Preclosure Safety Analysis for Seismically Initiated Event Sequences

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Abstract

This paper describes a methodology to determine probabilities of occurrence of seismically initiated event sequences, considering event occurrence probabilities and performance of structures, systems, and components (SSCs). The methodology can be used to assess safety of the preclosure facility for the seismic hazard at the proposed geologic repository at Yucca Mountain, Nevada, and to demonstrate compliance with the risk-informed, performance-based regulations in the U.S. Code of Federal Regulations, Title 10, Part 63. The probability of occurrence of an event sequence leading to an SSC failure is determined by convolution of the seismic hazard curve with the conditional failure probabilities (i.e., fragility) of the SSCs. The methodology is illustrated using examples of potential event sequences. The methodology described in the paper shows how the safety of a facility during a seismic event can be determined using the performance-based regulations. The scope of the paper is limited to estimating the probabilities of occurrence of potential event sequences leading to failure of SSCs and potential release of radioactivity; it does not discuss dose or risk estimates.

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1. Introduction

The U.S. Nuclear Regulatory Commission's (NRC's) mission is to license and regulate the Nation's use of byproduct, source, and special nuclear materials, to ensure adequate protection of public health and safety, promote the common defense and security, and protect the environment. NRC's regulations are in the U.S. Code of Federal Regulations (CFR), Title 10, Chapter 1 and address nuclear safety throughout the lifetime of the facility. These regulations include requirements to prevent release of radioactive materials in the event of man-made hazards (e.g., equipment failures, human errors, or aircraft crashes) and natural hazards (e.g., earthquake, tornado, and flood). In contrast to a design-based deterministic approach for regulating nuclear facilities, the recent trend has been to use risk-informed and performance-based regulations to demonstrate nuclear safety, consistent with the Commission's Policy Statement (Refs. 1, 2).

Regulations in the U.S. Code of Federal Regulations, Title 10, Part 63 (10 CFR Part 63) (Ref. 3), for the proposed high-level nuclear waste disposal facility at Yucca Mountain (YM), Nevada, USA, are risk-informed and performance-based. These regulations require explicit demonstration of the performance of structures, systems, and components (SSCs) that are relied on to demonstrate nuclear safety, defined as important to safety (ITS). The discussion in this paper is limited to a methodology for demonstrating the performance of SSCs ITS during a seismic event, for compliance with 10 CFR Part 63. The scope of the paper is limited to estimating the probabilities of occurrence of potential event sequences leading to failure of SSCs and potential release of radioactivity; it does not discuss dose nor risk estimates.

It should be noted that the methodology discussed in this paper is for the pre-closure safety analysis of the proposed geologic repository at YM. However, the methodology is general, and can be applied to evaluate the performance of engineered barriers during the longer time frames of the post-closure period of the geologic repository, if SSC conditional failure probabilities (i.e., fragility curves) are developed, based on considering the effects of the longer time periods on material capacities.

2. Discussion

Regulations in 10 CFR Part 63 are performance-based. Instead of specifying design requirements, 10 CFR 63.111 specifies performance-based standards for the geological repository operations area (GROA) as radiological dose limits, to the public, for Category 1 and 2 event sequences. Category 1 event sequences are those that are expected to occur one or more times before permanent closure of the GROA. Category 2 event sequences are those other event sequences that have at least one chance in 10,000 of occurring before permanent closure of the GROA. Event sequences with the probability of occurrence less than that of a Category 2 event sequence are screened out.

To meet the performance objectives of 10 CFR 63.111 for seismic hazard, the preclosure safety analysis must include: (1) a systematic examination of the site; (2) characterization of the seismic hazard; (3) resulting event sequences; and (4) potential radiological exposures to the public. Based on the review of these event sequences, and the potential release of radioactive material and estimated doses, SSCs ITS must be evaluated to demonstrate their ability to perform intended safety functions under seismic loads.

3. Seismic Performance Demonstration

The probability of occurrence of seismic initiating events and the failure probabilities of SSCs need to be considered to demonstrate that SSCs ITS will perform their intended safety functions. The probability of occurrence of an event sequence leading to an SSC ITS failure, is determined by convolution of the mean seismic hazard curve with the mean conditional failure probabilities (i.e., fragility) of the SSCs ITS (Ref. 4). The mean fragility curve for an SSC ITS may be estimated using: (1) probability density functions for controlling parameters in a Monte Carlo analysis; (2) the simplified methods outlined in Section 4 of Electric Power Research Institute, TR-103959 (Ref. 5); or (3) other methods that capture the appropriate variability and uncertainty in parameters used to estimate the capacity of the SSCs ITS to withstand seismic events.

The methodology described herein is based on evaluating event sequences for seismically initiated events and identifying SSCs ITS for seismic performance evaluation. The first step in estimating the probability of occurrence of seismic event sequences is to assess the seismic performance of the individual SSC ITS. For example, to obtain the mean fragility curve of the individual SSC ITS, the median capacity ($C_{50\%}$) and the composite logarithmic standard deviation (β) should be estimated using transparent technical bases. Failure criteria used for estimating the fragility curves should be consistent with the SSCs ITS functional requirements. The mean annual failure probability of the individual SSCs ITS can then be obtained by convolving the mean seismic hazard curve at the site, and the mean fragility curve.

If the annual probability of failure values of individual SSCs ITS for seismically initiated event sequences, estimated using the methodology discussed above, is less than 1 in 10,000 during the preclosure period, as defined in 10 CFR 63.2 for Category 2 event sequences, the SSC ITS is considered to perform its intended safety function and meets 10 CFR 63.111. If, however, the annual probability of failure of the individual SSCs ITS for seismically initiated event sequences is greater than, or equal to, 1 in 10,000, during the preclosure period, DOE may demonstrate compliance with 10 CFR 63.111 by showing that the annual probability of occurrence of each of the seismic event sequences containing multiple SSCs ITS in an event sequence is less than 1 in 10,000 during the preclosure period. Alternatively, the dose consequence to the public at the site boundary from the event sequence can be calculated to show that the dose is less than the dose limits in 10 CFR 63.111(b)(2). It should be noted that Part 63 regulations require consideration of a single seismically initiated event sequence for meeting the dose performance limit, in contrast to consideration of all seismically initiated event sequences to determine the dose in a probabilistic risk analysis of a nuclear reactor facility.

The methodology described above is shown in a flowchart, in Figure 1.

4. Conclusion

Performance of SSCs relied on to ensure nuclear safety during a seismic event can be determined using a methodology, as described in this paper, to demonstrate compliance with the risk-informed performance-based regulations of Part 63. The methodology is based on the convolution of the seismic hazard curve and the SSC conditional failure probabilities or fragility curves.

5. References

1. U.S. Nuclear Regulatory Commission, *Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities;* Final Policy Statement, *Federal Register*, August 16, 1995, Washington, DC, Vol. 60, No. 158, pp. 42622-42629.

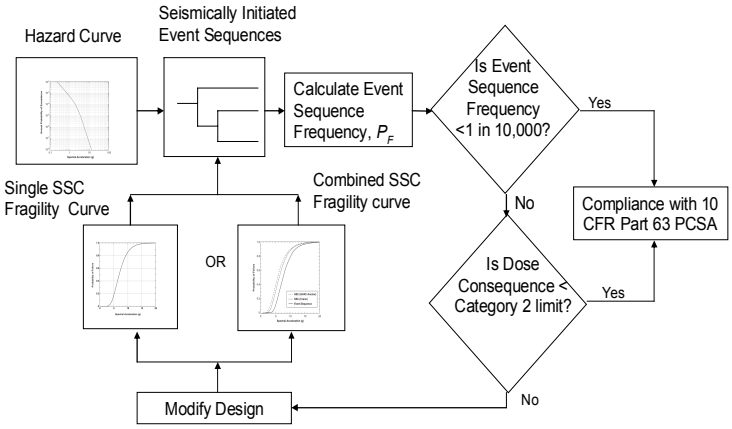
2. U.S. Nuclear Regulatory Commission, *White Paper on Risk-Informed and Performance-Based Regulations*, SECY 98-144, June 22, 1998, as revised by the Staff Requirements Memorandum, March 1, 1999.

3. U.S. Nuclear Regulatory Commission, *Disposal of High-Level Nuclear Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain*, *Nevada*, Final Rule, *Federal Register*, November 2, 2001, Washington, DC, Vol. 66, No. 213, pp. 55732-55816.

4. American Society of Civil Engineers, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*, ASCE/SEI 43-05, 2005.

5. Electric Power Research Institute, *Methodology for Developing Seismic Fragilities*, EPRI TR-103959, June 1994.

Figure 1. Methodology for Evaluation of Seismically initiated Event Sequences



SSC – structure, system, or component
PCSA – preclosure safety analysis