SUMMARY OF PRELICENSING ACTIVITIES ON POSTCLOSURE CRITICALITY SAFETY—PROGRESS REPORT

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ABSTRACT

This report provides a historical summary of the U.S. Department of Energy (DOE) prelicensing approach to disposal criticality for waste forms in the potential repository at Yucca Mountain, Nevada. The information is compiled to better inform the review of the postclosure criticality portion of the potential license application for a high-level radioactive waste geologic repository. The disposal criticality prelicensing activities cover about a 25-year time span. There were changes in the DOE approach to disposal criticality and the U.S. Nuclear Regulatory Commission (NRC) regulatory review process and changes in NRC technical and management staffs involved during this time. This report presents an organizational memory on the potential repository postclosure criticality safety. The report very briefly addresses the main conditions controlling the self-sustaining chain nuclear fission process, describes past examples of uncontrolled criticality incidents outside nuclear reactors in both natural and engineered settings, presents regulatory citations and guidance, relevant to postclosure repository criticality, outlines the timeline of some of the prelicensing interactions on postclosure criticality and evolution, and covers the status of the DOE prelicensing criticality approach. Many criticality technical issues raised during prelicensing activities were resolved, some became irrelevant due to modified design and methodology, and some issues remain unresolved. The report does not explicitly invoke or discuss these issues but provides key references that would assist a potential license application reviewer in the review process.

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1 INTRODUCTION

The U.S. Department of Energy (DOE) submitted to the U.S. Nuclear Regulatory Commission (NRC) an application for a construction authorization for a potential repository at the Yucca Mountain site in Nevada. NRC licensing criteria at 10 CFR 63.114(e) require a postclosure performance assessment to provide the technical basis for inclusion or exclusion of specific features, events, and processes. This report focuses on the DOE approach and supporting technical basis for screening features, events, and processes related to postclosure criticality for their potential inclusion or exclusion from the performance assessment.

DOE has evaluated disposal criticality using various approaches during the past 25 years of prelicensing activity. During this time, there also have been changes in NRC technical and management staffs involved in reviewing these approaches. This report serves as a historical basis to help prepare NRC review of postclosure criticality in the DOE license application.

1.1 Purpose

This report summarizes the history of the DOE approach to considering postclosure criticality. It captures an organizational memory of topics related to postclosure criticality for the potential repository and includes some background information on criticality to facilitate the understanding of the DOE treatment of postclosure criticality.

1.2 Background Information

Before providing a history of the DOE approach to considering postclosure criticality, it is helpful to understand some background on nuclear criticality. Nearly all of the waste packages that would be disposed in a potential repository would contain spent nuclear fuel of some type, such as commercial power, navy, research, production, or other special reactor spent nuclear fuel. Nuclear fuel contains fissile materials and is designed to achieve a controlled, self-sustaining chain nuclear fission process under certain conditions existing inside a nuclear reactor on thermal neutrons. The main conditions include a geometric configuration of the fuel and the presence of a neutron moderator, a neutron reflector, and a neutron absorber. The mutual geometric configurations and material content of the fuel, moderator, reflector, and absorber allow the system to achieve a controlled fission process inside a reactor and to control the fission process at a desirable level of power. The self-sustained fission chain reaction is often referred to as a critical state of a certain system containing fissile material. Such a system is characterized by a neutron multiplication factor or k_{eff}. If a system is subcritical, its k_{eff} is less than 1; if a system becomes supercritical, its k_{eff} is greater than 1. Nuclear reactors are specifically designed to achieve and sustain k_{eff} = 1 under controlled conditions and to provide shielding against the radiation and containment of the radioactive products produced during normal operations. Outside of a reactor, fissile materials, including fresh or spent nuclear fuel, must be managed to keep k_{eff} below 1, with a sufficient safety margin to avoid an inadvertent nuclear excursion—often referred to as a criticality accident.

Past examples of uncontrolled criticality incidents include both natural and engineered settings. In a natural geologic setting, multiple criticalities occurred at Oklo uranium deposits in Africa and lasted intermittently between 2×10^5 and 8×10^5 years (Rechard, et al., 2000; Eisenbud and Gesell, 1997; Pearcy and Murphy, 1991). About 60 known criticality accidents that have occurred around the globe since 1945 (Los Alamos National Laboratory, 2000) are outside the scope of this report because they took place in engineered settings in laboratories, processing, and reactor facilities and therefore are not directly relevant to the geologic repository postclosure period.

Most individual waste packages would contain a sufficient amount of fissile materials (i.e., critical mass) to sustain a chain reaction if other necessary conditions were introduced. Postclosure criticality could potentially have adverse effects on performance. Therefore, nuclear criticality is an event that needs to be addressed as part of scenario analysis in the performance assessment. As described in Section 2.1, specific events (e.g., criticality) can be excluded, as part of the scenario analysis, from the performance assessment either based on probability or consequence considerations.

Prevention of nuclear criticality in operation facilities involves a combination of neutron physics, engineering, and management measures. Nuclear criticality analyses, which include consideration of those factors, have been used to determine the probability of criticality occurring in the postclosure period. Several analyses related to potential disposal criticality at the potential repository have been performed during the prelicensing period (e.g., Wilson and Evans, 1995; Bowman and Venneri, 1996; Garwin, 1996; Van Konynenburg, 1996; Greenspan, et al., 1996; Kastenberg, et al., 1996; Ahn, 1997; CRWMS M&O, 1998; Rechard, et al., 2003a,b). Detailed discussion of these analyses is beyond the scope of this report, but the reports may be referenced by those who require a more detailed insight into disposal nuclear criticality.

1.3 Scope

Section 2.1 of this report presents specific regulatory citations that address postclosure criticality at the potential high-level waste geologic repository as part of the overall licensing criteria for the disposal of high-level waste. Section 2.2 presents excerpts from the regulatory guidance to be used in review of postclosure criticality portions of the potential DOE license application. Section 2.3 lists other applicable NRC guidance documents that may help in the evaluation of disposal criticality analyses in a license application review. Section 3 outlines the timeline of some of the prelicensing interactions on disposal criticality and the evolution and status of the DOE prelicensing criticality approach.

2 REGULATORY CITATIONS AND GUIDANCE PERTINENT TO CRITICALITY AT THE REPOSITORY

2.1 Citations in 10 CFR Part 63 Addressing Criticality

Material and geometric configurations of the fissile materials and neutron absorbers are among the most important waste form characteristics that can be used to assess the probability of postclosure criticality. These configurations will be established during the preclosure period. In addition, in the postclosure scenario analyses the U.S. Department of Energy (DOE) relies on the design and process controls anticipated during preclosure period (Sandia National Laboratories, 2008a,b). Therefore, preclosure criticality provisions in 10 CFR Part 63 (Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada) are included in this section along with the postclosure provisions pertinent to disposal criticality. Although criticality is not specifically cited in the requirements for the postclosure performance assessment, 10 CFR 63.114 provides the requirements in which postclosure criticality is assessed.

"§63.78 Material control and accounting records and reports.

DOE shall implement a program of material control and accounting (and accidental criticality reporting) that is the same as that specified in §§72.72, 72.74, 72.76, and 72.78 of this chapter.

§63.102 Concepts.

…(j) *Performance Assessment.*

…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 effect of radionuclide sorption; potentially adverse effect of fracture flow or a criticality event)…

§63.112 Requirements for preclosure safety analysis of the geologic repository operations area.

The preclosure safety analysis of the geologic repository operations area must include:…

(e) An analysis of the performance of the structures, systems, and components to identify those that are important to safety. This analysis identifies and describes the controls that are relied on to limit or prevent potential event sequences or mitigate their consequences. This analysis also identifies measures taken to ensure the availability of safety systems. The analysis required in this paragraph must include, but not necessarily be limited to, consideration of…

(6) Means to prevent and control criticality;…

§63.114 Requirements for performance assessment.

Any performance assessment used to demonstrate compliance with §63.113 must:

…(d) Consider only events that have at least one chance in 10,000 of occurring over 10,000 years.

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

(f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, would be significantly changed by their omission.

§63.142 Quality assurance criteria.

…(d) *Design control*

…(2)(i) ...Design control measures must be applied to items such as: criticality physics...and preclosure and postclosure analyses…"

2.2 Postclosure Disposal Criticality Topics in the Yucca Mountain Review Plan

The Yucca Mountain Review Plan (NRC, 2003), was developed to ensure the quality and uniformity of the U.S. Nuclear Regulatory Commission (NRC) staff review of the DOE license application for a geologic repository. The document, contains information relevant to review of postclosure criticality (see Appendix A).

2.3 Applicable Regulatory Guides and Standards

Regulatory Guide 3.71, Nuclear Criticality Safety Standards for Fuels and Material Facilities (NRC, 2005), is not specific to criticality in the potential high-level waste repository, but it provides relevant information that addresses criticality safety analyses outside nuclear reactors. Regulatory Guide 3.71 may be followed in postclosure performance reviews (NRC, 2000). The guide recommends the licensees follow procedures outlined in certain American National Standards Institute/American Nuclear Society-8 nuclear criticality standards.

3 TIMELINE OF PRELICENSING INTERACTIONS PERTINENT TO DISPOSAL CRITICALITY

Table 3-1 provides brief summaries of some of the key meetings, publications, U.S. Department of Energy submissions, U.S. Nuclear Regulatory Commission responses, and interactions between the two agencies, during the prelicensing period, pertinent to disposal criticality.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality			
Date	**NRC Activities**	**DOE Activities**	**Reference**
February 1994	The U.S. Nuclear Regulatory Commission (NRC) issues Topical Report Review Plan (Holonich, 1994). The plan emphasizes that the topical report approach is appropriate if the topical report (i) deals with the subject requiring a safety assessment that could be reviewed independently of any specific license application (e.g., design, analytical models, or techniques or performance testing of components or systems), (ii) is capable of being referenced in multiple license applications, (iii) contains complete and detailed information on the specific subject presented, and (iv) would increase efficiency of the application review upon completion of the report review. The plan emphasizes that clear benefits can be achieved using a topical report approach in the high-level waste program. If the U.S. Department of Energy (DOE) submits a topical report, the NRC staff will prepare a safety evaluation documenting the results of the review. If NRC staff accept the topical report after resolution of any issues and if the staff finds the topical report acceptable for referencing in the license application, DOE may incorporate the topical report by reference in the license application for a high-level waste repository.	—	Holonich, J.J. "Topical Review Plan." Letter (February 28) to D.E. Schelor, DOE. ADAMS Accession No. ML031750474. LSN Accession No. NRC00006542. Washington, DC: NRC. 1994.
August 1995	—	DOE submits Disposal Criticality Analysis Topical Report Annotated Outline to NRC.	Not found.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
October 1995	NRC reviews and provides comments to DOE on Disposal Criticality Analysis Topical Report Annotated Outline.	—	NRC. U.S. Department of Energy Annotated Outline for Topical Report, "Disposal Criticality Analysis." (Letter). ADAMS Accession No. ML033080064. LSN Accession No. NRC000020328. Washington, DC: NRC. 1995.
1995	—	Idaho National Laboratory evaluates a potential nuclear fuel repository criticality scenario (Wilson and Evans, 1995). The estimated frequency of criticality is 3×10^{-7} per year.	Wilson, J.R. and D. Evans. "Evaluation of a Potential Nuclear Fuel Repository Criticality: Lessons Learned." Presentation at the Joint American Society of Mechanical Engineers/Japan Society of Mechanical Engineers Pressure Vessels and Piping Conference, Honolulu, Hawaii, July 23–27, 1995. INEL–94/00106. CONF–950740–99. Idaho Falls, Idaho: Idaho National Engineering Laboratory. 1995.
January 1996	—	DOE responds to NRC comments on Disposal Criticality Analysis Topical Report Annotated Outline—Response to NRC Comments (DOE, 1996). DOE agrees that criticality consequence analyses are important, and they will be performed.	DOE. "Disposal Criticality Analysis Topical Report Annotated Outline—Response to NRC Comments."

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
		The analyses methodology will be provided in a separate chapter of the topical report.	Enclosure 1. LSN Accession No. DN2001425258. Washington, DC: DOE. 1996.
1996	—	Scientists from Los Alamos National Laboratory raise concerns about a possible spontaneous underground autocatalytic criticality in the geologic repository once the disposal canisters are breached (Bowman and Venneri, 1996).	Bowman, C.D. and F. Venneri. "Underground Supercriticality From Plutonium and Other Fissile Material." *Science and Global Security*. Vol. 5, No. 3. pp. 279–302. 1996.
November 1998	—	DOE submits Disposal Criticality Analysis Methodology Topical Report, Revision 00 (CRWMS M&O, 1998). The criticality methodology outlined in the report includes a Master Scenario List that represents a comprehensive set of configuration degradation scenarios that must be considered as part of the criticality analysis for any waste form. The possible degraded configurations are grouped into classes that are defined by a set of scenarios from the Master Scenario List. The potential for criticality for each configuration is then evaluated by calculating the configuration k_{eff}. The probability of exceeding the criticality limit (i.e., the value of k_{eff} at which the system is considered potentially critical) is evaluated for each class. A consequence analysis of potential criticality events is performed if the k_{eff} of the configuration exceeds the criticality limit. A consequence analysis methodology is limited only to an incremental inventory increase as a result of inadvertent criticality. DOE indicates that if NRC accepts the methodology in the topical report, the methodology	CRWMS M&O. "Disposal Criticality Analysis Methodology Topical Report." Rev. 00. YMP/TR–004Q. ADAMS Accession No. ML003742456. LSN Accession No. DEN001434519. Las Vegas, Nevada: CRWMS M&O, Yucca Mountain Site Characterization Office. 1998.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)

Date	NRC Activities	DOE Activities	Reference
		will be fully validated for repository design applications to which it will be applied in the license application and its references.	
February 1999	NRC accepts the submittal of the Disposal Criticality Analysis Methodology Topical Report, Revision 0.	—	—
May 1999	Technical exchange on criticality is held between NRC and DOE.		—
August 1999	NRC issues Requests for Additional Information to the Disposal Criticality Analysis Methodology Topical Report, Revision 0 (Reamer, 1999).	—	Reamer, C.W. “U.S. Nuclear Regulatory Commission Request for Additional Information on the U.S. Department of Energy Topical Report on Disposal Criticality Analysis Methodology.” Letter (August 18) with Enclosure to S. Brocoum, Acting Assistant Manager, Office of Licensing and Regulatory Compliance, DOE, CRWMS M&O. ADAMS Accession No. ML031780523. LSN Accession No. NRC000014885. Washington, DC: NRC. 1999.
October 1999	—	Naval Nuclear Propulsion Program submits to NRC the Addendum to the Disposal Criticality Analysis Methodology Topical Report, Revision 0 (Mowbray, 1999).	Mowbray, G.E. “Naval Nuclear Propulsion Program Addendum to the Yucca Mountain Site Characterization Office—Disposal Criticality Analysis Methodology

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
			Topical Report." Letter (October 29) to C.W. Reamer, NRC. LSN Accession No. DN2001890274. Washington, DC: Department of the Navy. 1999.
March 2000	NRC and DOE hold technical exchange (Reamer, 2000) to discuss results of the NRC staff evaluation of the Disposal Criticality Analysis Methodology Topical Report, Revision 0. The NRC findings are documented in the Draft Safety Evaluation Report. NRC indicates that per Regulatory Guide 3.71 (NRC, 2005a), credit for fuel burnup may be taken only if supported by physical measurements. NRC indicates that the approach to postclosure criticality risk should be included in the topical report (Reamer, 2000). DOE considers the criticality risk analysis as part of the total system performance assessment, not of the criticality topical report. DOE indicates that all of the criticality probability and consequence analysis will be provided to DOE Total System Performance Assessment staff. DOE states that the probabilistic distribution rather than the single discrete value will be used for consequence analysis to estimate the power yield of the potential criticality event.	—	Reamer, C.W. "Summary of Technical Exchange Meeting Between Staff of NRC and DOE Regarding Draft Safety Evaluation Report on Disposal Criticality Analysis Methodology Topical Report." Rev. 0. Letter (April 21) to S. Brocoum, Acting Assistant Manager, office of Licensing and Regulatory Compliance, DOE, CRWMS M&O. ADAMS Accession No. ML023370643. LSN Accession No. NRC000026080. Washington, DC: NRC. 2000. NRC. Regulatory Guide 3.71, "Nuclear Criticality Safety Standards for Fuels and Material Facilities." Rev. 1. ADAMS Accession No. ML051940351.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)

Date	NRC Activities	DOE Activities	Reference
			Washington, DC: NRC. 2005a.
June 2000	NRC issues Final Safety Evaluation Report on Disposal Criticality Analysis Methodology Topical Report, Revision 0 (NRC, 2000a). NRC accepts most of the DOE proposed approaches with respect to methodology, modeling, and validation. Some approaches are accepted with conditions. Twenty-eight safety evaluation report open items presented in Appendix B of this report cover remaining technical issues. The open items include the staff expectations for some major parts of the methodology (e.g., risk analysis, criticality consequence analysis, validation approach for criticality consequence model). In the open items, staff also reiterate their expectations that burnups of spent fuel assemblies must be verified through measurements before spent fuel assemblies are loaded into the waste package.	—	NRC. “Safety Evaluation Report for Disposal Criticality Analysis Methodology Topical Report.” Rev. 0. ADAMS Accession No. ML003722229. LSN Accession No. NRC000005336. Washington, DC: NRC, Office of Nuclear Material Safety and Safeguards. 2000a.
October 2000	NRC and DOE staffs hold technical exchange (NRC, 2000b) to discuss subissues related to criticality.		NRC. “NRC/DOE Technical Exchange and Management Meeting on Subissues Related to Criticality (October 23–24, 2000).” Letter (October 27) to S. Brocoum, Acting Assistant Manager, Office of Licensing and Regulatory Compliance, DOE, CRWMS M&O. ADAMS Accession No. ML003763270. Washington, DC: NRC. 2000b.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
February 2001	—	DOE submits Disposal Criticality Topical Report, Revision 01 (CRWMS M&O, 2000), addressing the 28 open items.	CRWMS M&O. "Disposal Criticality Analysis Methodology Topical Report." Rev. 01. YMP/TR–004Q. ADAMS Accession No. ML010570207. LSN Accession No. DN2002045630. Las Vegas, Nevada: CRWMS M&O, Yucca Mountain Site Characterization Office. 2000.
March 2002	NRC issues Revision 1 of the Draft Safety Evaluation Report for the Naval Nuclear Propulsion Program Addendum to the Disposal Criticality Analysis Methodology Topical Report (Schlueter, 2002). The Draft Safety Evaluation Report documents the staff acceptance of the overall methodology except where identified as incomplete for the 2 open items and as clarified in the 14 acceptance conditions. The two open items deal with the methodology to determine the likelihood of criticality in the repository and the approach for evaluating igneous events. The acceptance conditions address (i) the status of the features, events, and processe approaches and conclusions,(ii) the neutronic modeling of naval fuel, (iii) consideration of different aspects in determining the most reactive time in the life of an assembly, and (iv) identification of trending	—	Schlueter, J. "Draft SER for the Naval Nuclear Propulsion Program Addendum to the Disposal Criticality Analysis Methodology Topical Report." Rev. 01. Letter (March 8) to J. McKenzie, Acting Director of Regulatory Affairs Naval Nuclear Propulsion Program, Naval Sea Systems Command. ADAMS Accession No. ML020710413. LSN Accession No. NRC000015189. Washington, DC: NRC. 2002.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
	parameters. A summary of the open items and acceptance conditions is provided in Appendix B.		
December 2002	—	DOE submits Summary of the Supplemental Model Reports Supporting the Disposal Criticality Analysis Methodology Topical Report, Revision 01 (Bechtel SAIC Company, LLC, 2002). The summary contains descriptions and a schedule for nine model reports that would document the methodology to be utilized in the Disposal Criticality Analysis Methodology Topical Report, Revision 01. The model reports are supplements to the topical report, detailing and validating the methodology outlined in the topical report.	Bechtel SAIC Company, LLC. "Summary of the Supplemental Model Reports Supporting the Disposal Criticality Analysis Methodology Topical Report." TDR–EBS–NU–000003. Rev. 01. LSN Accession No. DN2001915875. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2002.
August 2003	The NRC issues the Safety Evaluation Report for the Naval Nuclear Propulsion Program Addendum to the Disposal Criticality Analysis Methodology Topical Report. The NRC issues an unclassified letter to the Naval Nuclear Propulsion Program (Schlueter, 2003) documenting the review of the Naval Nuclear Propulsion Program methodology to determine the probability of a nuclear criticality with naval reactor spent nuclear fuel in the repository. This letter notes that NRC deferred reviewing the Naval Nuclear Propulsion Program probability methodology portion of the topical report that is used to determine the probability of a criticality event involving naval spent nuclear fuel due to previously unaddressed regulatory issues. The letter identifies such areas as: (i) human reliability during manufacturing, loading, or handling of components and (ii) the materials quality assurance program, where the Naval Nuclear Propulsion Program methodology should	—	Schlueter, J. "Results of NRC Review of the Naval Nuclear Propulsion Program Probability Methodology." Letter (August 4) to J. McKenzie, Acting Director of Regulatory Affairs Naval Nuclear Propulsion Program, Naval Sea Systems Command. ADAMS Accession No. ML032170659. LSN Accession No. NRC000029617. Washington, DC: NRC. 2003.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)

Date	NRC Activities	DOE Activities	Reference
	be revised and enhanced to provide a transparent and defensible basis for evaluating the probability calculation. Regarding the use of risk-informed analyses, specifically, consequence analyses, the letter states that "the NNPP has previously indicated that it intends to use its probability methodology to determine whether a nuclear criticality event involving naval SNF should be included in the performance assessment… However, evaluating criticality events using both probability and consequences may provide a more defensible technical basis with less overall effort, including less effort by the NRC staff. Preliminary analyses performed by the NRC staff indicate that the effect of a criticality event in a single waste package on repository performance may be limited. These preliminary analyses suggest that a risk calculation may provide additional information useful for evaluating whether a nuclear criticality event involving naval SNF should be included in the performance assessment."		
November 2003	—	DOE submits Disposal Criticality Methodology Topical Report, Revision 02 (CRWMS M&O, 2003). The previous DOE approach outlined in Revision 01 of the report undergoes the following major revision: if the total probability of all critical configurations for all the waste forms and all waste packages is estimated below the regulatory probability criterion [i.e., 10 CFR 63.114(d)], no consequence analyses for any potentially critical configurations will be performed. The previous approach that DOE depicted in the Disposal Criticality Methodology Topical Report, Revision 01 (CRWMS M&O, 2000) included consequence	CRWMS M&O. "Disposal Criticality Analysis Methodology Topical Report." Rev. 02. YMP/TR–004Q. ADAMS Accession No. ML033290322. LSN Accession No. NRC000021818. Las Vegas, Nevada: CRWMS M&O, Yucca Mountain Site Characterization Office.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
		analyses for all identified potentially critical configuration classes.	2003. CRWMS M&O, 2000.
December 2003	NRC initiates acceptance review for the Disposal Criticality Methodology Topical Report, Revision 02. This review focuses on whether the open items have been addressed and whether DOE has provided enough information to address those aspects of the methodology DOE identified for NRC acceptance.	—	—
December 2003	NRC terminates both the topical report approach for disposal criticality and the ongoing acceptance review of the Disposal Criticality Methodology Topical Report, Revision 02, and subsequently documents the decision. The March 2005 letter to DOE states that "the staff is discontinuing the topical report approach … for criticality postclosure issues and has no plans to issue a revised SER" (Kokajko, 2005a,b).	—	Kokajko, L.E. "Pre-Licensing Evaluation of Key Technical Issue Agreements: Container Life and Source Term 5.01, 5.03, 5.04, and 5.05; Evolution of the Near-Field Environment 5.01 and 5.03; Radionuclide Transport 4.01 and 4.03; Pre-Closure 7.01; and General 1.01 Comments 21 and 64." Letter (March 17) to J.D. Ziegler, Director, Office of License Application and Strategy, Office of Repository Development, DOE. ADAMS Accession No. ML050530424. LSN Accession No. NRC000027043. Washington, DC: NRC. 2005a.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
			Kokajko, L.E. "NRC Office of Nuclear Material Safety and Safeguards Review of DOE Key Technical Issue Agreement Responses Related to the Potential Geologic Repository at Yucca Mountain, Nevada: Container Life and Source Term 5.01, 5.03, 5.04, and 5.05; Evolution of the Near-Field Environment 5.01 and 5.03; Radionuclide Transport 4.01 and 4.03; Pre-Closure 7.01; and General 1.01 Comments 21 and 64." Enclosure to Letter (March 17) to J.E. Ziegler, Director, Office of License Application and Strategy, Office of Repository Development, DOE. ADAMS Accession No. ML050530431. LSN Accession No. NRC000027023. Washington, DC: NRC. 2005b.
May 2004	NRC staff and the Naval Nuclear Propulsion Program representatives hold a 1-day meeting discussing the methodology for determining the likelihood of a criticality involving naval reactor spent nuclear fuel in a geologic repository and how it will be utilized in support of the license application.		—
October 2004		DOE makes public its estimate of the probability of postclosure criticality as 1.44×10^{-8} for the 10,000-year postclosure period (Bechtel SAIC	Bechtel SAIC Company, LLC. "Screening Analysis of Criticality Features,

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
		Company, LLC, 2004a). Probability evaluations are performed utilizing the configuration generator described in Configuration Generator Model report (Bechtel SAIC Company, LLC, 2004b), a component of the methodology from Disposal Criticality Analysis Methodology Topical Report Revision 02 (CRWMS M&O, 2003). The probability estimate for naval reactor spent nuclear fuel is calculated and provided separately by Naval Nuclear Propulsion Program using their own methodology (McKenzie, 2005). The total estimate is the sum of the probabilities for nonnaval waste forms and naval reactor spent nuclear fuel. The DOE estimate for all nonnaval waste forms is based on the application of event-tree analysis performed separately for basecase, rockfall, igneous, and seismic scenarios. The following assumptions are made for the 10,000-year basecase and rockfall scenarios. • Rockfall does not negatively impact the engineered barrier system • Drip shields do not fail • Ten percent of waste packages fail • Water does not seep into or condense inside failed waste packages The total probability of criticality for all waste forms including naval reactor spent nuclear fuel is determined solely by the combined probability of criticality caused by seismic and igneous events.	Events, and Processes for License Application.” ANL–EBS–NU–000008. Rev. 01. LSN Accession No. DN2002140903. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004a. Bechtel SAIC Company, LLC. “Configuration Generator Model.” CAL–DSO–NU–000002. Rev. 00A. LSN Accession No. DN2002141328. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004b. CRWMS M&O, 2003. McKenzie, J.M. “Meeting Minutes from September 20–21, 2004 Regarding Matters Related to the Preparation of NNPP Technical Support Document for the License Application.” Letter (January 5) to W.J. Arthur, III. LSN Accession No. DN2001691634. Washington, DC: Department of the Navy. 2005

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)

Date	NRC Activities	DOE Activities	Reference
April 2005	NRC issues Revision 1 of the Integrated Issue Resolution Status Report (NRC, 2005b). In the report, NRC staff emphasize that "DOE should provide parameter ranges in criticality probability that are consistent with those used in the total system performance assessment. Alternatively to the development of probability arguments to screen criticality events from the performance assessment model, DOE may evaluate consequences of criticality events."	—	NRC. NUREG–1762, "Integrated Issue Resolution Status Report." Vol.1. Rev 1. ADAMS Accession No. ML051360159. LSN Accession No. NRC000027746. Washington, DC: NRC. March 2005b.
February 2007	—	DOE issues a technical work plan (Sandia National Laboratories, 2007, Appendix A) that makes public its decision not to perform criticality consequence analysis, as opposed to probabilistic screening, to demonstrate compliance with 10 CFR Part 63 requirements. In support of this decision DOE cites political, public, and licensing risks and insufficient data to support the phenomenological analysis. The decision is documented in the letter from the director of the DOE Regulatory Authority Office to the director of the DOE Office of Civilian Radioactive Waste Management and included as Appendix A of the technical work plan (Sandia National Laboratories, 2007). The decision to pursue an option of screening criticality from performance considerations based on low probability is further reiterated. The bases for the analysis supporting this screening argument include use of a burnup credit for the commercial spent nuclear fuel and performance of corrosion-resistant neutron absorbers. DOE indicates, in Sandia National Laboratories (2007, Appendix A), that without burnup credit, criticality cannot be screened for 97 percent of pressurized water reactor spent nuclear fuel and 7 percent of	Sandia National Laboratories. "Technical Work Plan for Development of Technical Data Needed to Justify Full Burnup Credit in Criticality Safety Licensing Analyses Involving Commercial Spent Nuclear Fuel." TWP–EBS–MD–000019. Rev. 01. LSN Accession No. DN2002371201. Las Vegas, Nevada: Sandia National Laboratories, CRWMS Lead Laboratory for Repository Systems. 2007.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
		boiling water reactor spent nuclear fuel loaded in waste packages of the current design. Without burnup credit, this fuel would require disposal in an alternate waste package design. To justify application of burnup credit for postclosure criticality screening analysis, the computational tools need to be validated. To collect technical data for such validation, DOE proposes a 5-year program of experimental work that would support burnup credit in criticality safety licensing analyses involving commercial spent nuclear fuel. DOE states that the ultimate goal of this experimental work is to develop and/or obtain the technical data needed to justify full (actinide and fission product) burnup credit in criticality safety licensing analyses involving commercial spent nuclear fuel. The output data from this data collection program are anticipated to support the postclosure criticality screening argument. Data developed in this work will also be used in the supporting documents to the license application, in any postlicense application license amendments, and in license defense. DOE summarizes these burnup credit supporting arguments in Sandia National Laboratories (2007, Appendix A) by making several recommendations for the actions necessary to support license application submittal and NRC licensing reviews. These recommendations are briefly outlined next: 1. Develop detailed plans for acquisition of radiochemical assays and laboratory critical experiments data. 2. Purchase the rights to use the French Haut	

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
		Taux de Combustion (i.e., high burnup rate in French) experimental results for actinide critical experiments. 3. Complete evaluation of the French experimental results for fission product critical experiments. 4. Perform analyses to evaluate whether all 29 principal isotopes outlined in the topical report will be included in burnup credit analyses. 5. Complete a postclosure criticality license application analysis based on available data. DOE also indicates, Sandia National Laboratories (2007, Appendix A) that the NRC issued a Safety Evaluation Report in June 2000 accepting the burnup credit methodology outlined in the Disposal Criticality Methodology Topical Report, Revision 0, but omits mention of the NRC Safety Evaluation Report 28 unresolved open items and that the methodology outlined in Disposal Criticality Methodology Topical Report, Revision 0, had been revised but not reviewed by the NRC. Seven of the open items, however, are mentioned by Sandia National Laboratories (2007) as the regulatory guidance to be addressed by activities or products in the technical work plan.	
May 2007	—	DOE makes public the list of the documents that would support a license application submission (CRWMS M&O, 2007). The list includes Postclosure Criticality Methodology Topical Report,	CRWMS M&O. "License Application Product Baseline." ADAMS Accession

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)

Date	NRC Activities	DOE Activities	Reference
		Revision 02.	No. ML072270438. LSN Accession No. NRC000029163. Las Vegas, Nevada: CRWMS M&O. 2007.
August 2007	NRC and DOE staffs hold a 1-day criticality technical exchange meeting discussing the overall approach to criticality, preclosure methodology, and postclosure methodology (Davis, 2007). The main preclosure discussion points follow, these points also are pertinent to postclosure. • For preclosure criticality safety analysis involving spent nuclear fuel arriving at the geologic repository operations area in transportation casks, DOE plans to use the amount of burnup credit granted for spent nuclear fuel in transportation casks during the cask certification process. Once the transportation cask configuration is altered at the geologic repository operations area, the bounding assumption of fresh fuel will be applied in further analyses. Because the waste packages will be loaded in a pool with application of burnup credit, it is not clear whether the fresh fuel assumption under flooded conditions or under the moderator exclusion exemption or borated water will be used in criticality safety analyses. For this operation, postclosure disposal criticality analysis that uses burnup credit overlaps with preclosure criticality safety analysis that most likely does not use burnup credit (Bechtel SAIC Company, LLC, 2008). • Transportation, aging, and disposal canisters will be loaded by utilities and at the geologic repository operations area facilities according to the loading curves specific to different transportation, aging, and disposal canisters and waste package designs (i.e., with application of burnup credit). This point is relevant to postclosure because the same amount of burnup credit will be used in postclosure criticality analysis (Bechtel SAIC Company, LLC, 2008). • Some DOE fuel may require “moderator exclusion” to demonstrate criticality safety (i.e., waiver of the fully flooded condition for criticality safety analyses). Moderator exclusion, if used, will affect postclosure criticality because there will be a certain amount of water seepage in the disposal drifts (Bechtel SAIC Company, LLC, 2008). • Neutron absorbers intrinsic to sealed geologic repository operations area casks will be relied upon		Davis, J. “Summary of Technical Exchange on Preclosure and Postclosure Criticality, August 16, 2007.” Letter (September 26) to Dr. A.V. Gil, Acting Director, Regulatory Authority Office, CRWMS M&O, DOE. ADAMS Accession No. ML072710239. LSN Accession No. NRC000029330. Washington, DC: NRC. 2007. Bechtel SAIC Company, LLC. “Preclosure Criticality Safety Analysis.” TDR–MGR–NU–000002. Rev. 01. LSN Accession No. DEN001594169. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2008. NRC, 2005b.

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)			
Date	**NRC Activities**	**DOE Activities**	**Reference**
	in preclosure safety analysis. Degraded neutron absorbers will be relied upon to screen out criticality during the postclosure period (Bechtel SAIC Company, LLC, 2008; NRC, 2005b; Sandia National laboratories, 2008a,b). The main postclosure discussion points follow. • DOE reiterates its approach to screen out criticality from the features, events, and processes of the postclosure performance assessment, based on low probability (Davis, 2007). • The long-term performance of neutron absorbers will be credited in the screening analysis for nominal (nondisruptive) and disruptive scenarios (Sandia National Laboratories, 2008a,b,c). • Probability screening in the nominal scenario will be done for all nonnaval fuel types without use of burnup credit (Davis, 2007). • DOE expects to rely on burnup credit for disruptive seismic and igneous scenarios to screen out criticality (Davis, 2007). • If early waste package failures become part of the nominal scenario, burnup credit will be used in the screening analysis for the nominal scenario to screen out criticality (Davis, 2007 and Sandia National Laboratories, 2008b,c). • DOE will reexamine the isotopic model for commercial spent nuclear fuel burnup credit to modify how Δk_{iso} (i.e., penalty for isotopic composition bias and uncertainty) is determined. No revision of the isotopic model is planned; the current model will be used in the revised determination of Δk_{iso} (Sandia National Laboratories, 2008a). • The burnup credit analysis and loading curves will be based on the use of existing data and on the output of the proposed 5-year-long data collection experimental program. Loading curves will be revised as additional data and designs become available. DOE expects the new data will support the validity of current models and preliminary conclusions in burnup credit analyses (Sandia National Laboratories, 2007).		Sandia National Laboratories. "CSNF Loading Curve Sensitivity Analysis." ANL–EBS–NU–000010. Rev. 00. LSN Accession No. DEN001582453. Las Vegas, Nevada: Sandia National Laboratories. 2008a. Sandia National Laboratories. "Features, Events, and Processes for the Total System Performance Assessment Analysis." ANL–WIS–MD–000027. Rev. 00. LSN Accession No. DEN001584824. Las Vegas, Nevada: Sandia National Laboratories. 2008b. Sandia National Laboratories. "Screening Analysis of Criticality Features, Events, and Processes for License Application." ANL–DSO–NU–000001. Rev. 0. LSN Accession No. DEN001582190. Las Vegas, Nevada;

Table 3-1. Prelicensing Activities Pertinent to Geologic Repository Disposal Criticality (continued)

Date	NRC Activities	DOE Activities	Reference
	• There are risks in the experimental program associated with intractable measurement error and usability of results. There is also a risk that obtained radiochemical analysis data may be applicable to only sampled assembly types, not to the entire commercial spent nuclear fuel inventory. DOE indicates that the risks are manageable (Sandia National Laboratories, 2007). • During transportation, aging, and disposal canister loading and in criticality safety analyses, DOE and utilities will rely on reactor records in determining commercial spent nuclear fuel burnup; no additional burnup measurements are planned at any stage of the fuel processing. DOE assumes that the shipping records for the fuel assemblies are correct (Davis, 2007 and Bechtel SAIC Company, LLC, 2003). Potential assembly misloads will be factored into the determination of probability of postclosure criticality (NRC, 2005b; Bechtel SAIC Company, LLC, 2003; Sandia National Laboratories, 2008b,c).		Sandia National Laboratories. 2008c. Sandia National Laboratories, 2007. Bechtel SAIC Company, LLC. "Commercial Spent Nuclear Fuel Waste Package Misload Analysis." CAL–WHS–MD–000003. Rev. 00A. LSN Accession No. DEN001389054. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003.
October 2007	NRC and Naval Nuclear Propulsion Program staffs hold a technical exchange meeting discussing current status of the Naval Nuclear Propulsion Program disposal criticality methodology (NRC, 2007b). The Naval Nuclear Propulsion Program will calculate the naval reactor spent nuclear fuel probability of postclosure criticality using its own methodology and submit results of the analysis in classified technical support documents separately but alongside a license application submission. The probability of naval reactor spent nuclear fuel criticality will be explicitly included in a license application, while the supporting analyses will be included by reference.		NRC. "Forthcoming NRC and DOE Appendix 7 Meeting." Closing Meeting Notice. ADAMS Accession No. ML072700461. Washington, DC: NRC. 2007b.

4 CONCLUSIONS

Based on a review of prelicensing documents, the U.S. Department of Energy (DOE) plans to screen out criticality from the features, events, and processes of the postclosure performance assessment, based on low probability. The bases for the analysis supporting this screening argument are expected to include use of burnup credit for commercial spent nuclear fuel, performance of corrosion-resistant neutron absorbers, and prototype transportation, aging, and disposal canisters without neutron flux traps. The DOE license application is currently under review by staff. Based on the screening, no performance assessment of potential criticality events will be performed. Nominal and disruptive scenarios criticality probabilities will determine the total postclosure criticality probability. The total postclosure criticality probability will include a naval reactor spent nuclear fuel contribution with supporting analyses included in the license application by reference. The Naval Nuclear Propulsion Program will calculate the naval reactor spent nuclear fuel probability of postclosure criticality using its own methodology and submit to the U.S. Nuclear Regulatory Commission (NRC) results of the analysis in a classified technical support document separately from the license application submission.

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APPENDIX A

INFORMATION ON POSTCLOSURE DISPOSAL CRITICALITY IN THE YUCCA MOUNTAIN REVIEW PLAN (NRC, 2003)

This appendix presents excerpts of information pertinent to postclosure criticality from the Yucca Mountain Review Plan (NRC, 2003). The Yucca Mountain Review Plan was prepared assuming the probability of postclosure criticality could be greater than 10^{-8} per year; thus the detailed language in Section 2.2.1.2.2 directs the staff on how to review criticality if the probability is greater than 10^{-8} per year. The Yucca Mountain Review Plan was written assuming criticality could be an abstracted model in the performance assessment; thus the detailed language is used in multiple subsections of Section 2.2.1.3. If postclosure criticality is screened out, then the guidance in Section 2.2.1.2.1 is applicable to the review of postclosure criticality.

"2.2 Repository Safety After Permanent Closure

2.2.1 Performance Assessment…

2.2.1.2 Scenario Analysis and Event Probability

2.2.1.2.1 Scenario Analysis…

2.2.1.2.1.1 Areas of Review…

This section reviews identification of features, events, and processes affecting compliance with the overall performance objective. Reviewers will also evaluate the information required by 10 CFR 63.21(c)(1) and (9).…

2.2.1.2.1.2 Review Methods

Review Method 1 Identification of a List of Features, Events, and Processes

Verify that the U.S. Department of Energy list of features, events, and processes includes all features, events, and processes having a potential to influence repository performance.…

Review Method 2 Screening of the List of Features, Events, and Processes

Examine the excluded features and processes. Evaluate the adequacy of the rationale for excluding each feature and process, based on the description of the site, the design specifications, and the waste characteristics. Consider information from site and regional characterization, natural analog studies, and the repository design, during this evaluation.

Examine the U.S. Department of Energy event-screening rationale, to determine whether an event is appropriately defined. Use the results of the review, conducted using Section 2.2.1.2.2 of the Yucca Mountain Review Plan, for this purpose. Assess the U.S. Department of Energy justification (i.e., whether the probability of occurrence can be technically supported) for those events that fall below the regulatory probability criterion, to evaluate whether the U.S. Department of Energy defined these events too narrowly, and they were inappropriately excluded.

Review the criteria used to screen features, events, and processes related to the geologic setting, and the degradation, deterioration, or alteration of engineered barriers from the performance assessment, based on having no significant change on the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment. Evaluate the U.S. Department of Energy analyses or calculations supporting this screening and the use of bounding or representative estimates for the consequences. Independently assess, using tools such as an alternative total system performance assessment code, the potential consequences to confirm the U.S. Department of Energy screening of features, events, and processes.

Review Method 3 Formation of Scenario Classes Using the Reduced Set of Events

Evaluate the U.S. Department of Energy description of the approach and technical bases, to determine whether the resulting scenario classes are mutually exclusive and include all events that have not been screened from the performance assessment.

Review Method 4 Screening of Scenario Classes

Review the criteria used by the U.S. Department of Energy to screen scenario classes from the performance assessment on the basis that their omission would not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment. Examine the U.S. Department of Energy analyses or calculations supporting this screening and the use of bounding or representative estimates for the consequences. Independently assess, using tools such as an alternative total system performance assessment code, as needed, the potential consequences to confirm the U.S. Department of Energy screening of scenario classes.…

Use the results of the review, conducted using Section 2.2.1.2.2 of the Yucca Mountain Review Plan, to examine the U.S. Department of Energy technical justification for screening scenario classes from the performance assessment, based on their probability of being below the regulatory criterion.…

2.2.1.2.1.3 Acceptance Criteria…

The following acceptance criteria are based on meeting the requirements at 10 CFR 63.114(e) and (f).…

Acceptance Criterion 1 The Identification of a List of Features, Events, and Processes Is Adequate.

… the comprehensive features, events, and processes list includes, but is not limited to, potentially disruptive events related to igneous activity (extrusive and intrusive); seismic shaking (high-frequency-low magnitude, and rare large-magnitude events); tectonic evolution (slip on existing faults and formation of new faults); climatic change (change to pluvial conditions); and <u>criticality</u>.…

Acceptance Criterion 2 Screening of the List of Features, Events, and Processes Is Appropriate.…

(2) The U.S. Department of Energy has provided justification for those features, events, and processes that have been excluded. An acceptable justification for excluding features, events, and processes is that either the feature, event, and process is specifically excluded by regulation; probability of the feature, event, and process (generally an event) falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment; and

(3) The U.S. Department of Energy has provided an adequate technical basis for each feature, event, and process, excluded from the performance assessment, to support the conclusion that either the feature, event, or process is specifically excluded by regulation; the probability of the feature, event, and process falls below the regulatory criterion; or omission of the feature, event, and process does not significantly change the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment.

Acceptance Criterion 3 Formation of Scenario Classes Using the Reduced Set of Events Is Adequate.

(1) Scenario classes are mutually exclusive and complete, clearly documented, and technically acceptable.

Acceptance Criterion 4 Screening of Scenario Classes Is Appropriate.

(1) Screening of scenario classes is comprehensive, clearly documented, and technically acceptable;

(2) The U.S. Department of Energy has adequately considered coupling of processes in estimates of consequences used to screen scenario classes. Scenario classes were not prematurely excluded by a narrow definition;

(3) Scenario classes that are screened from the performance assessment, on the basis that they are specifically ruled out by regulation or are contrary to stated regulatory assumptions are identified, and sufficient justifications are provided;

(4) Scenario classes that are screened from the performance assessment, on the basis that their probabilities fall below the regulatory criterion, are identified, and sufficient justifications are provided; and

(5) Scenario classes that are screened from the performance assessment, on the basis that their omission would not significantly change the magnitude and time of the resulting radiological exposure to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, are identified, and sufficient justifications are provided.…

2.2.1.2.2 Identification of Events with Probabilities Greater Than 10^{-8} Per Year

2.2.1.2.2.1 Areas of Review

This section reviews identification of events with probabilities greater than 10^{-8} per year, that may affect compliance with the postclosure performance standards. Reviewers will also evaluate information required by 10 CFR 63.21(c)(1) and (9).

The staff will evaluate the following parts of the identification of events with probabilities greater than 10^{-8} per year, using the review methods and acceptance criteria in Sections 2.2.1.2.2.2 and 2.2.1.2.2.3:

(1) Definitions of events that may affect compliance with the postclosure performance standards, such as faulting, seismicity, igneous activity, and criticality;

(2) The probability assigned to each event, and the technical bases used to support this assignment;

(3) Conceptual models evaluated or considered in determining the probabilities of events;

(4) Parameters used to calculate the probabilities of events; and

(5) Uncertainty in models and parameters used to calculate the probabilities of events.

2.2.1.2.2.2 Review Methods

Review Method 1 Event Definition

…Confirm that probabilities of intrusive and extrusive igneous events are estimated separately. Verify that definitions of faulting and earthquakes are derived from the historical record, paleoseismic studies, or geological analyses. Confirm that criticality events, for the purpose of initial screening of the features, events, and processes list, are calculated separately, only by location of the criticality event (e.g., in-package, near-field, and far-field).

Review Method 2 Probability Estimates

…Evaluate whether probability estimates for future criticality events have considered design characteristics and natural features of the proposed Yucca Mountain repository system. Verify that the U.S. Department of Energy has included various fuel types to be disposed at the proposed Yucca Mountain repository in calculating probability of future criticality events. Confirm that the estimate of probability of criticality is determined using methodology outlined in the "U.S. Department of Energy Topical Report on Disposal Criticality" (U.S. Department of Energy, 1998), as amended by responses to the

U.S. Nuclear Regulatory Commission request for additional information,[1] and subject to conditions and limitations in the U.S. Nuclear Regulatory Commission Safety Evaluation Report (U.S. Nuclear Regulatory Commission, 2000).

Review Method 3 Probability Model Support

Confirm that models, used to estimate the probability of future criticality events, are validated, using methodology outlined in the "U.S. Department of Energy Topical Report on Disposal Criticality" (U.S. Department of Energy, 1998), as amended by responses to the U.S. Nuclear Regulatory Commission request for additional information,[2] and subject to conditions and limitations contained in the U.S. Nuclear Regulatory Commission Safety Evaluation Report (U.S. Nuclear Regulatory Commission, 2000).…

Review Method 5 Uncertainty in Event Probability

For events applicable to the Yucca Mountain repository, verify whether the U.S. Department of Energy has adequately identified and propagated uncertainties in estimating probabilities. Confirm that an adequate technical basis, that includes treatment of uncertainty, is provided for the probability value. For probability distributions or ranges, confirm that a technical basis for the analysis is provided, and that the distribution or range accounts for the uncertainty in the probability estimates. [Note: Although probability distributions or ranges can include probabilities less than 10^{-8} per year, the mean of the distribution range is to be used to screen an event from the performance assessment.]…

2.2.1.2.2.3 Acceptance Criteria

The following acceptance criteria are based on meeting the requirements at 10 CFR 63.114(d).…

Acceptance Criterion 1 Events Are Adequately Defined.

…Criticality events are calculated separately by location.

Acceptance Criterion 2 Probability Estimates for Future Events Are Supported by Appropriate Technical Bases.

(1) Probabilities for future natural events have considered past patterns of the natural events in the Yucca Mountain region, considering the likely future conditions and interactions of the natural and engineered repository system. These probability estimates have specifically included igneous events, faulting and seismic events, and criticality events.…

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[1]U.S. Department of Energy. "U.S. Department of Energy Response to U.S. Nuclear Regulatory Commission Request for Additional Information on the DOE Topical Report on Disposal Criticality Analysis Methodology." Letter (November 19) to C.W. Reamer, U.S. Nuclear Regulatory Commission. LSN Accession No. DEN001277469. Washington, DC: U.S. Department of Energy. 1999.
[2]U.S. Department of Energy. "U.S. Department of Energy Response to U.S. Nuclear Regulatory Commission Request for Additional Information on the DOE Topical Report on Disposal Criticality Analysis Methodology." Letter (November 19) to C.W. Reamer, U.S. Nuclear Regulatory Commission. LSN Accession No. DEN001277469. Washington, DC: U.S. Department of Energy. 1999.

2.2.1.2.2.5 References

U.S. Department of Energy. "Disposal Criticality Analysis Methodology Topical Report." YMP/TR–004Q. Rev. 0. ADAMS Accession No. ML003742456, LSN Accession No. DEN001434519. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. November 1998.

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2.2.1.3 Model Abstraction…

2.2.1.3.1 Degradation of Engineered Barriers…

2.2.1.3.1.2 Review Methods

Review Method 1 Model Integration

…Evaluate the technical bases that the U.S. Department of Energy used for selecting the design criteria, that mitigate any potential impact of in-package criticality on repository performance, including all features, events, and processes that may increase the reactivity of the system inside the waste package; all the configuration classes and configurations that have potential for nuclear criticality; and changes in radionuclide inventory and thermal conditions, in the abstraction of the degradation of engineered barriers. Verify that the U.S. Department of Energy reviews follow guidance such as NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches.…

2.2.1.3.2 Mechanical Disruption of Engineered Barriers…

2.2.1.3.2.2 Review Methods

Review Method 1 Model Integration

…Evaluate the U.S. Department of Energy conclusion with respect to the impact of transient criticality on the integrity of the engineered barriers.

2.2.1.3.2.3 Acceptance Criteria

Acceptance Criterion 1 System Description and Model Integration Are Adequate.…

(6) The conclusion, with respect to the impact of transient criticality on the integrity of the engineered barriers, is defensible…

2.2.1.3.3 Quantity and Chemistry of Water Contacting Engineered Barriers and Waste Forms…

2.2.1.3.3.2 Review Methods

Review Method 1 Model Integration

Evaluate the abstraction of in-package criticality or external-to-package criticality within the emplacement drift, and the associated technical basis for screening these events. Confirm that if either event is included in the total system performance assessment, the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of the quantity and chemistry of water contacting engineered barriers packages and waste forms. Verify that the U.S. Department of Energy reviews follow the guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.…

Review Method 3 Data Uncertainty…

If in-package criticality or external-to-package criticality is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor.

2.2.1.3.3.3 Acceptance Criteria

Acceptance Criterion 1 System Description and Model Integration are Adequate.

(11) The abstraction of in-package criticality or external-to-package criticality, within the emplacement drift, provides an adequate technical basis for screening these events. If either event is included in the assessment, then the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of the quantity and chemistry of water contacting engineered barriers and waste forms;…

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.…

(5) If criticality is included in the total system performance assessment, then the U.S. Department of Energy uses an appropriate range of input parameters for calculating the effective neutron multiplication factor;…

2.2.1.3.4 Radionuclide Release Rates and Solubility Limits…

2.2.1.3.4.2 Review Methods

Review Method 1 Model Integration

Evaluate the total system performance assessment abstraction of in-package criticality or external-to-package criticality, within the emplacement drift, and the associated technical basis for screening these events. Confirm that if either event is included in the total system performance assessment, the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on the repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of radionuclide release rates and solubility limits.
Verify that the U.S. Department of Energy reviews follow the guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or make an acceptable case for using alternative approaches.

Review Method 3 Data Uncertainty

…If in-package criticality or external-to-package criticality is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor.…

2.2.1.3.4.3 Acceptance Criteria

The following acceptance criteria are based on meeting the relevant requirements of 10 CFR 63.114(a)–(c) and (e)–(g), as they relate to the radionuclide release rates and solubility limits model abstraction. U.S. Nuclear Regulatory Commission staff should apply the following acceptance criteria, according to the level of importance established in the U.S. Department of Energy risk-informed license application.

Acceptance Criterion 1 System Description and Model Integration Are Adequate.

…(7) The abstraction of in-package criticality or external-to-package criticality, within the emplacement drift, provides an adequate technical basis for screening these events. If either event is included in the total system performance assessment, then the U.S. Department of Energy uses acceptable technical bases for selecting the design criteria that mitigate the potential impact of in-package criticality on the repository performance; identifies the features, events, and processes that may increase the reactivity of the system inside the waste package; identifies the configuration classes and configurations that have potential for nuclear criticality; and includes changes in thermal conditions and degradation of engineered barriers in the abstraction of radionuclide release rates and solubility limits…

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

…(6) If criticality cannot be excluded from total system performance assessment, then the U.S. Department of Energy provides an appropriate range of input parameters for calculating the effective neutron multiplication factor;…

2.2.1.3.7 Radionuclide Transport in the Unsaturated Zone…

2.2.1.3.7.2 Review Methods…

Review Method 3 Data Uncertainty

…If criticality in the unsaturated zone is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor. Evaluate the consequences calculated by the U.S. Department of Energy for criticality in the unsaturated zone. Verify that the U.S. Department of Energy appropriately establishes possible statistical correlations between parameters.

2.2.1.3.7.3 Acceptance Criteria…

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

…(3) If criticality in the unsaturated zone far field is included in the total system performance assessment, an appropriate range of input parameters for calculating the effective neutron multiplication factor is used. The effects on performance of criticality in the unsaturated zone are adequately evaluated;…

2.2.1.3.9 Radionuclide Transport in the Saturated Zone

2.2.1.3.9.2 Review Methods…

Review Method 3 Data Uncertainty

…If criticality in the saturated zone is included in the total system performance assessment, examine the methods and parameters used by the U.S. Department of Energy to calculate the effective neutron multiplication factor. Evaluate the consequences calculated by the U.S. Department of Energy for criticality in the saturated zone.

2.2.1.3.9.3 Acceptance Criteria…

Acceptance Criterion 3 Data Uncertainty Is Characterized and Propagated Through the Model Abstraction.

…(3) If criticality in the saturated zone is included in the total system performance assessment, an appropriate range of input parameters for calculating the effective neutron multiplication factor is used. The effects on performance of criticality in the saturated zone are adequately evaluated;…

2.2.1.3.12.5 References

Altman, W.D., J.P. Donnelly, and J.E. Kennedy. NUREG–1297, “Generic Technical Position on Peer-Review for High-Level Nuclear Waste Repositories.” Washington, DC: NRC. February 1988a.

———. NUREG–1298, “Generic Technical Position on Qualification of Existing Data for High-Level Nuclear Waste Repositories.” Washington, DC: NRC. February 1988b.”

REFERENCE

NRC. NUREG–1804, Rev 2, “Yucca Mountain Review Plan.” LSN Accession No. NRC000002735, ADAMS Accession No. ML032030389. Washington, DC: NRC. July 2003.

APPENDIX B

THE CRITICALITY OPEN ITEMS AND ACCEPTANCE CONDITIONS

B–1 THE CRITICALITY OPEN ITEMS FOR COMMERCIAL SPENT NUCLEAR FUEL

1. The staff believes that burnups of spent fuel assemblies must be verified through measurements before their loading into the waste package for the purpose of burnup credit verification;

2. The consequence criteria for transient and external criticalities are not addressed in the topical report. The U.S. Department of Energy (DOE) must specify if it intends to perform full consequence analyses for transient and external criticality events and include them in total system performance assessment or use some type of criteria for the purpose of criticality control design selection;

3. The DOE needs to provide a modeling approach for igneous-activity-induced criticality;

4. The DOE must include the effects of radionuclide migration from an intact fuel assembly through pinholes and cracks in the cladding;

5. The DOE must include a criticality margin when comparing k_{eff} values from regression analyses to criticality limit values;

6. The DOE must present an approach for developing the criticality margin;

7. The DOE must demonstrate the adequacy of using one-dimensional calculations to capture three-dimensional neutron spectrum effect in their point-depletion calculation or use two/three dimensional calculations for determining the neutron spectra during the depletion cycles to be used in the depletion analyses;

8. The DOE needs to use the cross-section data corresponding to the temperature for the waste package or critical benchmarks;

9. The DOE must include the cross-dependency of configuration parameters for k_{eff} regression equations;

10. The DOE must provide the technical basis for the correction factors developed for boron remaining in the solution;

11. The DOE is required to develop an acceptable methodology for establishing bias and uncertainties for the isotopic depletion model;

12. The DOE needs to establish the bias and associated uncertainty regarding the analysis or model, keeping track of the isotopic inventory loss, through cracks or pinholes, within intact spent fuel assemblies;

13. The DOE should address the types of criticality uncertainties and biases, which is based on American National Standards Institute/American Nuclear Society-8.17, presented by the staff in this Safety Evaluation Report (NRC, 2000);

14. The DOE must include a multi-parameter approach in its bias-trending analysis;

15. The DOE is required to include the isotopic bias and uncertainties as part of Δk_c if not included as isotopic correction factors;

16. The DOE must present a validation methodology or work scope for external criticality models;

17. The DOE should subject the method used for extending the trend to the procedures defined in American National Standards Institute/American Nuclear Society-8.1-1998, C4(a) and C4(b);

18. The DOE must verify and validate the regression equation or look-up table for all ranges of configuration and waste package parameters affecting k_{eff};

19. The DOE is required to include all uncertainties and variabilities introduced by the regression equation or the look-up table;

20. In developing the methodology for steady-state criticality consequences, the DOE must consider other types of moderators, especially with respect to external criticality;

21. The DOE must also consider the loss of soluble neutron-absorbing isotopes through pinholes and cracks in the spent fuel cladding, and its effect on steady state criticality consequence;

22. The DOE must also include other types of steady-state criticality consequences, especially with respect to internal criticality, in its consequence analysis approach;

23. The DOE needs to develop, and present for acceptance, the modeling approach for an external steady-state criticality consequence;

24. The DOE must develop and present a request for approval of a methodology for transient criticality consequence;

25. The DOE needs to develop and present, for NRC acceptance, the modeling approach for transient criticality consequence;

26. The DOE needs to develop a validation approach for the power model for steady-state criticality consequences;

27. The DOE must develop a validation approach for a transient criticality consequence model; and

28. The DOE should describe the interface between Figure 1-1 of the request for additional information responses and the total system performance assessment criticality risk analysis."[1]

B–2 THE CRITICALITY OPEN ITEMS AND ACCEPTANCE CONDITIONS FOR NAVAL SPENT NUCLEAR FUEL

In 2002 the U.S. Nuclear Regulatory Commission (NRC) staff issued a Draft Safety Evaluation Report for the Naval Nuclear Propulsion Program Addendum to the Disposal Criticality Analysis Methodology Topical Report, Revision 1 (Schlueter, 2002). The report identified areas where overall methodology is incomplete as two open items and fourteen acceptance conditions. Table B-1 presents a summary of these open items and acceptance conditions for naval spent nuclear fuel.

Table B–1. The Criticality Open Items and Acceptance Conditions for Naval Spent Nuclear Fuel*

Naval Nuclear Propulsion Program Open Item for Acceptance Number	Description	U.S. Nuclear Regulatory Commission Open Items	U.S. Nuclear Regulatory Commission Acceptance Conditions
1	Criticality Limit Acceptance Criterion	0	0
2	Methodology Acceptance Criterion (includes material related acceptance conditions)	0	3
1-2	**Acceptance Criterion Items for Acceptance Subtotal**	**0**	**3**
3	Identification of Features, Events, and Processes	0	0
4	Evaluation of Features, Events, and Processes	1	1
5	Inclusion or Exclusion of Features, Events, and Processes	0	1
4 and/or 5	Related to Multiple Features, Events, and Processes Items for Acceptance	1	2

[1]Excerpted from Safety Evaluation Report for Disposal Criticality Analysis Methodology Topical Report (NRC, 2000).

Table B-1. The Criticality Open Items and Acceptance Conditions for Naval Spent Nuclear Fuel* (continued)			
Naval Nuclear Propulsion Program Open Item for Acceptance Number	**Description**	**U.S. Nuclear Regulatory Commission Open Items**	**U.S. Nuclear Regulatory Commission Acceptance Conditions**
3-5	**Features, Events, and Processes Items for Acceptance Subtotal**	**2**	**4**
6	Depletion Modeling	0	3
7	Principal Isotope List	0	1†
8	Biases and Uncertainties	0	2
9	Reactivity Codes and Cross-Section Data	0	0
10	Trending Parameters	0	1
11	Benchmarks Used for Validation	0	0
6-11	**Neutronic Items for Acceptance Subtotal**	**0**	**7**
1-11	**Total Open Items and Acceptance Conditions**	**2**	**14**

*Schlueter, J. "Revision 1 of the Draft SER for the Naval Nuclear Propulsion Program Addendum to the Disposal Criticality Analysis Methodology Topical Report." Letter (March 8) to J. McKenzie, Acting Director of Regulatory Affairs Naval Nuclear Propulsion Program, Naval Sea Systems Command. ADAMS Accession No. ML020710413, LSN Accession No. NRC000015189. Washington, DC: NRC. 2002.
†One acceptance condition to Item for Acceptance 6 also applies to Item for Acceptance 7.

REFERENCES

CRWMS M&O. "Disposal Criticality Analysis Methodology Topical Report." YMP/TR–004Q. Rev. 00. ADAMS Accession No. ML003742456, LSN Accession No. DEN001434519. Las Vegas, Nevada: CRWMS M&O, Yucca Mountain Site Characterization Office. 1998.

NRC. "Safety Evaluation Report for Disposal Criticality Analysis Methodology Topical Report." Rev 0. ADAMS Accession No. ML03722229, LSN Accession No. NRC000005336. Washington, DC: NRC. 2000.

Schlueter, J. “Results of the U.S. Nuclear Regulatory Commission Review of the Naval Nuclear Propulsion Program Probability Methodology.” Letter (August 4) to J. McKenzie, Acting Director of Regulatory Affairs Naval Nuclear Propulsion Program, Naval Sea Systems Command. ADAMS Accession No. ML032170659, LSN Accession No. NRC000029617. Washington, DC: NRC. 2003.

———. “Revision 1 of the Draft SER for the Naval Nuclear Propulsion Program Addendum to the Disposal Criticality Analysis Methodology Topical Report.” Letter (March 8) to J. McKenzie, Acting Director of Regulatory Affairs Naval Nuclear Propulsion Program, Naval Sea Systems Command. ADAMS Accession No. ML020710413, LSN Accession No. NRC000015189. Washington, DC: NRC. 2002.

APPENDIX C

DISPOSAL CRITICALITY FEATURES, EVENTS, AND PROCESSES

Table C–1 lists 16 criticality-related features, events, and processes for the U.S. Department of Energy (DOE) Total System Performance Assessment for the license application. This list is excerpted from Bechtel SAIC Company, LLC (2004a) and, according to this document, is excerpted from the DOE dataset “MO0407SEPFEPLA.000 LA FEP List” dated July 20, 2004. The process of classification and identification of the features, events, and processes is described in Bechtel SAIC Company, LLC (2004b).

Table C–1. Disposal Criticality Features, Events, and Processes*

Features, Events, and Processes Number in the U.S. Department of Energy Database*	Features, Events, and Processes	Features, Events, and Processes Description
Basecase Features, Events, and Processes		
2.1.14.15.0A	In-package criticality (intact configuration)	The waste package internal structures and the waste form remain intact. If there is a breach in the waste package that allows water to either accumulate or flow through the waste package, then criticality could occur *in situ*. In-package criticality resulting from disruptive events is addressed in separate features, events, and processes.
2.1.14.16.0A	In-package criticality (degraded configurations)	The waste package internal structures and the waste form may degrade. If a critical configuration (sufficient fissile material and neutron moderator, lack of neutron absorbers) develops, criticality could occur *in situ*. Potential *in-situ* critical configurations are defined in Figures 3.2a and 3.2b of Disposal Criticality Analysis Methodology Topical Report.† In-package criticality resulting from disruptive events is addressed in separate features, events, and processes.
2.1.14.17.0A	Near-field criticality	Near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of Disposal Criticality Analysis Methodology Topical Report.† In-package criticality resulting from disruptive events is addressed in separate features, events, and processes.

Table C–1. Disposal Criticality Features, Events, and Processes* (continued)		
Features, Events, and Processes Number in the U.S. Department of Energy Database*	**Features, Events, and Processes**	**Features, Events, and Processes Description**
2.2.14.09.0A	Far-field criticality	Far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of Disposal Criticality Analysis Methodology Topical Report.† In-package criticality resulting from disruptive events is addressed in separate features, events, and processes.
Seismic Disruptive Event Features, Events, and Processes		
2.1.14.18.0A	In-package criticality resulting from a seismic event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a seismic disruptive event. If there is a breach in the waste package that allows water to either accumulate or flow through the waste package, then criticality could occur *in situ*.
2.1.14.19.0A	In-package criticality resulting from a seismic event (degraded configurations)	Either during or as a result of a seismic disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur *in situ*. Potential *in-situ* critical configurations are defined in Figures 3.2a and 3.2b of Disposal Criticality Analysis Methodology Topical Report.†
2.1.14.20.0A	Near-field criticality resulting from a seismic event	Either during or as a result of a seismic disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of Disposal Criticality Analysis Methodology Topical Report.†

Table C–1. Disposal Criticality Features, Events, and Processes* (continued)		
Features, Events, and Processes Number in the U.S. Department of Energy Database*	**Features, Events, and Processes**	**Features, Events, and Processes Description**
2.2.14.10.0A	Far-field criticality resulting from a seismic event	Either during or as a result of a seismic disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of Disposal Criticality Analysis Methodology Topical Report.†
Rockfall Disruptive Event for Features, Events, and Processes		
2.1.14.21.0A	In-package criticality resulting from rockfall (intact configuration)	The waste package internal structures and the waste form remain intact either during or after a rockfall event. If there is a breach (or breaches) in the waste package that allows water to either accumulate or flow through the waste package, criticality could occur *in situ*.
2.1.14.22.0A	In-package criticality resulting from rockfall (degraded configurations)	Either during or as a result of a rockfall event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur in situ. Potential in-situ critical configurations are defined in Figures 3.2a and 3.2b of Disposal Criticality Analysis Methodology Topical Report.†
2.1.14.23.0A	Near-field criticality resulting from rockfall	Either during or as a result of a rockfall event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of Disposal Criticality Analysis Methodology Topical Report.†
2.2.14.11.0A	Far-field criticality resulting from rockfall	Either during or as a result of a rockfall event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of Disposal Criticality Analysis Methodology Topical Report.†

Table C–1. Disposal Criticality Features, Events, and Processes* (continued)		
Features, Events, and Processes Number in the U.S. Department of Energy Database*	**Features, Events, and Processes**	**Features, Events, and Processes Description**
Igneous Disruptive Event Features, Events, and Processes		
2.1.14.24.0A	In-package criticality resulting from an igneous event (intact configuration)	The waste package internal structures and the waste form remain intact either during or after an igneous disruptive event. If there is a breach in the waste package that allows water to either accumulate or flow through the waste package, then criticality could occur *in situ*.
2.1.14.25.0A	In-package criticality resulting from an igneous event (degraded configurations)	Either during or as a result of an igneous disruptive event, the waste package internal structures and the waste form may degrade. If a critical configuration develops, criticality could occur *in situ*. Potential *in-situ* critical configurations are defined in Figures 3.2a and 3.2b of Disposal Criticality Analysis Methodology Topical Report.†
2.1.14.26.0A	Near-field criticality resulting from an igneous event	Either during or as a result of an igneous disruptive event, near-field criticality could occur if fissile material-bearing solution from the waste package is transported into the drift and the fissile material is precipitated into a critical configuration. Potential near-field critical configurations are defined in Figure 3.3a of Disposal Criticality Analysis Methodology Topical Report.†
2.2.14.12.0A	Far-field criticality resulting from an igneous event	Either during or as a result of an igneous disruptive event, far-field criticality could occur if fissile material-bearing solution from the waste package is transported beyond the drift and the fissile material is precipitated into a critical configuration. Potential far-field critical configurations are defined in Figure 3.3b of Disposal Criticality Analysis Methodology Topical Report.†
*Bechtel SAIC Company, LLC. "Screening Analysis of Criticality Features, Events, and Processes for License Application." ANL–EBS–NU–000008. Rev. 01. LSN Accession No. DN2002140903. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004. †CRWMS M&O. "Disposal Criticality Analysis Methodology Topical Report." YMP/TR–004Q. Rev. 02. ADAMS Accession No. ML033290322, LSN Accession No. NRC000021818. Las Vegas, Nevada: CRWMS M&O, Yucca Mountain Site Characterization Office. 2003.		

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Bechtel SAIC Company, LLC. “Screening Analysis of Criticality Features, Events, and Processes for License Application.” ANL–EBS–NU–000008. Rev. 01. LSN Accession No. DN2002075048. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004a.

———. “The Development of the Total System Performance Assessment-License Application Features, Events, and Processes.” TDR–WIS–MD–000003. Rev. 01. LSN Accession No. DN2002074408. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004b.