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SUMMARY OF PRECLOSURE SEISMIC DESIGN METHODOLOGY

Reference: *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain,* TDR-WHS-MD-000004, Revision 01

Enclosed is a summary of the Preclosure Seismic Design Methodology for the preclosure seismic design for Yucca Mountain, Nevada. The summary in the enclosure describes the technical approach that the U.S. Department of Energy (DOE) will use to demonstrate that the preclosure seismic design for Yucca Mountain will support compliance with the performance objectives of 10 CFR §63.111(a), (b) and (c) in a manner that is consistent with the risk-informed, performance-based framework of 10 CFR Part 63. The enclosure discusses the DOE approach for identifying seismic design basis initiating event(s) and attendant bases for the preclosure safety analysis. The information presented in the enclosure is summarized from the reference documents listed, which are available and have been previously provided to the U.S. Nuclear Regulatory Commission (NRC). The information in the enclosure in consistent with the Project documents previously provided to NRC, including the above referenced seismic design methodology report and the technical exchanges held on this topic including the November 2002 Technical Exchange.

It is noted that Part 63 does not prescribe a specific approach to seismic design. Nor has the NRC provided specific guidance for demonstrating compliance through the preclosure safety analysis, allowing broad flexibility to the DOE to develop an approach. Therefore, the DOE has developed a preclosure seismic design methodology that is based on the general regulatory requirements contained in Part 63 as well as on applicable regulatory precedents from commercial nuclear licensing as provided for in 10 CFR §63.102(f). Consistent with a risk-informed approach, this preclosure seismic design methodology is integrated with preclosure safety analysis, and both design methodology and safety analyses are used to demonstrate compliance with the preclosure performance objectives in 10 CFR §63.111(a), (b) and (c).

The DOE approach includes:

- A comprehensive and systematic identification of seismically initiated event sequences;

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- An analysis of the performance of structures, systems, and components (SSC) to categorize SSCs according to their importance to safety performance;
- Identification of two levels of design basis ground motion amplitudes that are based on the characteristics of the geologic setting and are consistent with precedents adopted for nuclear facilities with comparable or higher risks to workers and the public, including relevant criteria from 10 CFR Part 72;
- Use of well established seismic design and analysis methods that have nuclear facility precedent, including the use of the codes and standards identified in *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants* (NUREG 0800) for design of nuclear power plants. These codes and standards are used to ensure the adequacy and acceptance of design solutions for the important to safety SSCs;
- Use of Seismic Margin Assessment methodology to ensure that the combination of design basis ground motions and design procedures are adequately conservative to assess the seismic safety of the facilities. As part of this methodology, review level earthquake ground motions (the Yucca Mountain Project beyond design basis ground motions) are identified with amplitudes twice the design basis level to challenge the plant important to safety SSCs, and to determine seismic capacities and vulnerabilities. This methodology will demonstrate that seismic initiating events beyond the review level earthquake ground motions are not reasonable based on the characteristics of the repository and the precedents adopted for nuclear facilities with comparable or higher risks. As such, those seismic initiating events are not included in the Preclosure Safety Analysis pursuant to 10 CFR §63.102(f).

Use of the approach described in the enclosure provides a measure of seismic safety for important to safety SSCs that is consistent with other nuclear facilities of comparable or higher risk significance regulated by the NRC. Additionally, DOE believes that this approach identifies appropriate seismic design bases that will facilitate the NRC's determination that there is reasonable assurance that radioactive materials can be received and possessed at Yucca Mountain without unreasonable risk to the public health and safety, as required by §63.31(a)(1). The NRC's comments are requested regarding the DOE preclosure seismic design methodology and how DOE is limiting seismic-initiating events according to that methodology in the repository preclosure safety analysis.

There are no new regulatory commitments in the body or the enclosure to this letter. Please direct any questions concerning this letter and its enclosure to Jon P. Ake at (702) 794-5526 or e-mail jon_ake@ymp.gov, or Carol L. Hanlon at (702) 794-1324 or e-mail carol_hanlon@ymp.gov.

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Enclosure:
Summary of Preclosure Seismic Design Methodology

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ENCLOSURE

SUMMARY OF PRECLOSURE SEISMIC DESIGN METHODOLOGY

Introduction

The purpose of this enclosure is to describe the approach that the U.S. Department of Energy (DOE) intends to use to demonstrate reasonable assurance that preclosure seismic design of the surface and subsurface nuclear facilities satisfy the preclosure performance objectives contained in 10 CFR §63.111(a), (b), and (c). The approach integrates preclosure seismic design methodology with preclosure seismic safety analysis to demonstrate safety performance consistent with the risk-informed performance-based framework of the regulation. Both the seismic design methodology and the seismic safety assessment are used to demonstrate compliance with the preclosure performance objectives in §63.111(a), (b), and (c), and to provide reasonable assurance that there is no unreasonable risk to public health and safety per §63.31(a)(1).

10 CFR Part 63 does not provide specific guidance for an approach to prepare seismic analyses and design, nor does it provide guidance on how to demonstrate compliance with the safety standard. Rather than specifying design criteria or a methodology for analyses, the regulation allows the DOE to define an appropriate approach. As stated in the Yucca Mountain Review Plan (NRC 2003, p. 2.1-2):

> "No prescriptive design criteria are imposed in the Yucca Mountain Review Plan, because 10 CFR Part 63 allows the U.S. Department of Energy to develop the design criteria and demonstrate their appropriateness. Thus, the U.S. Department of Energy has flexibility to use any codes, standards, and methodologies it demonstrates to be applicable and appropriate. This flexibility is necessary when implementing a risk-informed, performance-based regulation."

DOE has developed a comprehensive approach based on the specific regulatory requirements contained in Part 63 as well as on regulatory precedents. This includes the risk-informed, performance-based regulatory framework outlined in 10 CFR Part 63 and supporting documents, in conjunction with the level of design detail that will be available at the time of license application submission for construction authorization. Consistent with a risk-informed approach, the DOE's preclosure seismic design methodology is integrated with preclosure safety analysis. Both design and safety analyses are used to demonstrate compliance with the preclosure performance objectives in 10 CFR §63.111(a), (b), and (c) for the geologic repository operations area through repository closure.

The essential components of the seismic design methodology and compliance approach are outlined in the following sections. This methodology is consistent with previous discussions with the U.S. Nuclear Regulatory Commission (NRC).

Identification of Potential Seismically Initiated Event Sequences

As a starting point, systematic analyses of potential seismically initiated hazards are conducted to identify potential event sequences (e.g., BSC 2004a). These analyses encompass waste handling operations of facilities within the geologic repository operations area and include a detailed examination of potential seismically initiated internal hazards (such as a potential drop of cask, waste package or fuel assembly from a crane) together with the identification of seismically unique hazards (such as a potential structural collapse). These analyses address the requirements of 10 CFR §63.112 (b) for a "... comprehensive identification of potential event sequences."

As part of the event sequence analyses, the structures, systems, and components (SSC) and associated procedural safety controls that are relied on to prevent or mitigate these seismically initiated event sequences are identified. The results of these event sequence analyses are evaluated for performance in compliance with the performance objectives of 10 CFR §63.111(a), (b), and (c) and the assignment of design basis ground motions. The SSCs credited in the analyses to prevent or mitigate the seismically initiated event sequences provide the basis for the identification of SSCs important to safety (ITS) for seismic considerations, consistent with the requirements in 10 CFR §63.112 (e).

Performance of the SSCs and Assignment of Design Basis Ground Motions.

To assign a seismic design basis to an SSC, potential radiological consequences (doses) are estimated and associated with each of the seismically-initiated event sequences. For conservatism, these potential dose estimates are unmitigated, such that no credit is taken for the confinement or filtration of radioactive materials that may be released from a damaged waste form or container. Therefore, any seismically-initiated event sequence that results in a radioactive release is assumed to result in a dose, both onsite and offsite. These doses are estimated as directly proportional to the numbers and types of waste forms that are damaged in a seismic event sequence.

The estimated dose consequences for identified event sequences are then used for the purpose of assigning design basis ground motion levels to the associated SSCs, and to identify what is ITS. Based on the performance objectives identified in 10 CFR §63.111(a) and (b), SSCs are assigned one of two design basis ground motion levels: DBGM-1 and DBGM-2, discussed further in the next section. Those SSCs in the event sequences that are not credited for prevention or mitigation of dose consequences in these analyses will be designed, as appropriate, to the seismic provisions of the International Building Code.

Design Basis Ground Motion Levels

The *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (BSC 2004b) describes the two design basis ground motion levels, DBGM-1 and DBGM-2, as defined by the ground motion having a mean annual probability of exceedance of 1×10^{-3} and 5×10^{-4}, respectively. These design basis ground motions are defined based on risk significance of the Yucca Mountain Project (YMP) facilities. Two levels of design basis ground motions are applied in the risk-informed framework in accordance with prevention or mitigation of the two levels of risk-informed performance objectives defined in 10 CFR §63.111(a) and (b). SSCs associated with prevention or mitigation of dose to comply with the performance objectives of 10 CFR §63.111(a) and (b)(1) are assigned DBGM-1. SSCs associated with prevention or mitigation of dose to comply with the performance objectives of 10 CFR §63.111(b)(2) are assigned DBGM-2. Because DBGM-1 has a mean annual probability of exceedance of 1×10^{-3} it is more likely to occur during the preclosure period than a DBGM-2 earthquake and, therefore, DBGM-1 prevention or mitigation features must comply with the more restrictive dose criteria associated with 10 CFR §63.111(a) and (b)(1).

A comparison has been made to the design bases of nuclear facilities having comparable, greater, and lesser risk significance (BSC 2004b, Table 3-2, see Reference 4) to verify that the design basis ground motions are reasonable relative to other NRC-regulated facilities and other DOE nuclear facilities. For example, NRC Regulatory Guide 1.165, *Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion,* specifies that the design basis ground motion for new nuclear power reactors should be a *median* annual probability of exceedance of 1 x 10^{-5}, which is approximately equivalent to a *mean* annual probability of exceedance of 1 x 10^{-4}. In contrast, Regulatory Guide 3.73, *Site Evaluations and Design Earthquake Ground Motion for Dry Cask Independent Spent Fuel Storage and Monitored Retrievable Storage Installations,* specifies the design basis ground motions for independent spent fuel storage facilities as the ground motion associated with a mean annual probability of exceedance of 5 x 10^{-4}.

The YMP surface and subsurface nuclear facilities are designed with no high pressure or high temperature systems (such as those which are common to nuclear power plants) whose failure could lead to active energetic dispersal of radionuclides (see Reference 15, *Preclosure Consequence Analyses for License Application* (DC #45303), Document ID: 000-00C-MGR0-00900-000-00C, Revision 00C). Therefore, DOE has concluded, based on the event sequences, radiological release scenarios, and dose consequences evaluated in Reference 15, that the risk significance of the Yucca Mountain preclosure facilities is less than nuclear power plants and comparable to that of spent nuclear fuel storage facilities. Accordingly, DOE has concluded that the use of DBGM-1 and DBGM-2 ground motion levels for the design of the surface and subsurface SSCs ITS is reasonable and appropriate. Using these DBGMs for the seismic design of SSCs ITS is consistent with 10 CFR §63.102(f), as these ground motions are based on the "... characteristics of the geologic setting and the human environment, and consistent with precedents adopted for nuclear facilities with comparable or higher risks to workers and the public."

Design Analysis Methods and Design Codes and Standards

The design and analysis for the DBGM-1 and DBGM-2 ground motion amplitudes will be prepared using well-established engineering methods and techniques that have been used and accepted on other nuclear facilities of comparable or higher risk. These methods and techniques include (as appropriate):

- Seismic response of buildings using multiple lump mass stick models for the nuclear surface facilities;

- Determination of the foundation impedance functions including equivalent soil spring constants and damping coefficients;

- Static analysis using accepted structural modeling and analytical methods;

- Design loads and loading combinations developed from *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants* (NUREG-0800), and referenced design codes therein;
- Combination of static and dynamic loads based on the loading combinations from the codes recommended in NUREG-0800;
- Design of SSCs ITS prepared in accordance with the codes and standards recommended in NUREG-0800;
- Use of materials, and material strength properties accepted on other nuclear facilities licensed by NRC.

Design documentation shall be developed under the requirements of the Yucca Mountain's *Quality Assurance Requirements and Description* (DOE 2004) to ensure the appropriate quality controls are applied.

Studies have been conducted to assess the seismic design margin (resistance to failure during ground motions greater than design basis) of nuclear power plants designed to NUREG-0800 codes and standards. Based on these studies, it is found that the SSCs designed to meet seismic demands with capacities derived from codes and standards identified in NUREG-0800 have inherently higher seismic design margins beyond code capacities. A common measure of seismic design margin is the risk reduction ratio R_R, which is the ratio of the probability of failure (where failure is defined as the loss of intended safety function) to the probability of the design basis ground motion. Comparison of the R_R values for the Yucca Mountain design criteria with those for other nuclear facilities demonstrates that there will be seismic design margins comparable to, or greater than, those for comparable or higher risk facilities (BSC 2004b, Table 3-2).

Seismic Margin Assessment - Seismic Safety Demonstration.

In addition to design of SSCs that are ITS to a specific design basis (either DBGM-1 or DBGM-2), the DOE intends to demonstrate additional margin in preclosure seismic safety using a Seismic Margin Assessment (SMA) approach. The SMA approach will be used to evaluate the seismic design margins of the SSCs ITS designed to DBGM-2 to determine the seismic safety of the surface and subsurface facilities ITS SSCs ITS. Specifically, the SMA will demonstrate that SSCs ITS have a high confidence of low probability of failure (HCLPF) capacity that exceeds the designated review level earthquake, termed beyond design basis ground motion (BDBGM) event for Yucca Mountain facilities, thereby assuring that the preclosure performance objectives of 10 CFR §63.111(a), (b), and (c) are met.

SMA has considerable precedent in seismic evaluations of SSCs for nuclear power plants and has been used to demonstrate the adequacy of seismic margins for the NRC-regulated power reactor facilities with levels of risks to workers and the public that are comparable to or higher than those at the YMP. NUREG-1407 (Chen et al. 1991) identifies SMA and probabilistic risk analyses as acceptable risk-informed approaches for evaluating seismic safety and identifying seismic vulnerabilities, as required by the NRC's Individual Plant Examination of External Events (IPEEE) program. The approach is based on a comparison of a conservative estimate of the *capacity* of the facility to maintain safety functions with the *demand* imposed by "review level earthquake" ground motions that are greater than the design basis ground motions. HCLPF capacities are assessed for SSCs ITS following the implementation guidance for SMAs given in EPRI (1991), including the use of the Conservative Deterministic Failure Margins (CDFM) approach to determine plant safety as a measure of the HCLPF capacity. The HCLPF capacity is defined as the ground motion level at which there is a mean conditional probability of failure of 0.01 or less. ASCE 4-98 (ASCE 4-98 2000, Appendix A) provides a discussion on the applicability of the SMA approach to demonstrate seismic safety of plants designed using NUREG-0800 codes and standards. NUREG-1742 (NRC 2001) indicates that 43 plant sites of 71 (NRC 2001, Table 2.1) used the SMA approach in their IPEEE evaluations. The DOE has established the HCLPF Seismic Margin Method for use on the YMP in Appendix B (BSC 2004b).

The review level earthquake (termed beyond design basis ground motion event or BDBGM for the Yucca Mountain facilities) is associated with a mean annual exceedance probability of 1×10^{-4} (BSC 2004b). Ground motion amplitudes associated with the BDBGM have been developed that are specific to the characteristics of the Yucca Mountain repository site (BSC 2004c). Consistent with implementation of the SMA approach for nuclear power plants, the review level earthquake loading should be sufficiently larger than the design basis to challenge the seismic margins of the facility. The average ratio between the review level earthquake ground motions and the design bases ground motions (peak ground acceleration (PGA) or peak spectral acceleration (PSA)) for nuclear power plants, used for SMA IPEEE evaluations, is approximately 1.5 to 1.9 respectively. The ratio for the Yucca Mountain surface facilities is approximately 2 (for both PGA and PSA), which is comparable and conservative with respect to the nuclear power plants evaluated using the SMA approach.

As discussed in the preclosure seismic design methodology report (BSC 2004b, Appendix B), design evaluation will ensure that the minimum ratio between the high-confidence-of-low-probability-of-failure capacity and the BDBGM event (review level earthquake) is 1.10. This will ensure that adequate seismic design margins will exist for SSCs ITS, such that they will maintain their defined functions credited in the preclosure safety analysis to prevent or mitigate dose consequences. The SMA approach will be used to demonstrate that the preclosure facilities have adequate seismic design margin to maintain credited safety functions of SSCs ITS to prevent and mitigate event sequences with the potential for exceeding the §63.111(a) and (b) dose limits. Accordingly, the SMA evaluation will be an integral part of the preclosure safety analysis to assure that the preclosure performance objectives of 10 CFR §63.111(c) are met. This method determines the seismic design margin at the review level earthquake for the SSCs credited with prevention or mitigation of dose, which is consistent with the seismic safety demonstration conducted for nuclear power plants using SMA for IPEEE evaluations. This methodology will demonstrate that seismic initiating events beyond the review level earthquake ground motions are not reasonable based on the characteristics of the Yucca Mountain repository and the precedents adopted for nuclear facilities with comparable or higher risks. As such, those seismic initiating events are not included in the Preclosure Safety Analysis pursuant to 10 CFR §63.102(f).

The DOE concludes that using the approach (methods, techniques, analyses, and SMA) outlined above provides adequate protection from seismically initiated event sequences during the preclosure period and is consistent and compliant with stated requirements of 10 CFR Part 63. Use of the approach described herein provides a measure of seismic safety for SSCs ITS that is consistent with other nuclear facilities of comparable or higher risk significance regulated by the NRC. Further, the DOE believes that this approach identifies appropriate seismic design bases that will facilitate the Commission determination that there is reasonable assurance that radioactive materials can be received and possessed at Yucca Mountain without unreasonable risk to the public health and safety, as required by §63.31(a)(1).

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