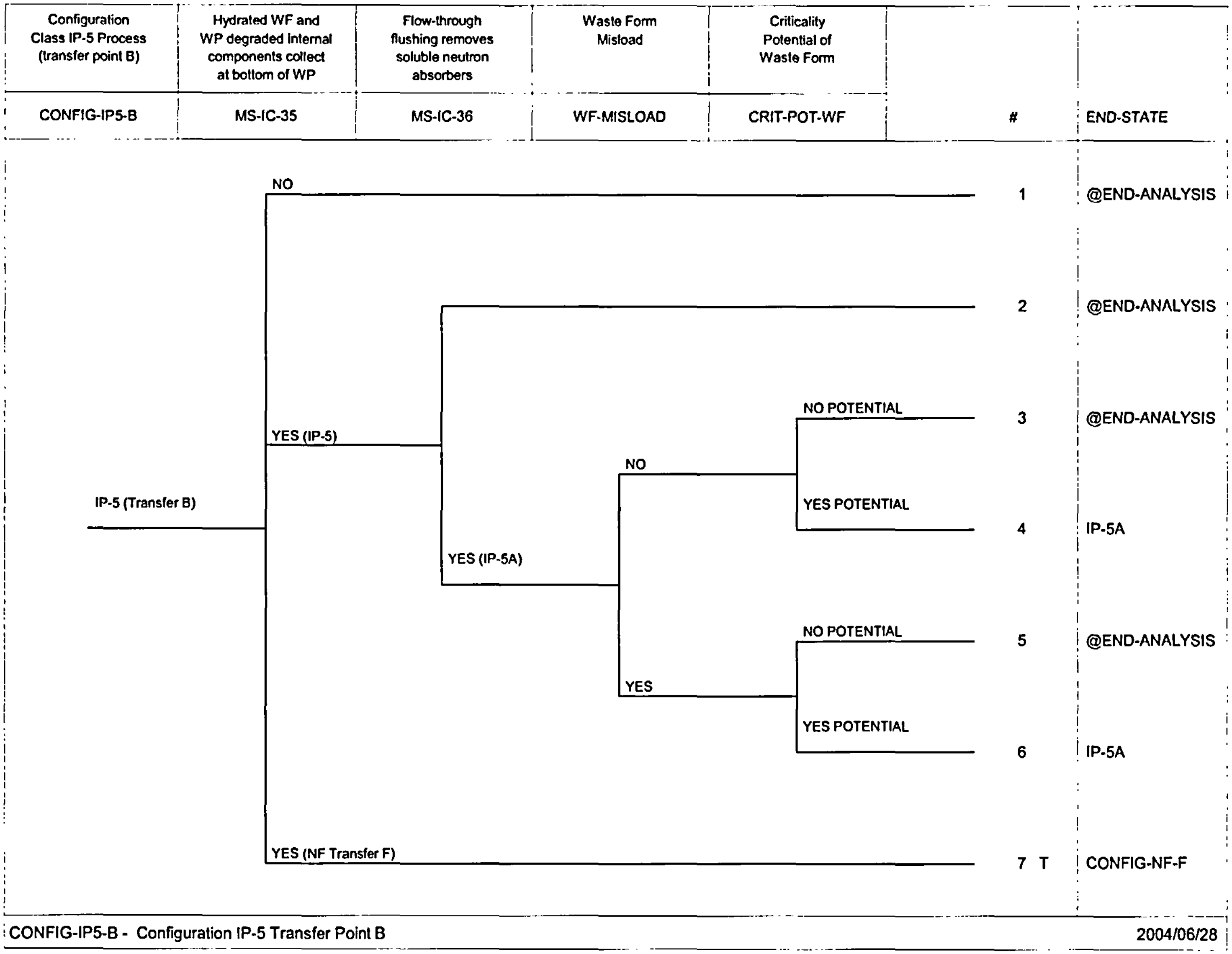

Figure I-12. Configuration Class IP-5 Event Tree — "CONFIG-IP5-B"

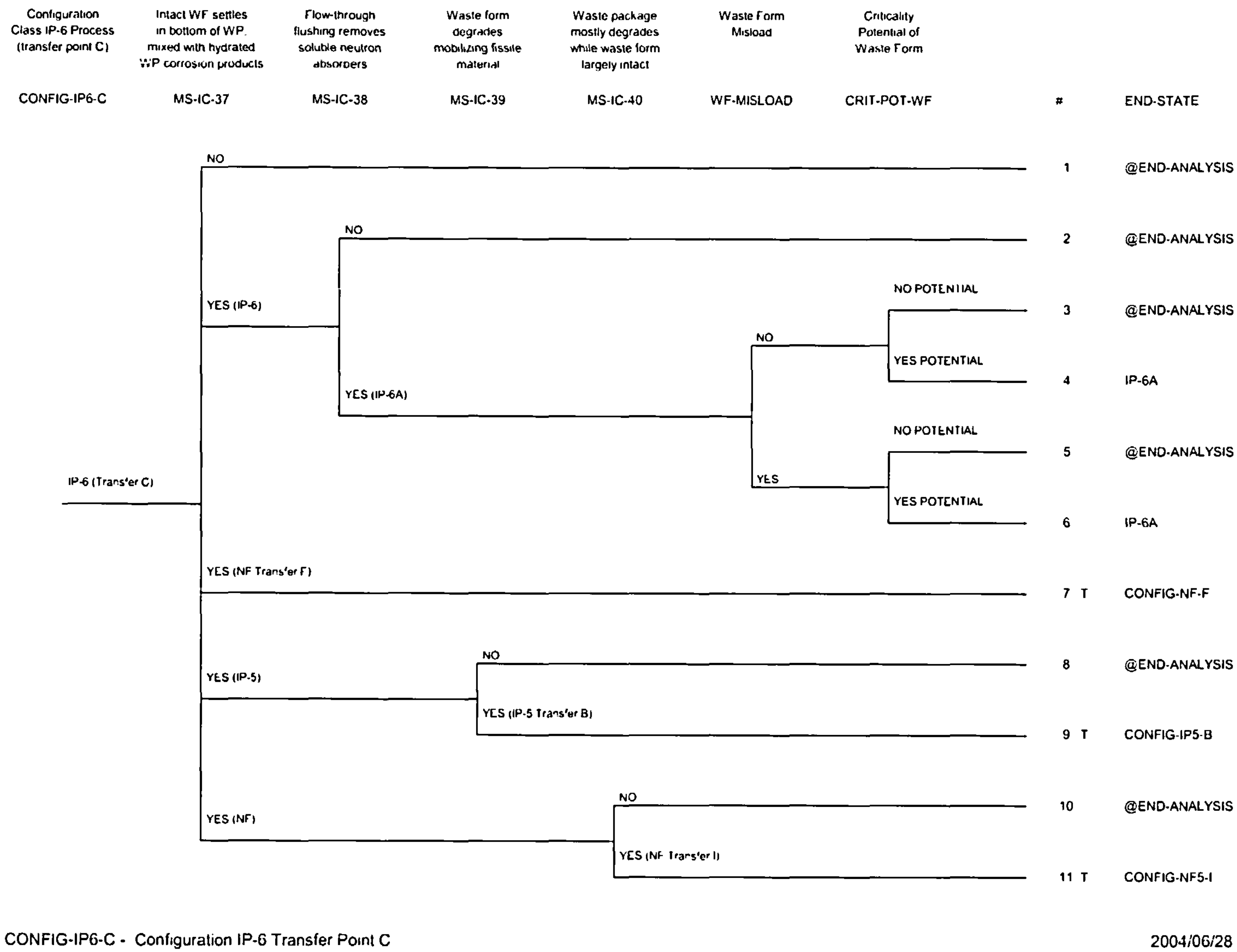

Figure I-13. Configuration Class IP-6 Event Tree — "CONFIG-IP6-C"

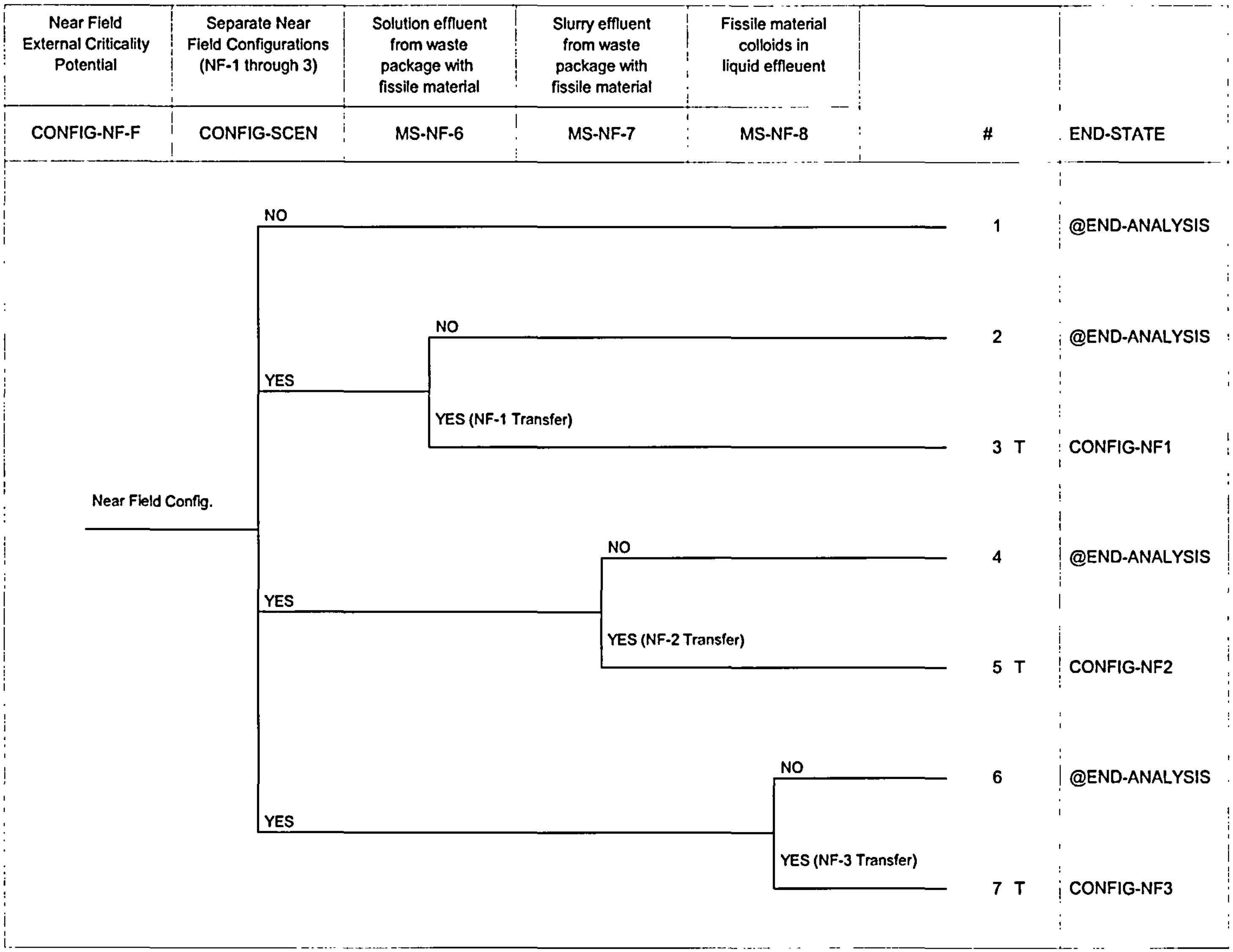

Figure I-14. Initial Near-Field Configuration Class Event Tree — "CONFIG-NF-F"

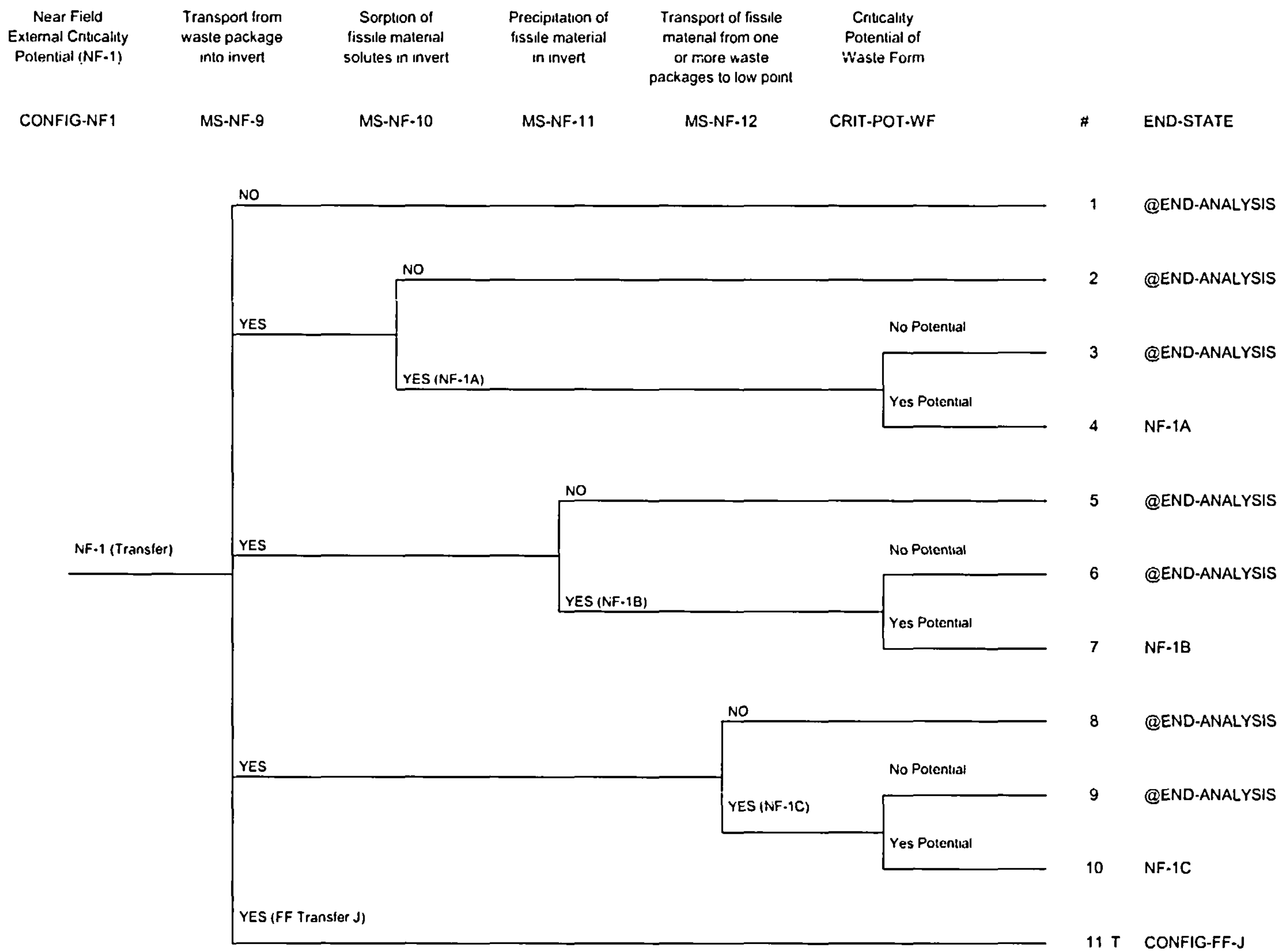

Figure I-15. Near-Field Configuration Class NF-1 Event Tree — "CONFIG-NF1"

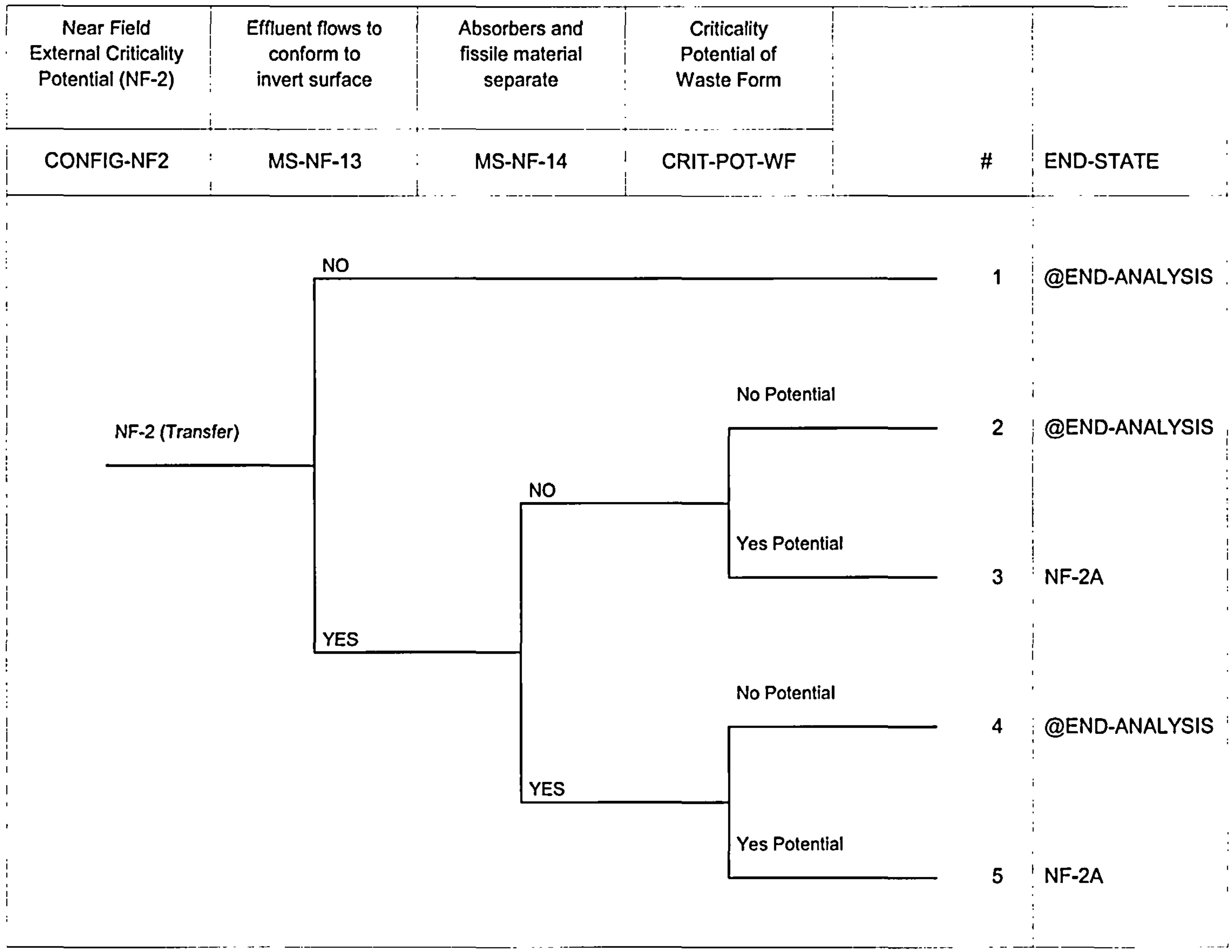

Figure I-16. Near-Field Configuration Class NF-2 Event Tree — "CONFIG-NF2"

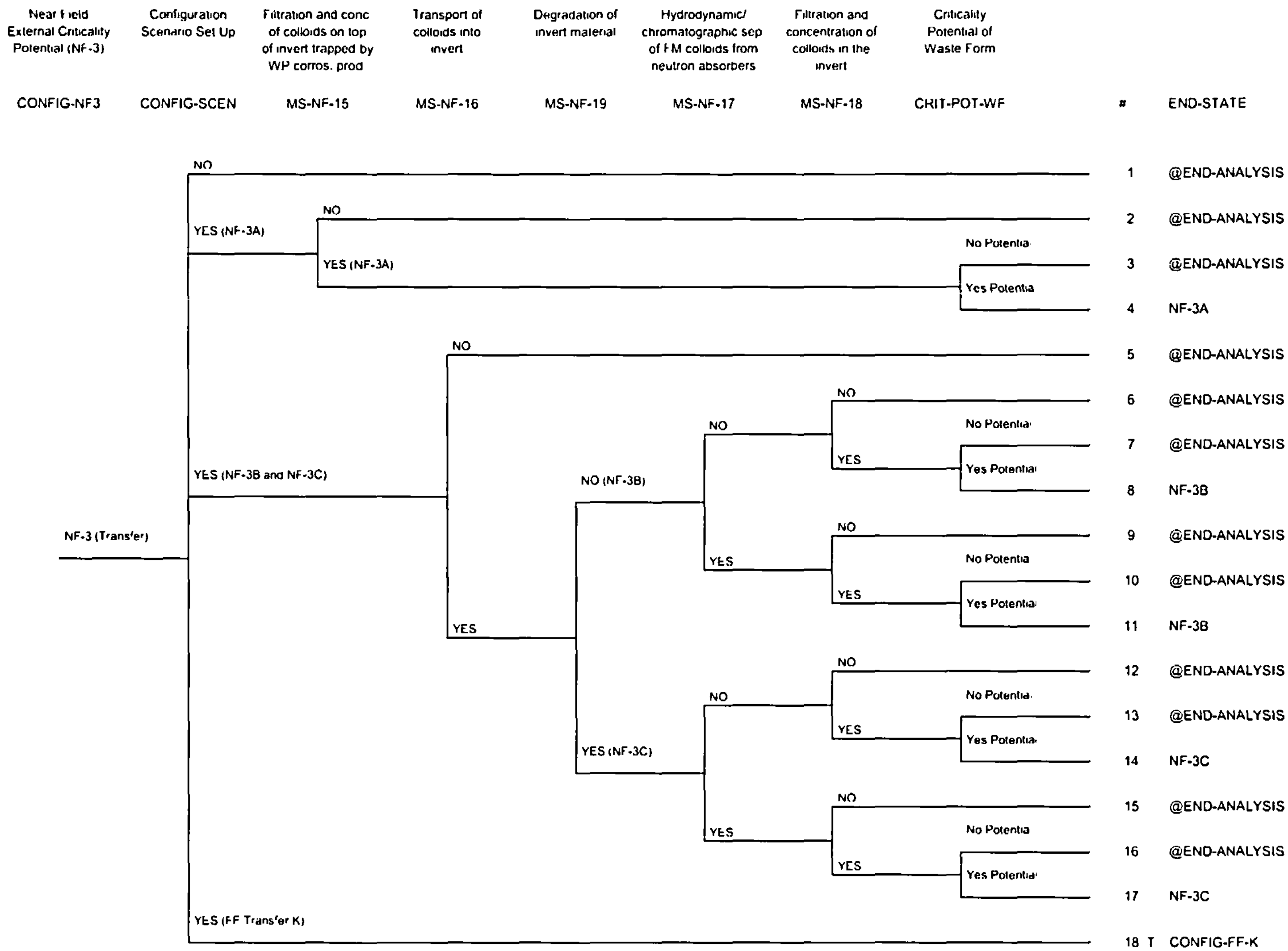

Figure I-17. Near-Field Configuration Class NF-3 Event Tree — "CONFIG-NF3"

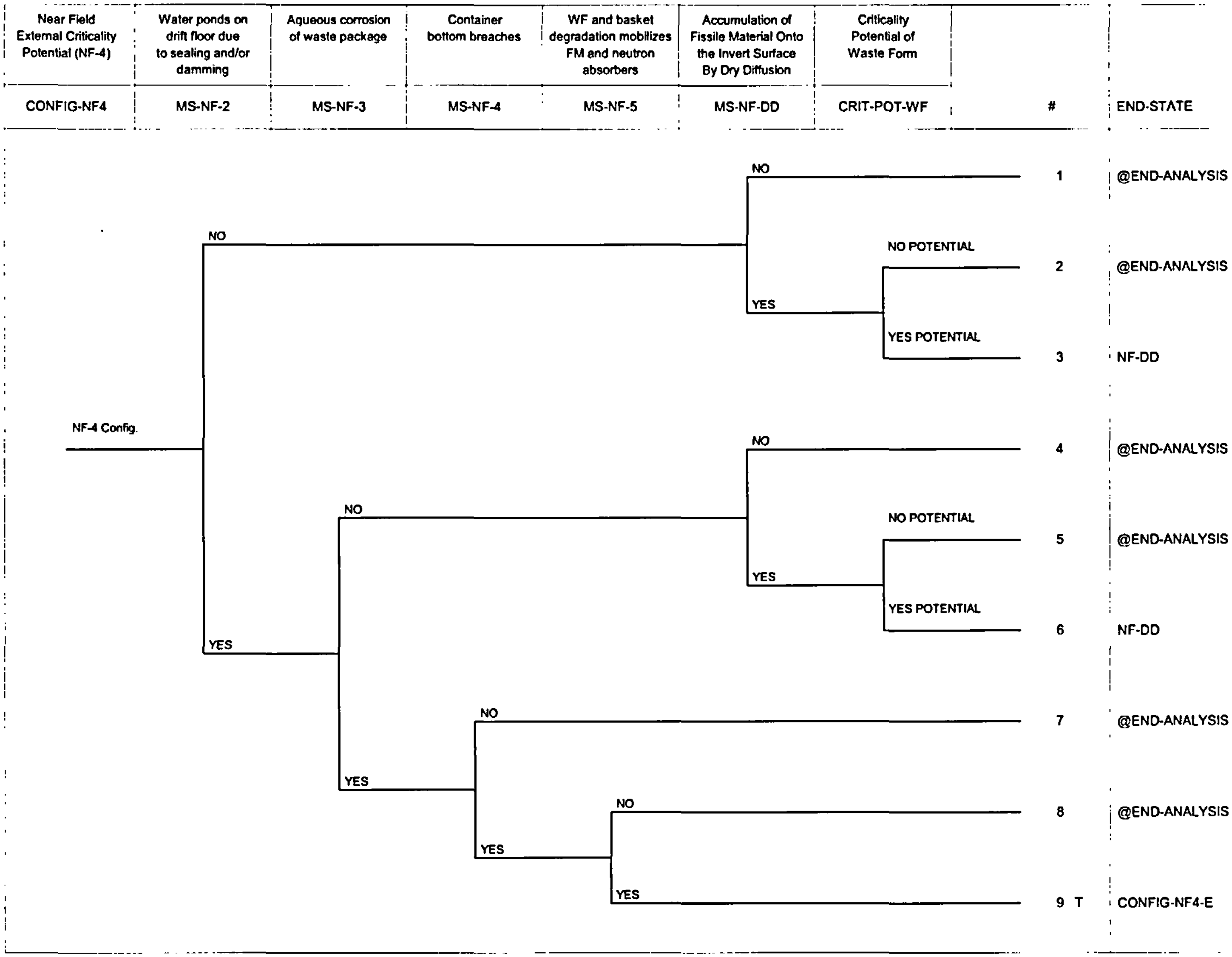

Figure I-18. Near-Field Configuration Class NF-4 Event Tree — "CONFIG-NF4"

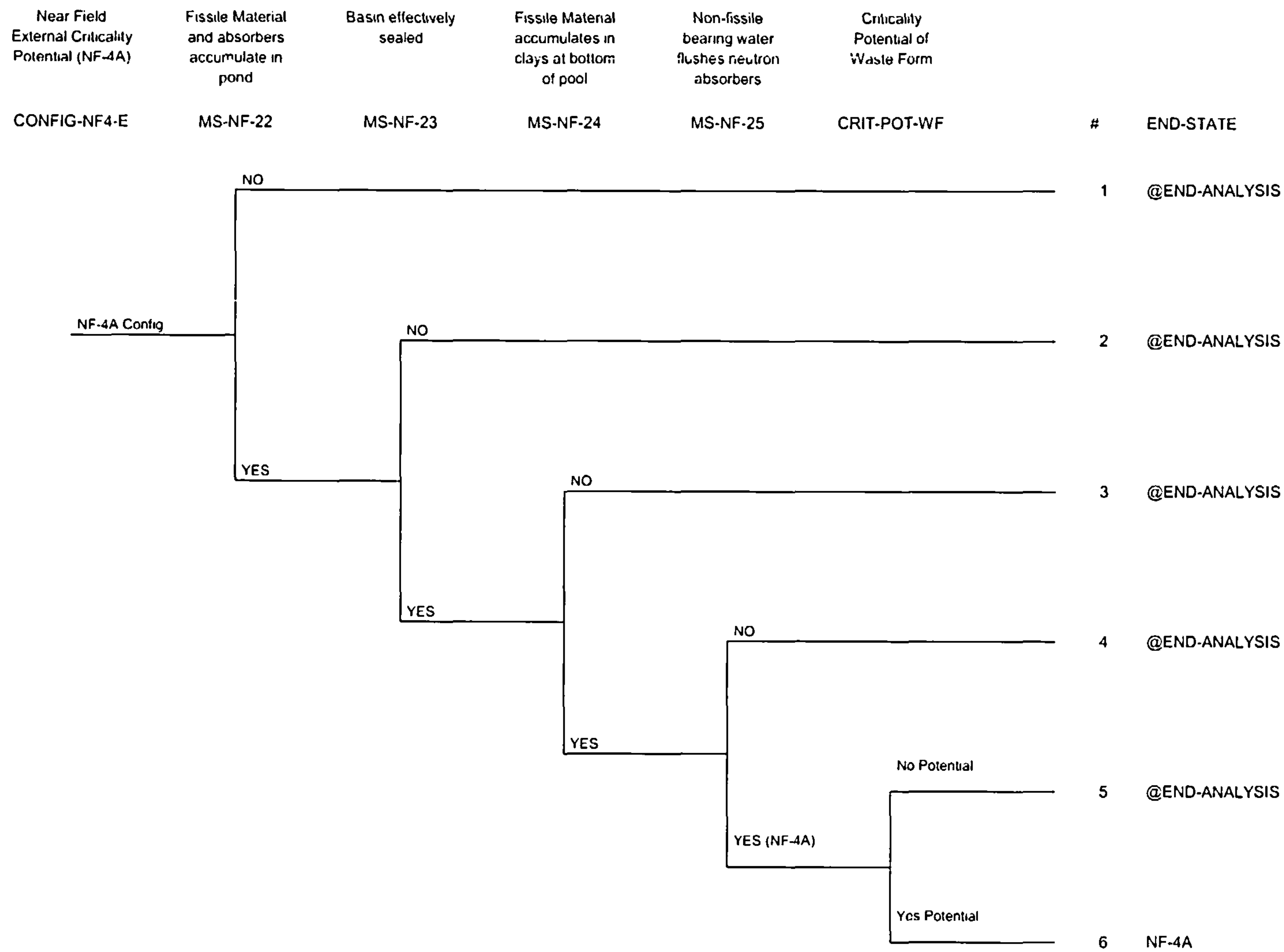

Figure I-19. Near-Field Configuration Class NF-4 Event Tree – Continued — "CONFIG-NF4-E"

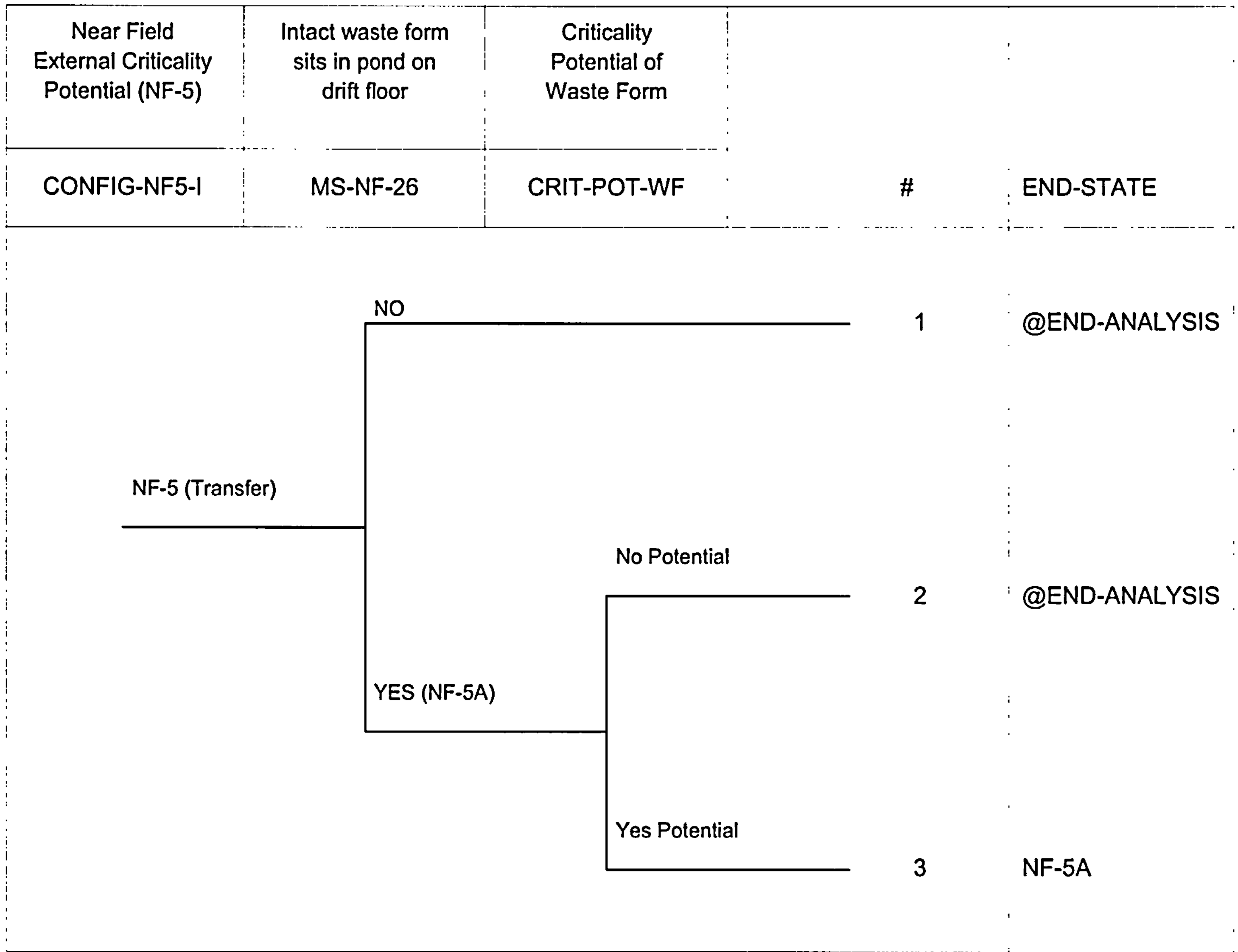

Figure I-20. Near-Field Configuration Class NF-5 Event Tree — "CONFIG-NF5-I"

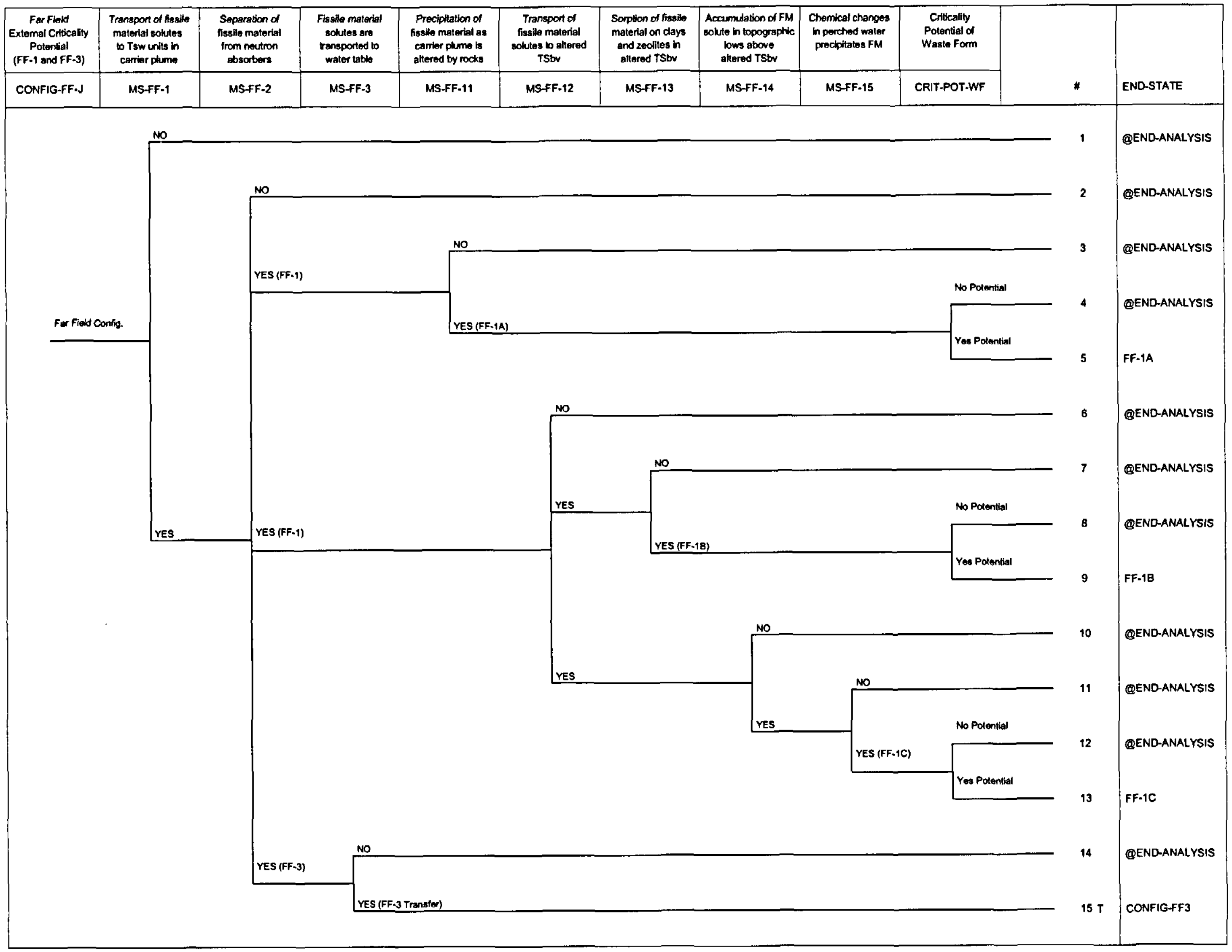

Figure I-21. Far-Field Configuration Class FF-1 Event Tree — "CONFIG-FF-J"

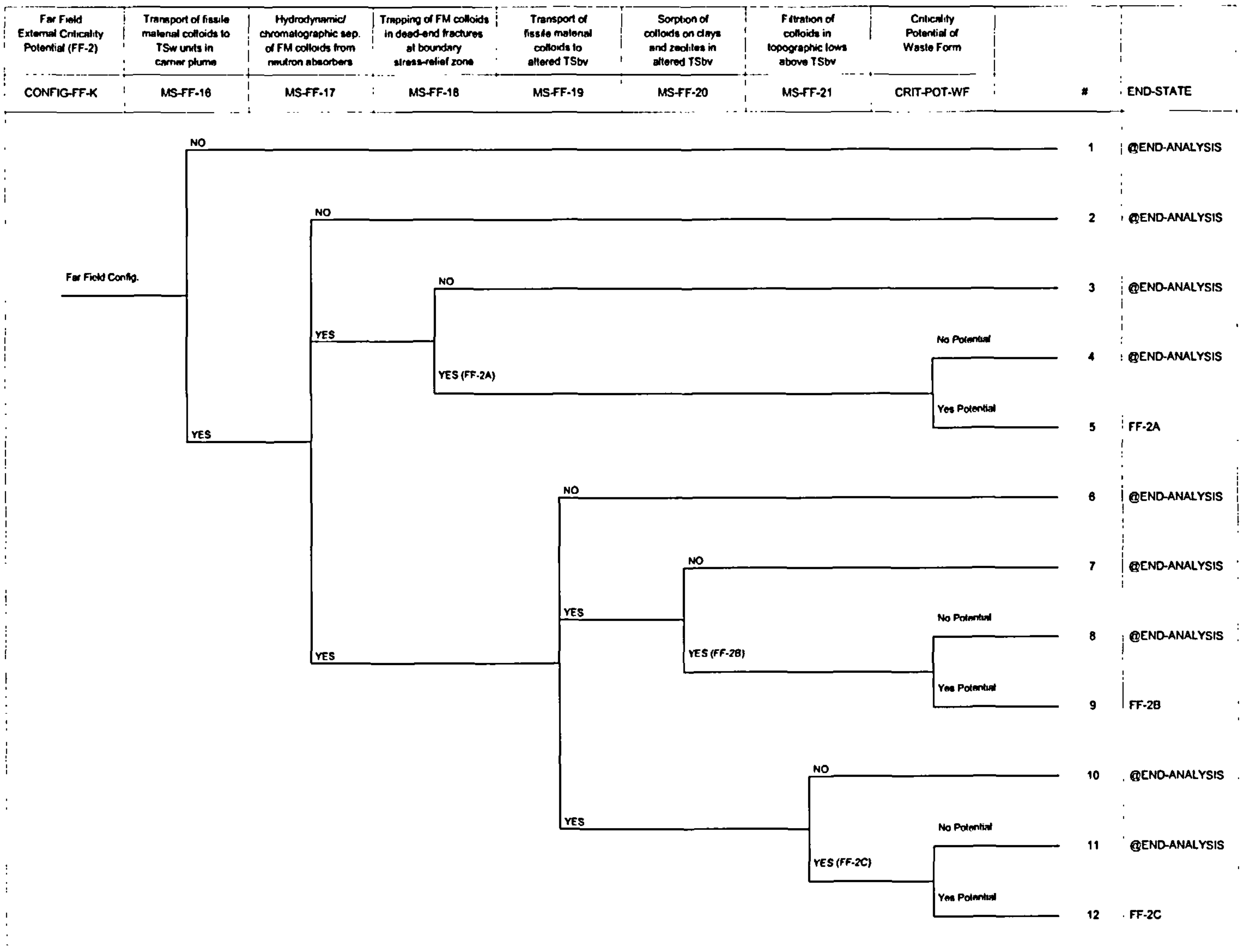

Figure I-22. Far-Field Configuration Class FF-2 Event Tree — "CONFIG-FF-K"

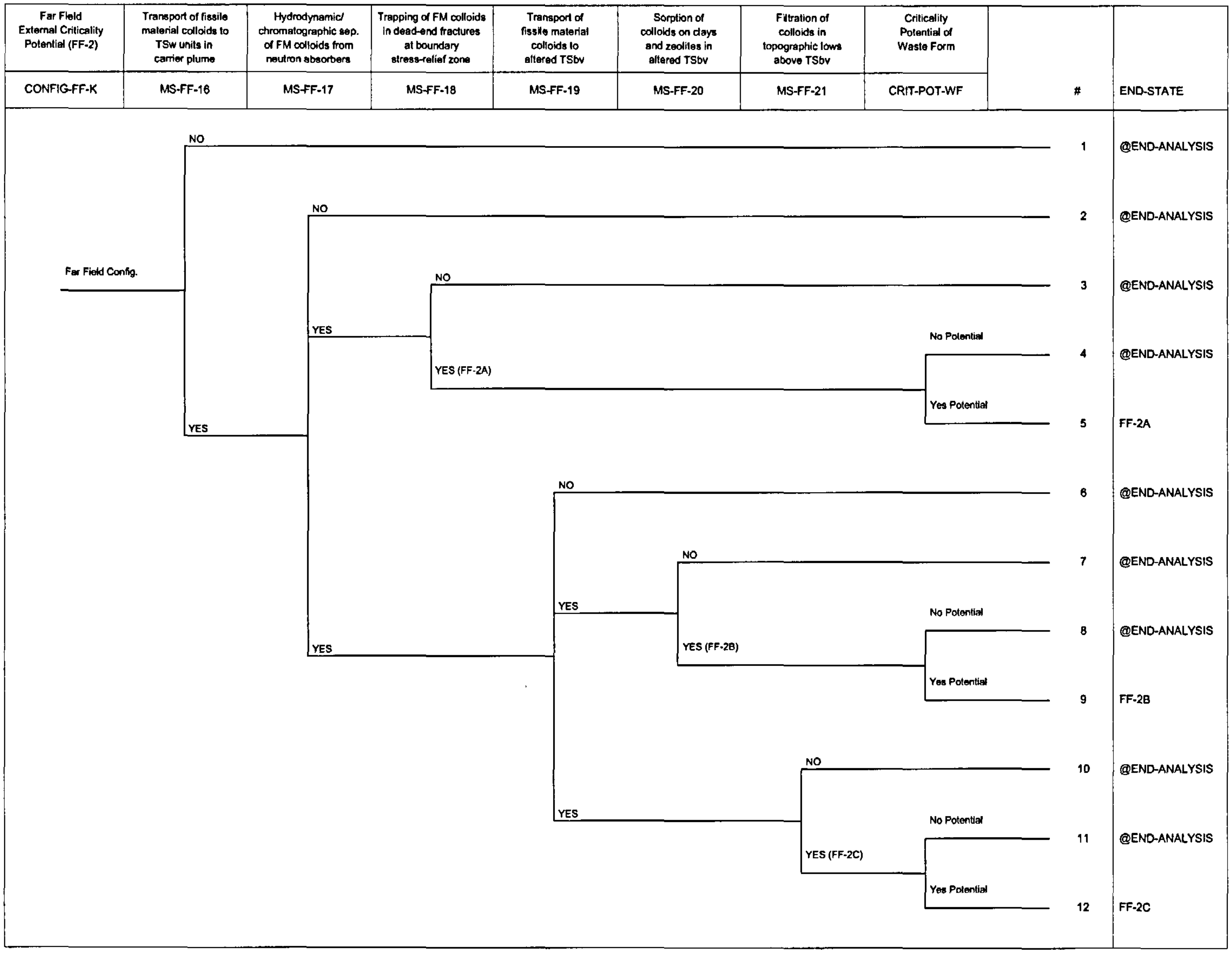

Figure I-22. Far-Field Configuration Class FF-2 Event Tree — "CONFIG-FF-K"

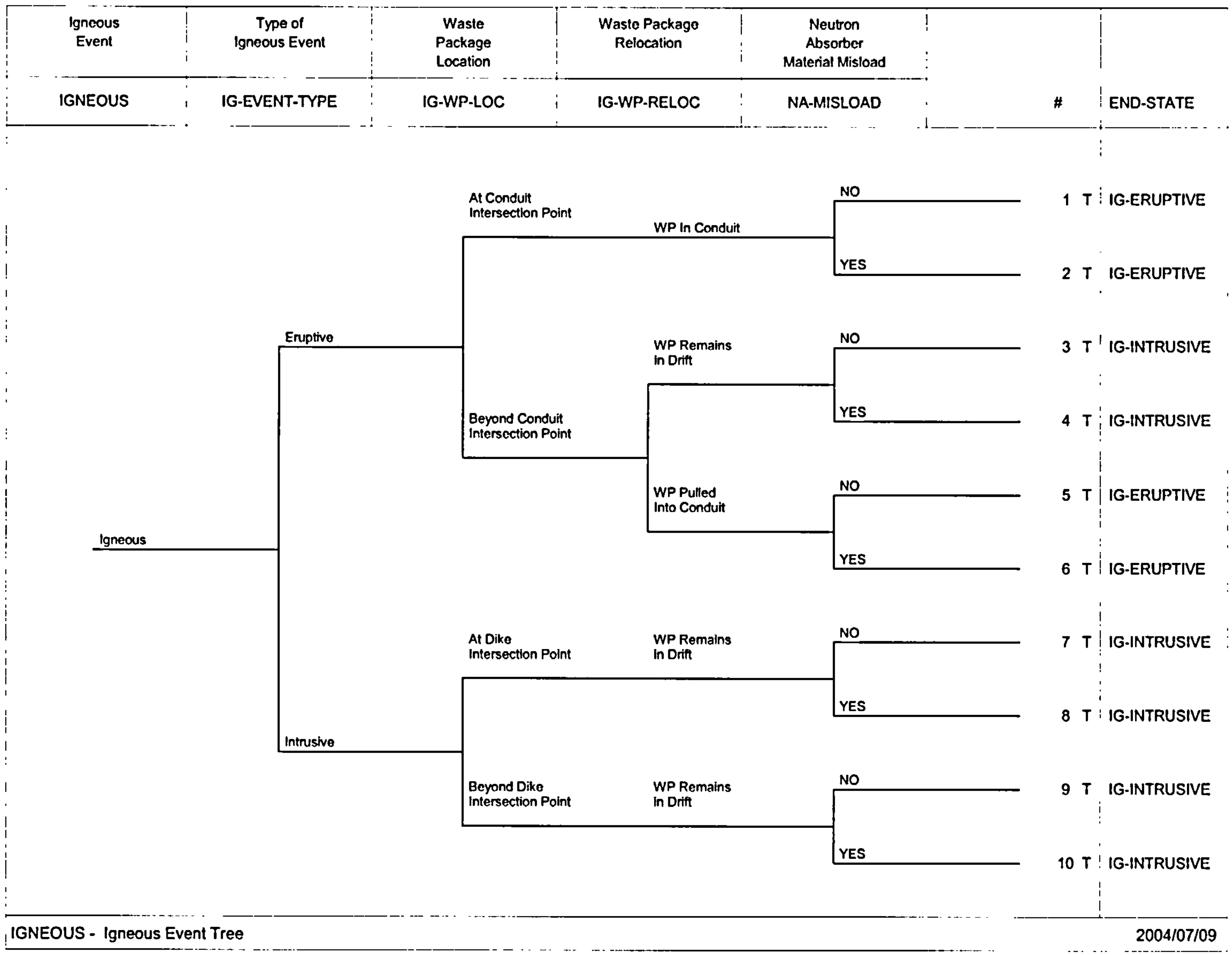

Figure I-24. Initial Igneous Event Tree — "IGNEOUS"

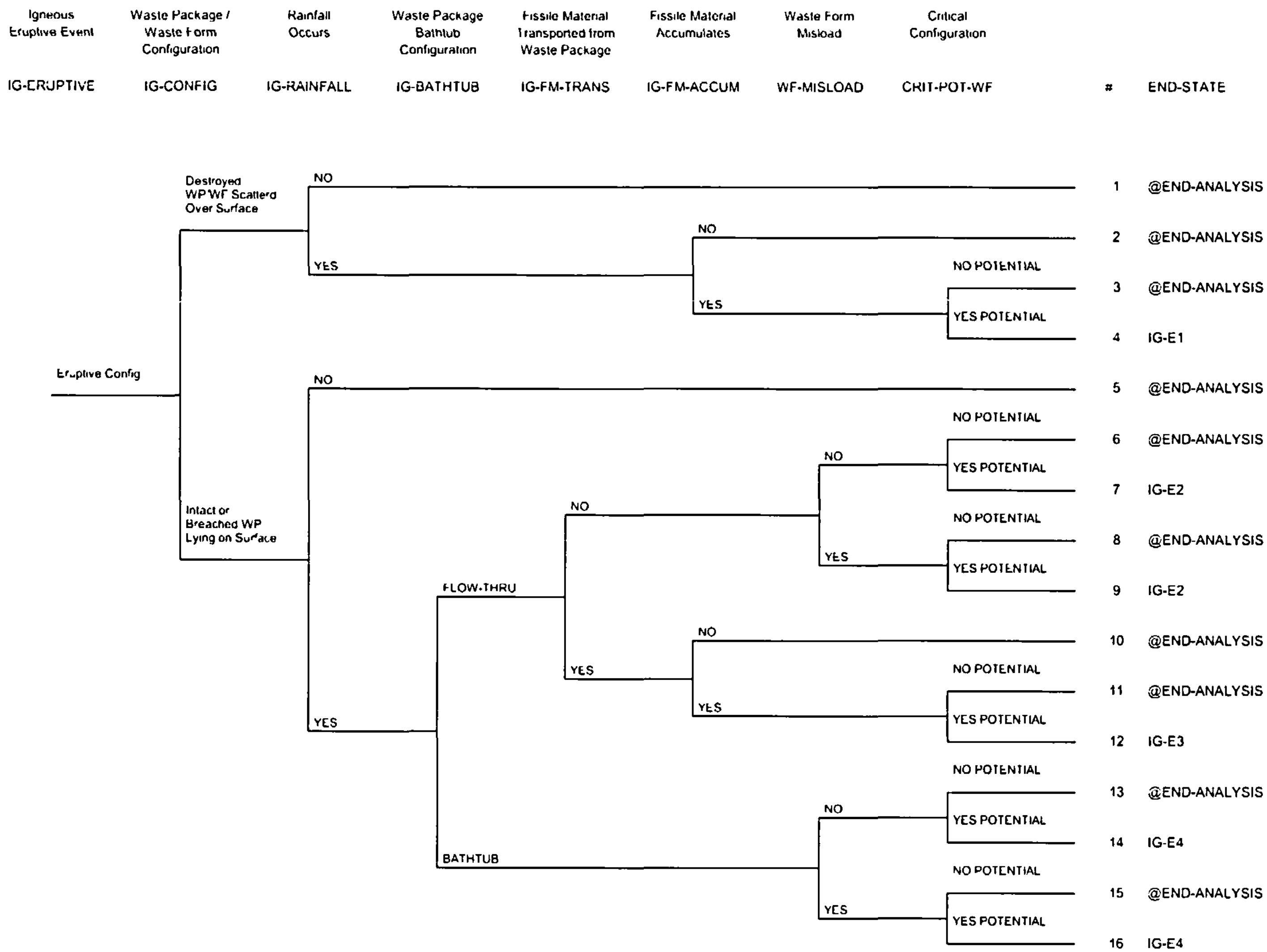

Figure I-25. Eruptive Scenario Igneous Event Tree — "IG-ERUPTIVE"

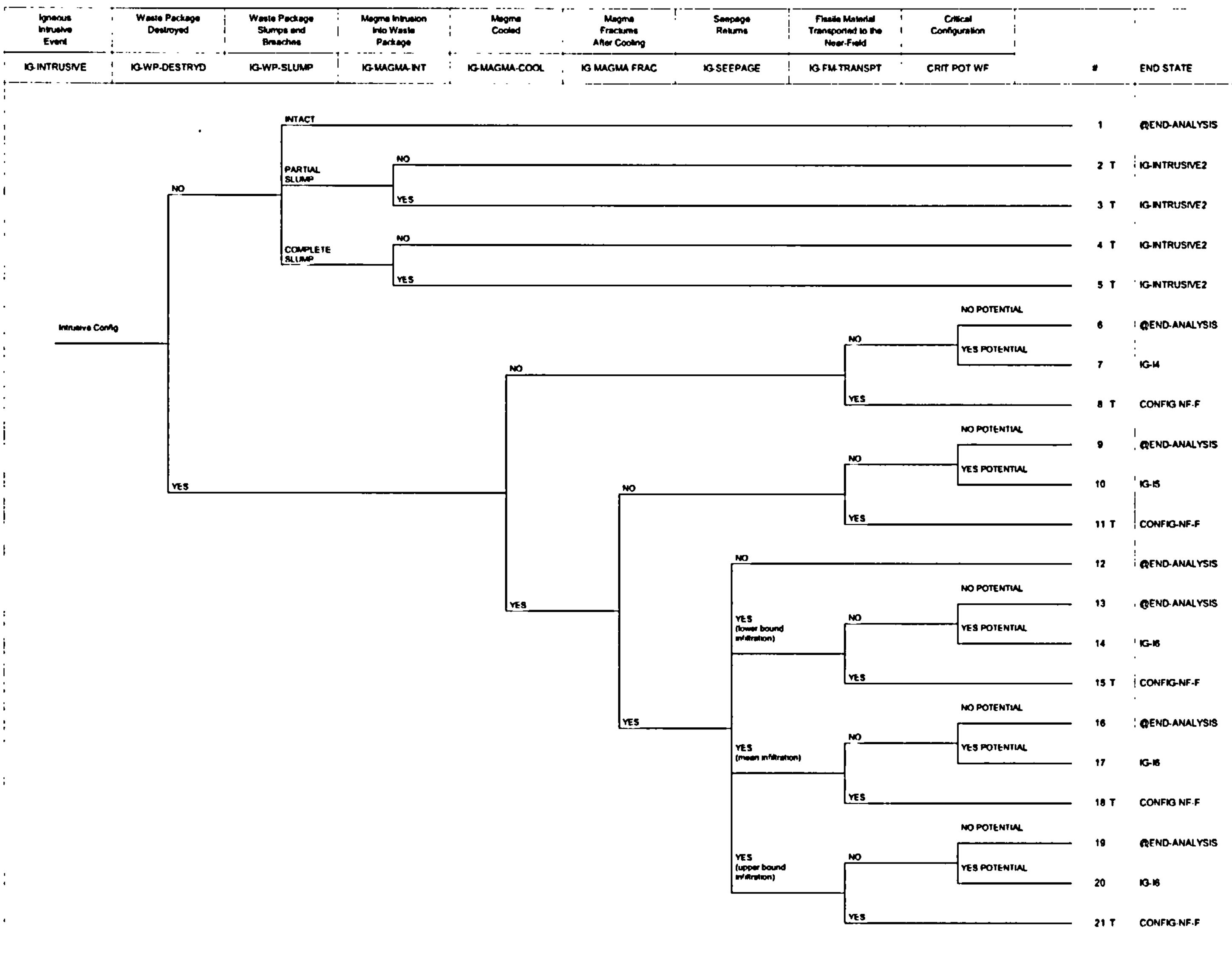

Figure I-26. Intrusive Scenario Igneous Event Tree — "IG-INTRUSIVE"

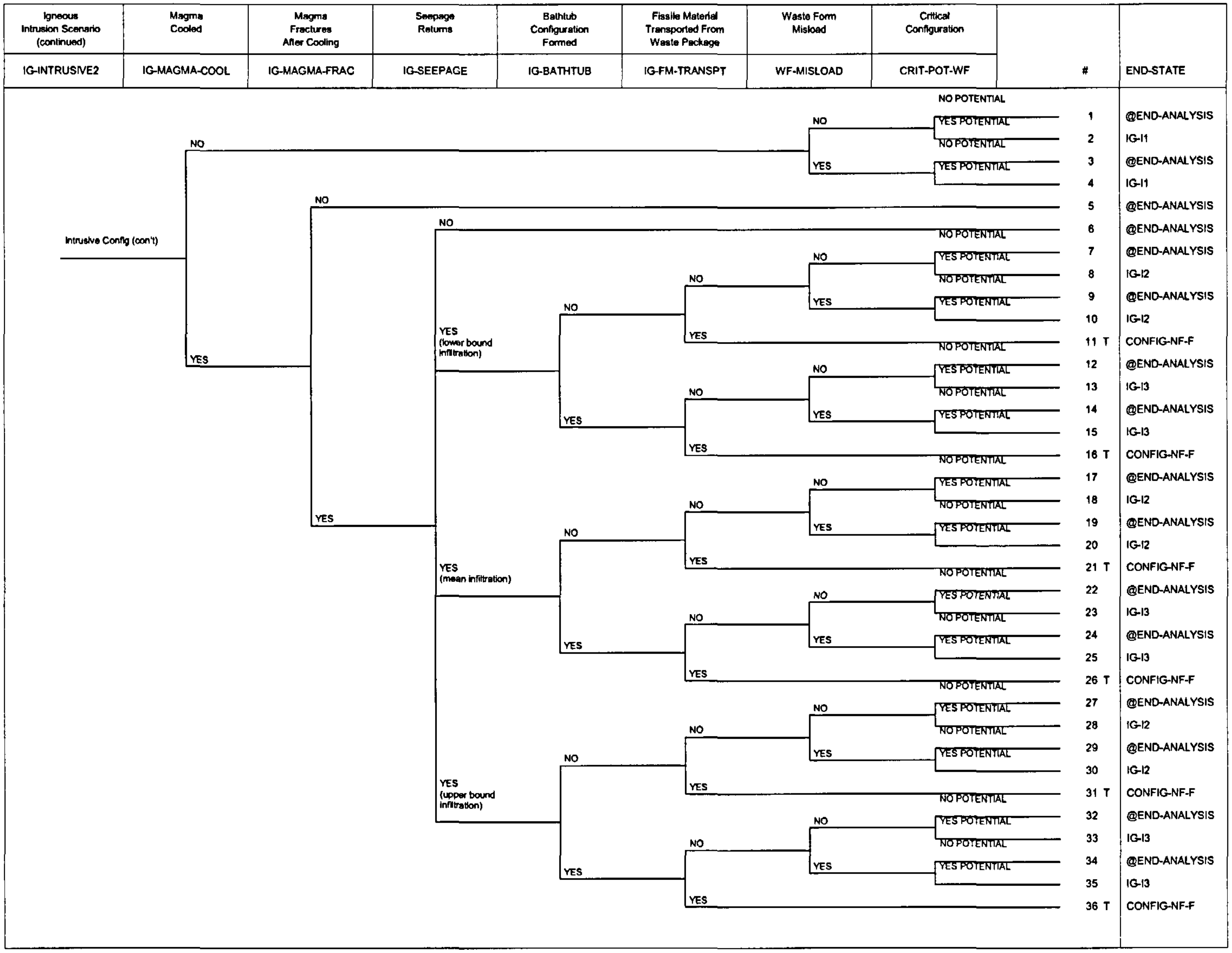

Figure I-27. Intrusive Scenario Igneous Event Tree - Continued — "IG-INTRUSIVE2"

I.2 LINKAGE RULES FOR THE "WP-WF" EVENT TREE (FIGURE I-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;
```

I.3 LINKAGE RULES FOR THE "YMP-INIT-EVENT" EVENT TREE (FIGURE I-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;
```

I.4 LINKAGE RULES FOR THE "IGNEOUS" EVENT TREE (FIGURE I-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.

```
|
| 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;
```

ATTACHMENT II

DESCRIPTION OF EVENT TREE TOPS

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ATTACHMENT II – DESCRIPTION OF EVENT TREE TOPS

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 I-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.

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

The 22 commercial and DOE SNF waste package types listed in Figure I-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 indicates the name of the event tree to which the transfer occurs.

The "YMP-INIT-EVENTS" event tree is presented in Figure I-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:

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 success 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 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 2004e). 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 2004e, Section 6.7). 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 2004e, Table 26). 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 II-1 and the information provided in Table II-1:

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

where: $\Delta\lambda$ is the difference in the seismic annual exceedance frequencies of interest (λ_2 - λ_1)
Δt is the difference in the time periods of interest ($t_1 - t_2$)

Table II-1. 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 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. Based on the drift area information, values are applied to DRIFT–ZONE. The upper branch of DRIFT-ZONE (i.e., /DRIFT-ZONE) will be assigned the complement value. 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 I-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 I -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" of Figures I-4 and I-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.

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. Both branches of this top event are evaluated in order to assess the criticality potential of these scenarios. Therefore, /MS-NF-T will be assigned a value of 0.00 (i.e., the complement of 1.00) and MS-NF-T will be assigned a value of 1.00.

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.

II.1 DESCRIPTION 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 (Attachment I, Figure I-4) and its continuation event tree "MSL-ET2" (Attachment I, Figure I-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 (Attachment I, Figure I-4) and its continuation event tree "MSL-ET2" (Attachment I, Figure I-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 sections provide descriptions of event trees "MSL-ET" and "MSL-ET2" for the base case. This event tree consists of 10 top events.

II.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

II.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 even are processed to ensure the evaluation of all configuration classes.

II.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 I-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).

II.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 (Attachment I, Figure I-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.

II.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 (Attachment I, Figure I -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).

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.

II.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.

II.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 (Attachment I, Figure I-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.

II.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 I-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.

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.

II.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.

II.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.

II.2 DESCRIPTION OF EVENT TREE "CONFIG–BATH"

The following subsections provide description of the top events of the event tree "CONFIG–BATH" (Attachment I, Figure I-6). This event tree consists of 10 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.3 DESCRIPTION OF EVENT TREE "CONFIG–NOBATH"

The following subsections provide description of the top events of the event tree "CONFIG–NOBATH" (Attachment I, Figure I-7). This event tree consists of 4 top events.

II.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.

II.3.2 Top Event MC-IC-29

The branching of top event MS-IC-29 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.

II.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.

II.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.

II.4 DESCRIPTION OF EVENT TREE "CONFIG–IP2-D"

The following subsections provide description of the top events of the event tree "CONFIG–IP2-D" (Attachment I, Figure I-8). This event tree consists of 5 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.5 DESCRIPTION OF EVENT TREE "CONFIG–IP3"

The following subsections provide description of the top events of the event tree "CONFIG–IP3" (Attachment I, Figure I-9). This event tree consists of 9 top events.

II.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 and third branches from the top of this top event. These two branches direct the evaluation of configuration subclass IP-3 and IP-6.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.5.8 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.

II.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.

II.6 DESCRIPTION OF EVENT TREE "CONFIG–IP3-G"

The following subsections provide description of the top events of the event tree "CONFIG–IP3-G" (Attachment I, Figure I-10). This event tree consists of 6 top events.

II.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.

II.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.

II.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.

II.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.

II.6.5 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.

II.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.

II.7 DESCRIPTION OF EVENT TREE "CONFIG–IP4-A"

The following subsections provide description of the top events of the event tree "CONFIG–IP4-A" (Attachment I, Figure I-11). This event tree initiates the evaluation of the internal waste package configuration subclasses IP-4A and IP-4B. This event tree consists of 6 top events.

II.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 convenience. The two 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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.8 DESCRIPTION OF EVENT TREE "CONFIG–IP5-B"

The following subsections provide description of the top events of the event tree "CONFIG-IP5-B" (Attachment I, Figure I-12). This event tree initiates the evaluation of the internal waste package configuration subclass IP-5B. This event tree consists of 4 top events.

II.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.

II.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.

II.8.3 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.

II.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.

II.9 DESCRIPTION OF EVENT TREE "CONFIG–IP6-C"

The following subsections provide description of the top events of the event tree "CONFIG–IP6-C" (Attachment I, Figure I-13). This event tree initiates the evaluation of the internal waste package configuration subclass IP-6C. This event tree consists of 6 top events.

II.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.

II.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.

II.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.

II.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.

II.9.5 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.

II.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.

II.10 DESCRIPTION OF EVENT TREE "CONFIG-NF-F"

The following subsections provide description of the top events of the event tree "CONFIG–NF-F" (Attachment I, Figure I-14). This event tree initiates the evaluation of the near-field configurations for the formation of potentially critical configurations. This event tree consists of 4 top events.

II.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.

II.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.

II.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.

II.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.

II.11 DESCRIPTION OF EVENT TREE "CONFIG-NF1"

The following subsections provide description of the top events of the event tree "CONFIG–NF1" (Attachment I, Figure I-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 5 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.12 DESCRIPTION OF EVENT TREE "CONFIG-NF2"

The following subsections provide description of the top events of the event tree "CONFIG-NF2" (Attachment I, Figure I-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 3 top events.

II.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.

II.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.

II.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.

II.13 DESCRIPTION OF EVENT TREE "CONFIG-NF3"

The following subsections provide description of the top events of the event tree "CONFIG–NF3" (Attachment I, Figure I-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 7 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.14 DESCRIPTION OF EVENT TREE "CONFIG-NF4"

The following subsections provide description of the top events of the event tree "CONFIG–NF4" (Attachment I, Figure I-18). This event tree initiates the evaluation of the near-field configuration class NF-4. This event tree consists of 6 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.14.6 Top Event CRIT-POT-WF

The branching of top event CRIT-POT-WF represents the criticality potential of near-field configuration subclass NF-4A. The upper branch indicates that this configuration does not have any criticality potential and the lower branch indicates that it does.

II.15 DESCRIPTION OF EVENT TREE "CONFIG-NF4-E"

The following subsections provide description of the top events of the event tree "CONFIG–NF4-E" (Attachment I, Figure I-19). This event tree initiates the evaluation of the near-field configuration class NF-4. This event tree consists of 5 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.16 DESCRIPTION OF EVENT TREE "CONFIG-NF5-I"

The following subsections provide description of the top events of the event tree "CONFIG–NF5-I" (Attachment I, Figure I-20). This event tree initiates the evaluation of the near-field configuration class NF-5. This event tree consists of 2 top events.

II.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.

II.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.

II.17 DESCRIPTION OF EVENT TREE "CONFIG-FF-J"

The following subsections provide description of the top events of the event tree "CONFIG–FF-J" (Attachment I, Figure I-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 9 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.18 DESCRIPTION OF EVENT TREE "CONFIG-FF-K"

The following subsections provide description of the top events of the event tree "CONFIG–FF-K" (Attachment I, Figure I-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 7 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.19 DESCRIPTION OF EVENT TREE "CONFIG-FF3"

The following subsections provide description of the top events of the event tree "CONFIG–FF3" (Attachment I, Figure I-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 9 top events.

II.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.

II.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 it is.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.20 DESCRIPTION OF EVENT TREE "IGNEOUS"

The following subsections provide description of the top events of the event tree "IGNEOUS" (Attachment I, Figure I-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 4 top events.

II.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. Therefore, IG-EVENT-TYPE is assigned a value of 1.00.

II.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.

II.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 get pulled into the conduit.

II.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 (Attachment I, Figure I-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.

II.21 DESCRIPTION OF EVENT TREE "IG-ERUPTIVE"

The following subsections provide description of the top events of the event tree "IG-ERUPTIVE" (Attachment I, Figure I-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 7 top events.

II.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).

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.22 DESCRIPTION OF EVENT TREE "IG-INTRUSIVE"

The following subsections provide description of the top events of the event tree "IG-INTRUSIVE" (Attachment I, Figure I-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 8 top events.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.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.

II.22.8 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.

II.23 DESCRIPTION OF EVENT TREE "IG-INTRUSIVE2"

The following subsections provide description of the top events of the event tree "IG-INTRUSIVE2" (Attachment I, Figure I-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 7 top events.

II.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.

II.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.

II.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.

II.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.

II.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. Both scenarios are evaluated in this analysis as being equiprobable for the determination of each configurations criticality potential.

II.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.

II.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.

ATTACHMENT III

LIST OF THE ELECTRONIC FILES IN ATTACHMENT IV

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ATTACHMENT III

LIST OF THE ELECTRONIC FILES IN ATTACHMENT IV

This attachment contains a listing and description of the zip file contained on the attachment CD of this model report. The zip archive was created using WinZip 8.1. The zip file attributes are:

Archive File Name	File Size (bytes)	FileDate	File Time
criticality-cgm-rev00A-model.zip	95,531	09/27/2004	2:59 PM

Upon the zip file extraction, 65 SAPHIRE V.7.18 files are found.

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