Preclosure Seismic Design Methodology and Performance Demonstration

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NRC/DOE Technical Exchange and Management Meeting
June 7, 2006

Outline

- Purpose
- Background
- Proposed DOE Approach
- NRC Actions
- Key Messages
- NRC Interim Staff Guidance, Draft HLWRS-ISG-01
- DOE YM Seismic Hazard
- Example Event Sequence Analyses
- Path Forward

Purpose

- Discuss staff guidance in draft HLWRS-ISG-01, *Review Methodology for Seismically Initiated Event Sequences*, including analyses for categorization of seismic event sequences

- Discuss staff review perspective on
  - Yucca Mountain site-specific hazard curve and
  - Fragility curves for structures, systems, and components (SSCs), important to safety (ITS)

Background

- DOE Topical Report YMP/TR-003-NP, *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain*, Revision 2, August 1997
- DOE Topical Report YMP/TR-003-NP, *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain*, Revision 3, October 2004
- DOE Letter providing summary of the preclosure seismic design methodology, August 25, 2005

Proposed DOE Approach

- DOE's proposed approach for compliance with 10 CFR Part 63 (Topical Report YMP/TR-003-NP, Revision 3, October 2004)
  - Design Bases Earthquakes
    - DBGM-1 and DBGM-2
  - NUREG-0800 criteria
  - Seismic Margin Assessment (SMA) for a Beyond Design Basis Ground Motion (BDBGM)

NRC Actions

- Staff level Interactions at the NRC on-site representative's office to clearly understand the DOE approach
- Staff feedback in January 24, 2006 letter to DOE
- Issuance of a draft HLWRS-ISG-01 for public comment on May 22, 2006

Key Messages

- DOE's proposed design basis ground motion, coupled with the proposed design criteria and the codes and standards, appear consistent with 10 CFR 63.112(f)(2)
- Seismic Margin Assessment (SMA), proposed by DOE to establish design margins of SSCs ITS against failures during a seismic event, is not a substitute for demonstrating compliance with 10 CFR 63.111

Key Messages (contd.)

- DOE should provide analyses to determine seismic performance of structures, systems, and components (SSCs), important to safety (ITS), and probabilities of occurrence of event sequences
- Seismic performance of SSCs ITS may be determined using a methodology outlined in the American Society of Civil Engineers (ASCE) Standard ASCE 43-05

Key Messages (contd.)

- Seismic hazard for the preclosure safety analysis (PCSA) should be characterized:
  - using an appropriate site response model
  - to low-enough values of annual probabilities of exceedance so that its combination with fragilities of SSCs ITS will result in reasonable estimates of event sequence probabilities of occurrence, as required for Part 63 PCSA

Key Messages (contd.)

- Fragility curves for SSCs ITS should be developed using transparent technical bases and the failure criteria consistent with the SSCs ITS functional requirements

- If more than one SSC ITS are relied on for categorizing an event sequence, individual SSCs fragility curves should be combined to determine the event sequence probability of occurrence

NRC Interim Staff Guidance, Draft HLWRS-ISG-01, *Review Methodology for Seismically Initiated Event Sequences*

Mahendra Shah

Part 63 Regulations for Preclosure Safety Analysis (PCSA)

- 10 CFR 63.111(a), 111(b)(1) for Category 1 Event Sequences. Category 1 event sequences are those that are expected to occur one or more times before permanent closure of GROA.

- 10 CFR 63.111(b)(2) for Category 2 Event Sequences. Category 2 event sequences are those other event sequences that have at least one chance in 10,000 of occurring before permanent closure of GROA.

YMRP sections supplemented

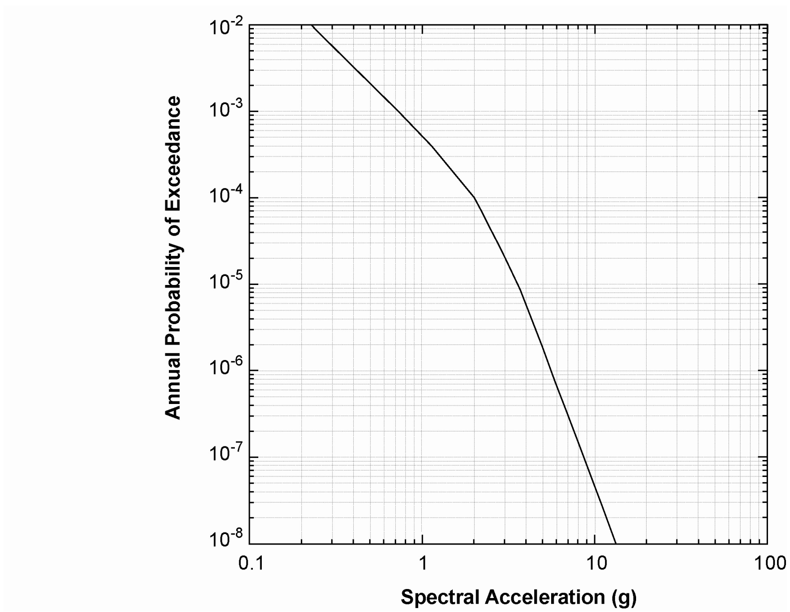
- Section 2.1.1.4.2, *Review Method 2 Categories 1 and 2 Event Sequences*
- Section 2.1.1.4.3, *Acceptance Criterion 2 Categories 1 and 2 Event Sequences are Adequately identified*

Seismically Initiated Event Sequence

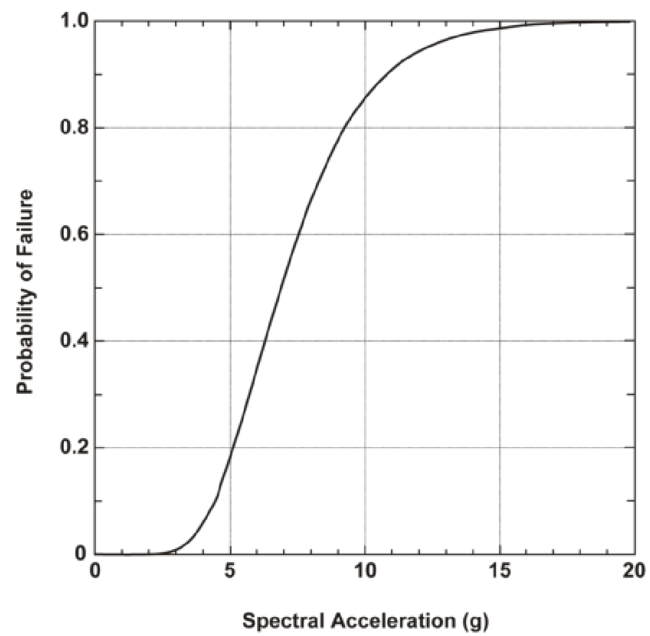
- Seismic hazard curve
- Fragility curve of an SSC ITS
- Probability of failure, P_F, of an SSC ITS can be computed by convolving the hazard curve with the fragility curve (see ASCE 43-05, equation C2-6)

Seismic Hazard and Fragility Curves

Hypothetical Seismic Hazard curve at a specified frequency



Example Seismic Fragility Curve for a specified frequency



Example for Illustration Only

Development of an SSC Fragility Curve

- Fragility curves for an SSC ITS should be developed using transparent technical bases and the failure criteria that are consistent with the SSCs ITS functional requirements at applicable hazard levels

- The log-normal distribution can be assumed to develop the corresponding mean fragility curve, which is expressed in terms of the median capacity level and the logarithmic standard deviation

- The fragility curve for an SSC ITS may be developed using a Monte Carlo analysis, simplified methods outlined in EPRI TR-103959, or other methods that capture appropriately the variability of the capacity

Compliance with Part 63 PSCA

- If P_F is less than 1 in 10,000 during the preclosure period for the evaluated SSC ITS, then the event sequence for the failure of the SSC would be a beyond Category 2 event sequence

Compliance with Part 63 PSCA (contd.)

- If, however, P_F of an individual SSC ITS is greater than or equal to 1 in 10,000 during the preclosure period, DOE may
  - use other SSCs ITS in the event sequence to combine the fragilities, determine the event sequence probability of occurrence, and categorize the event sequence
  - show that the dose consequence to the public at the site boundary is less than the dose limits in 10 CFR 63.111(b)(2)

DOE YM Seismic Hazard

Sarah Gonzalez

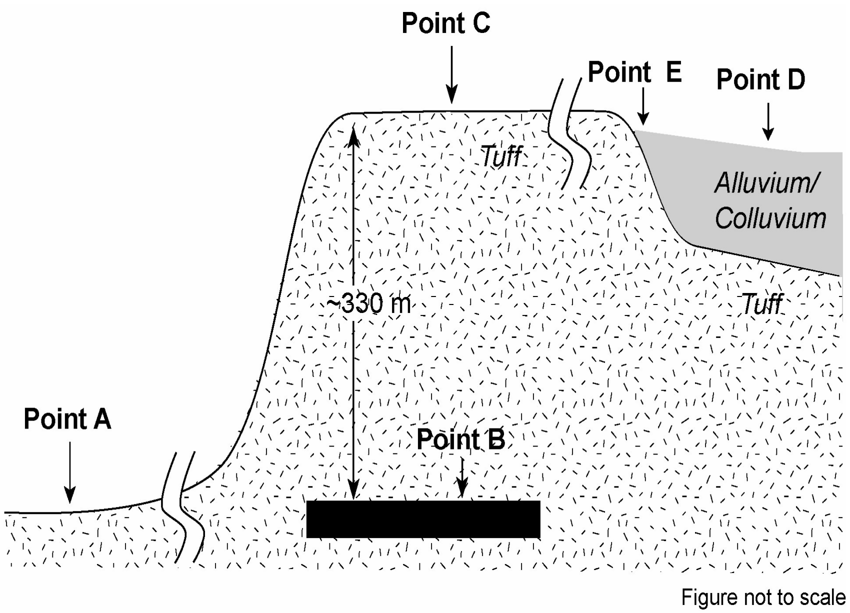
Purpose

- Discuss YM seismic hazard curves developed by DOE to date
- Provide NRC perspective on the development of the site-specific seismic hazard curves for the preclosure safety analysis

DOE YM Seismic Hazard

- YM PSHA (CRWMS M&O, 1998) provided hazard curves for Point A

- Site response modeling needed to obtain site specific hazard curves for points D, E, and B

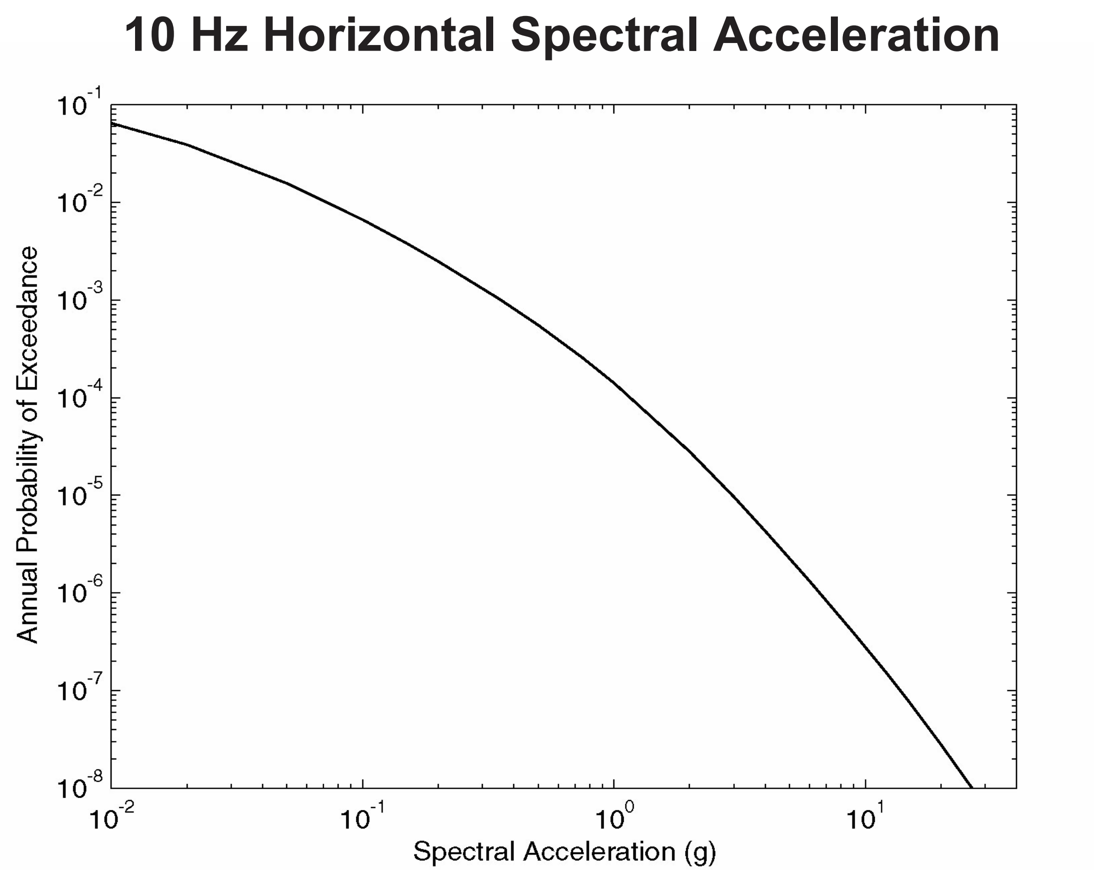


LEGEND

Point A - Reference rock outcrop used in PSHA
Point B - Rock site in waste emplacement level
Point C - Rock site above waste emplacement level
Point D - Soil site at surface facilities area
Point E - Shallow soil/rock at surface facilities area

Figure modified from Bechtel SAIC Company, LLC, 2004, MDL-MGR-GS-000003

YM Mean Seismic Hazard Curve (Point A)



Ref: Bechtel SAIC Company, LLC, 2004, MDL-MGR-GS-000003

DOE Site Specific Surface Hazard Curves for Preclosure Facilities

- DOE provided site specific response spectra at annual probabilities of exceedance of 10^{-3}, 5×10^{-4}, and 10^{-4} (Points D and E)
  - One-dimensional equivalent-linear modeling (Bechtel SAIC Company, LLC, 2004, MDL-MGR-GS-000003)
  - Site specific geotechnical data (Bechtel SAIC Company, LLC, 2002, ANL-MGR-GE-000003) for a portion of the Surface Facilities Area

NRC Perspective on the Development of Site Specific Hazard Curves

- Site response modeling considerations:
  - 2D and/or 3D site effects
  - Nonlinear site-response model
  - Appropriate site geotechnical data
- Development of an appropriate site specific hazard curve
  - Incorporation of recent site response modeling results
  - Appropriate annual probabilities of exceedance

NRC Perspective on the Development of Site Specific Hazard Curves (contd.)

- Seismic hazard for the preclosure safety analysis (PCSA) should be characterized to low-enough values of annual probabilities of exceedance so that its combination with fragilities of SSCs ITS will result in reasonable estimates of event sequence probabilities of occurrence, as required for Part 63 PCSA

Example Event Sequence Analyses

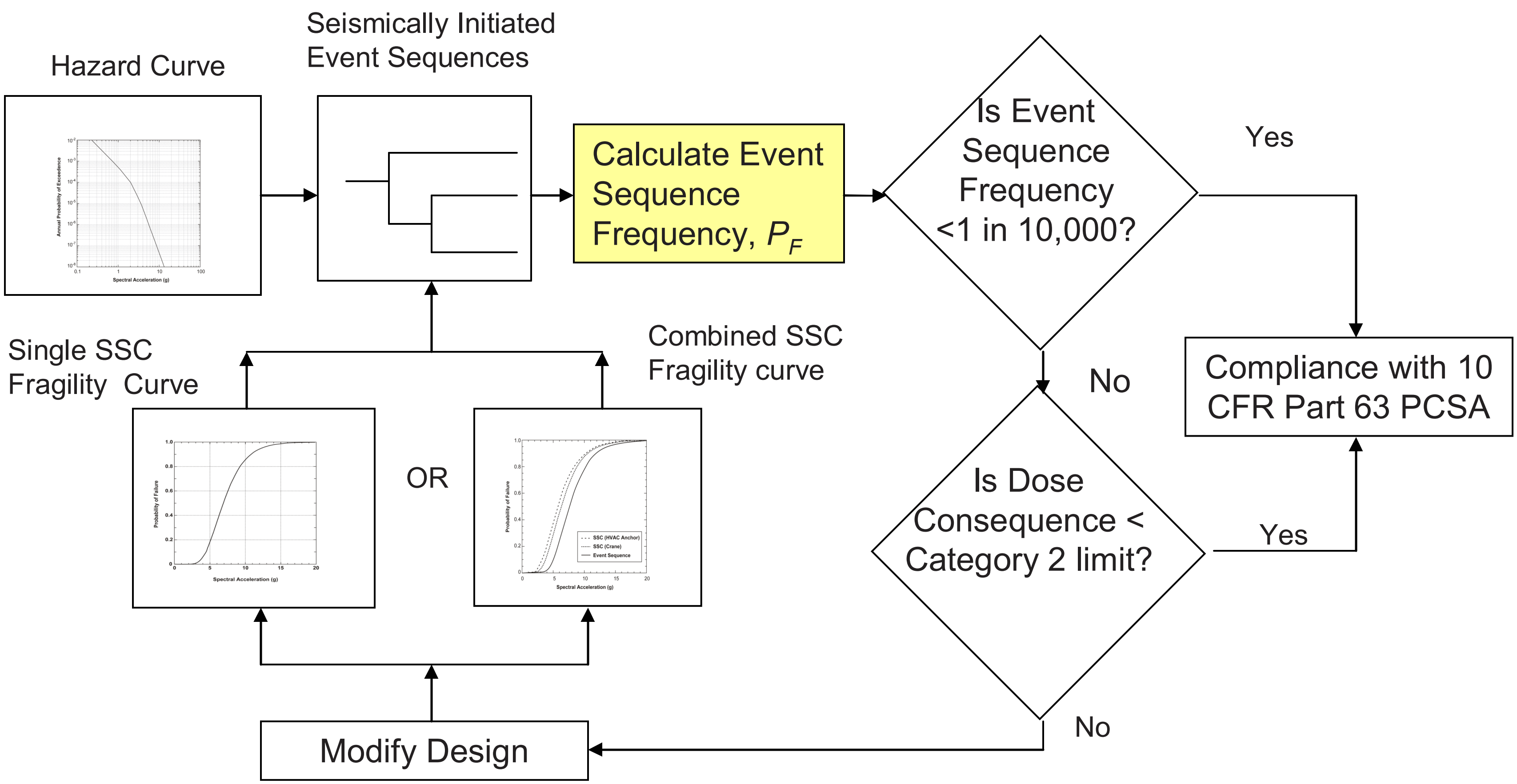
Biswajit Dasgupta

Purpose

- Discuss the application of the example methodology described in draft ISG to determine preclosure compliance for seismically initiated event sequences

- Discuss the example analyses presented in the draft ISG

Overview of Approach for Compliance with Part 63 PCSA



Example Event Sequence Analyses

- Appendices in the draft ISG-01
  - Appendix A: Example Methodology for Computing SSC ITS Probability of Failure during a Seismic Event
  - Appendix B: Example Methodology for Evaluation of Complete Event Sequences

Appendix A - Probability of Failure of SSC ITS

- Seismic Hazard Curve, $H(a)$:
  - Annual frequency of exceedance as a function of ground motion
- Fragility of a Component, $P_F(a)$
  - Assumes log-normal distribution
  - Median capacity, $C_{50\%}$
  - Logarithmic standard deviation, β
- Annual Probability of failure, P_F
  - P_F is obtained by convolving fragility and hazard curves (e.g., see ASCE 43-05, equation C2-6)

Probability of Failure of an SSC

- Seismic performance or failure probability of an SSC, P_F, is given by

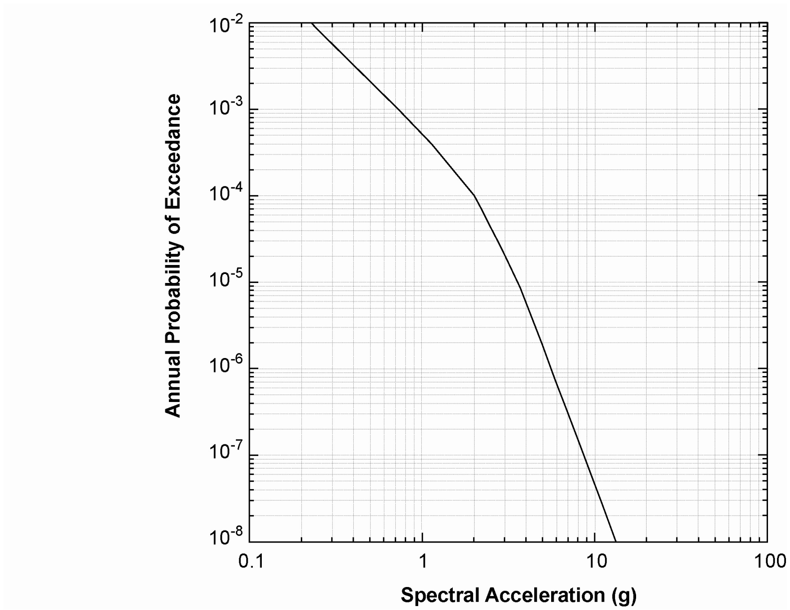
$$P_F = -\int_0^\infty P_F(a)\left(\frac{dH(a)}{da}\right)da \quad \text{or} \quad P_F = \int_0^\infty H(a)\left(\frac{dP_F(a)}{da}\right)da$$

Where

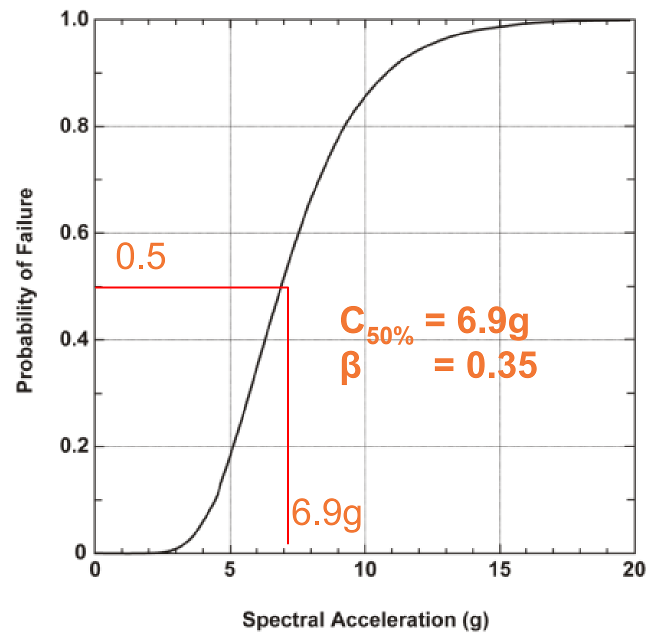
- *H(a)* is the annual probability of exceedance of ground motion level, *a*
- $P_F(a)$ is the conditional probability of failure given a value of the ground motion level, *a*

Seismic Hazard and Fragility Curves

Hypothetical Seismic Hazard curve at a specified frequency



Example Seismic Fragility Curve for a specified frequency



Example for Illustration Only

Probability of Failure Computation

– Numerical Integration

- Hazard curve is discretized into piecewise segments

– Annual Probability of Failure

$$P_F = \sum_{i=1}^{n} \left[H(a_i) - H(a_{i+1}) \right] P_F(a_{cgi})$$

Where, a_{cgi} is the acceleration at the center of gravity point of the hazard curve between a_i and a_{i+1} accelerations

Probability of Failure Computation (contd.)

– Closed-form Solution

- Hazard curve is approximated by a straight line in a log-log scale plot

$$H(a) = K_1 a^{-K_H}$$

- Fragility Curve: Log-normal distribution with a median capacity, $C_{50\%}$, and logarithmic standard deviation, β

- Annual Probability of Failure

$$P_F = K_1 (C_{50\%})^{-K_H} e^{0.5(K_H \beta)^2}$$

Where, K_H is a slope parameter, and K_1 is a constant

Probability of Failure Computation (contd.)

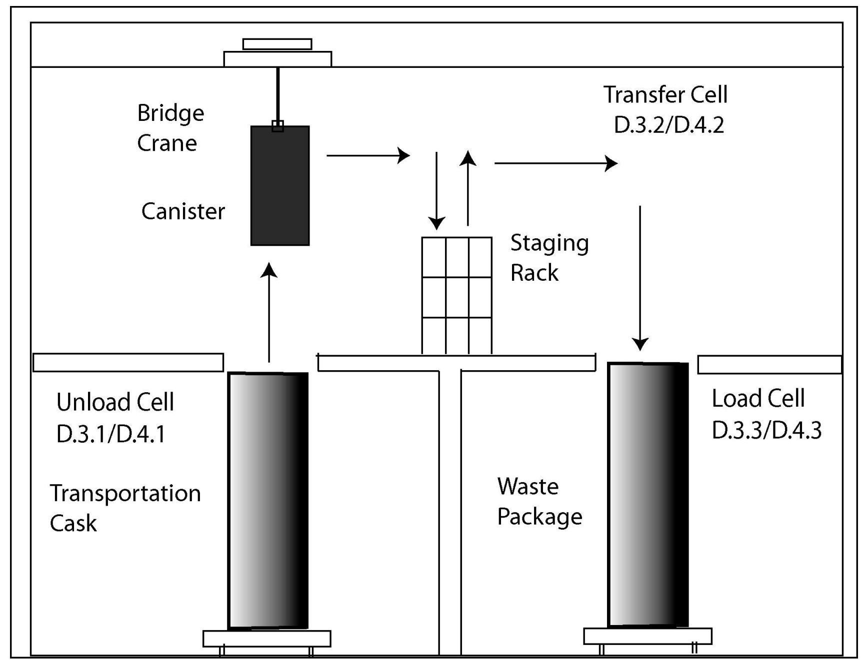
- Annual Probability of Failure of SSC ITS
  - Numerical Integration: 1.5×10^{-6}
  - Closed form solution: 1.8×10^{-6}

Appendix B - Methodology for Evaluation of Event Sequences

- Purpose of this example is to illustrate
  - How the probability of occurrence of a seismically initiated event sequence with more than one SSC ITS in the event sequence may be determined
  - How to categorize the event sequence for determining compliance with preclosure performance objectives

Conceptual Waste Handling Operations

- A bridge crane transfers a canister
- Concrete shear walls provide confinement
- HVAC-HEPA provides filtration to radionuclide particulates



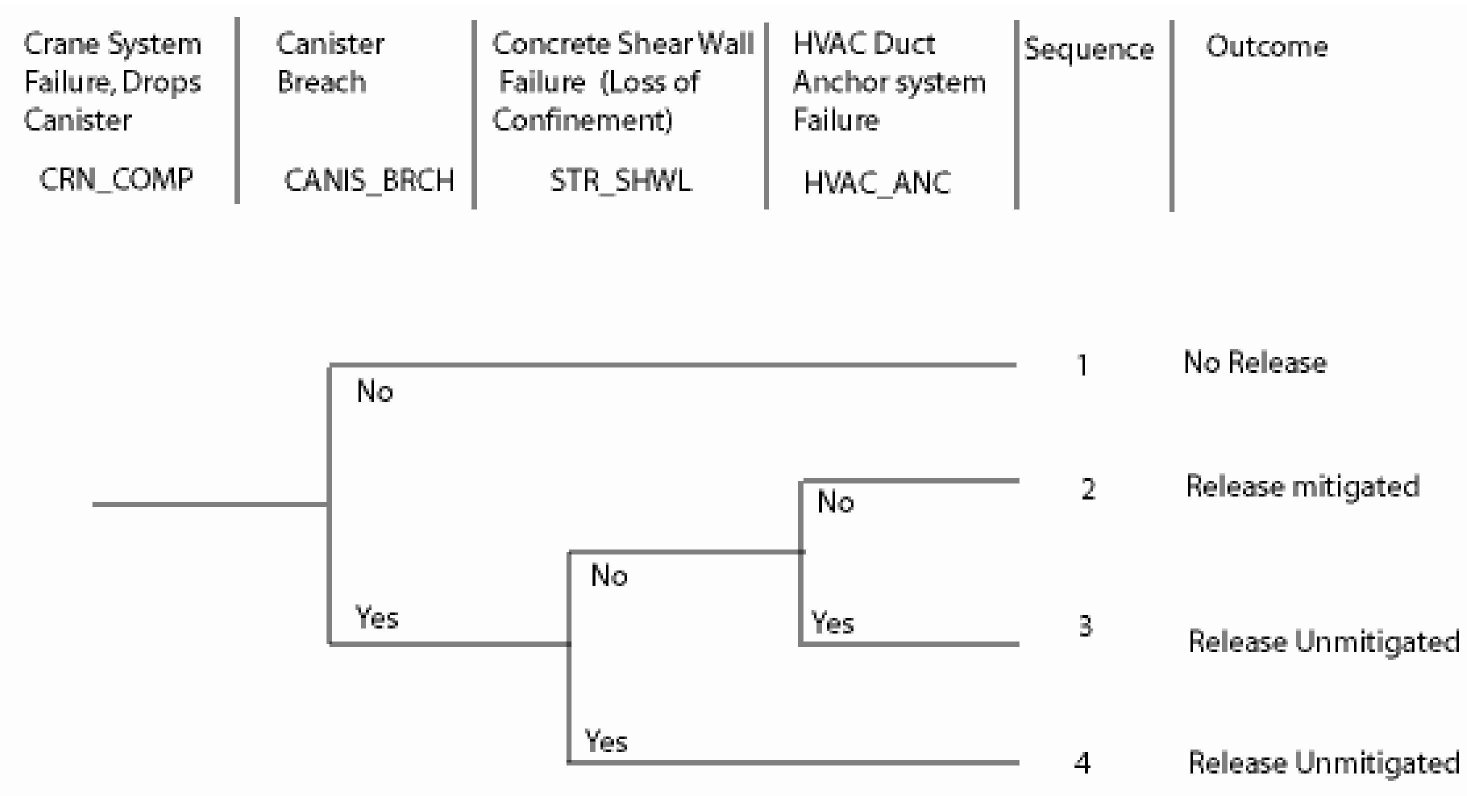
Example for Illustration Only

Assumptions

- Crane system, concrete shear wall, and HVAC duct anchor system respond independently for a given value of the ground motion parameter
- Failure of the concrete shear wall is associated with cracking resulting in loss of confinement
- If dropped, canister would breach and release radioactive material
- Considering a preclosure period of 100 years, Category 2 annual frequency of occurrence threshold is 10^{-6}

Example for Illustration Only

Seismically Initiated Event Sequences



Example for Illustration Only

Seismically Initiated Event Sequences (contd.)

- **Event Sequence 3**
  - Failure of the crane system + HVAC duct anchor system → potential consequence

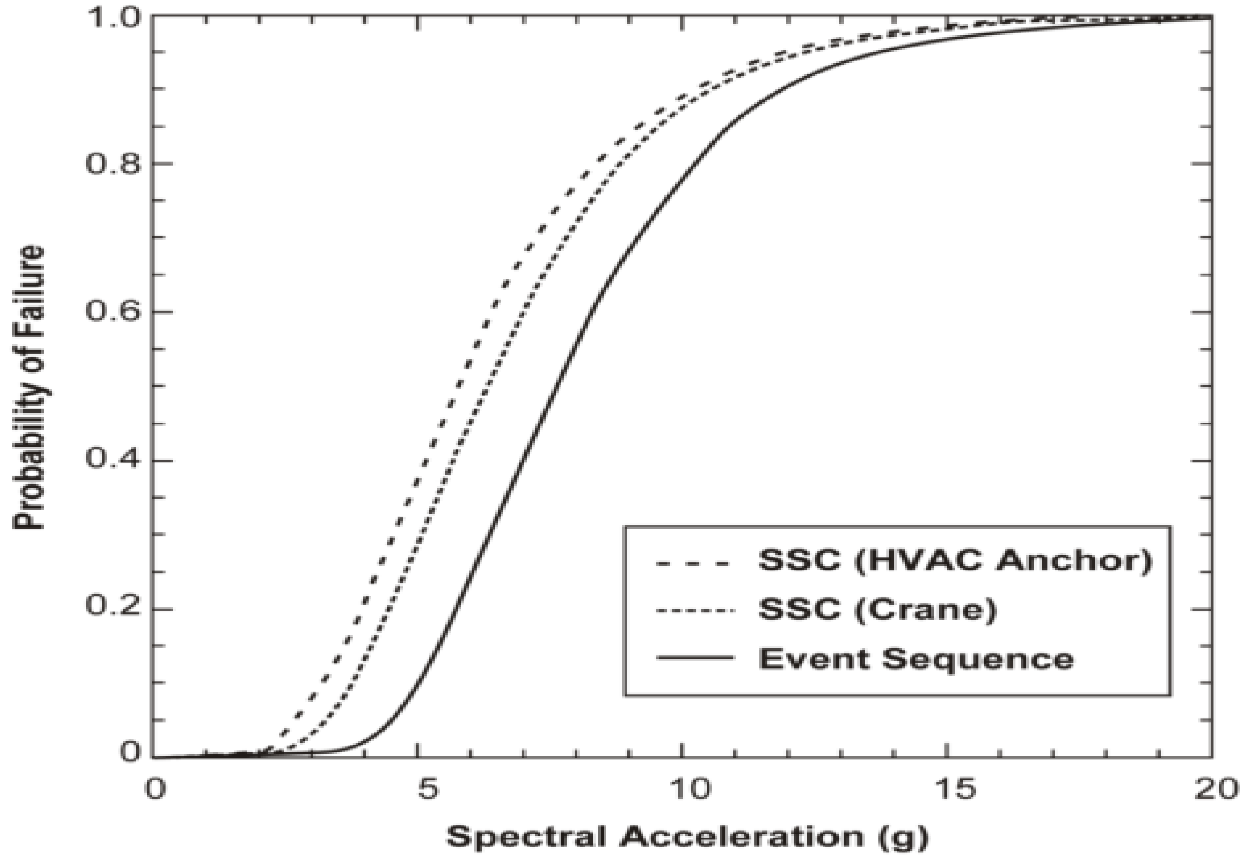
- **Event Sequence 4**
  - Failure of the crane system + concrete shear wall → potential consequence

Annual Failure Probabilities of Individual SSCs ITS

SSC ITS	$C_{50\%}$	β	Annual P_F	Probability Criteria Met ?
Crane System	6.3 g	0.4	3.2×10^{-6}	No
Concrete Shear Wall	7.2 g	0.35	1.2×10^{-6}	No
HVAC Duct Anchor System	5.7 g	0.45	6.7×10^{-6}	No

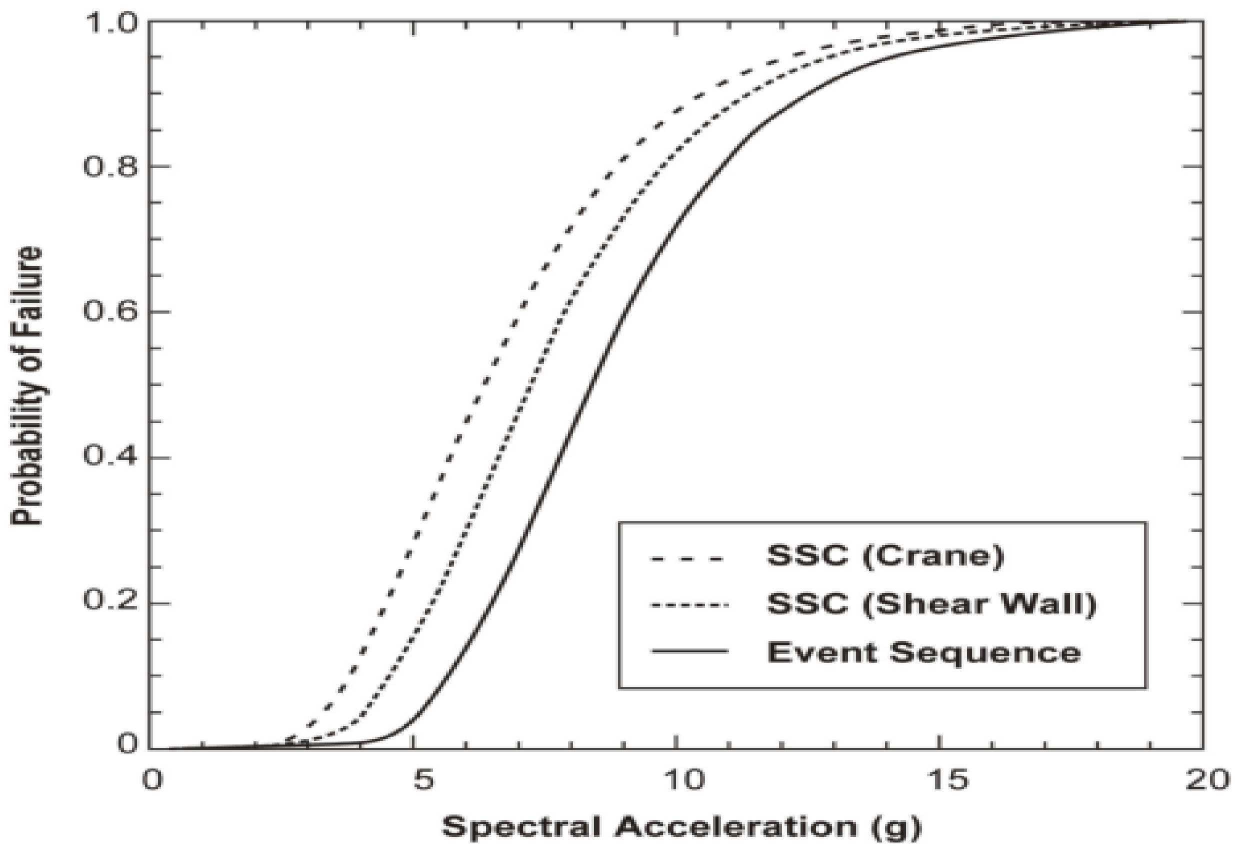
Example for Illustration Only

Event Sequence 3 Combined Fragilities



Example for Illustration Only

Event Sequence 4
Combined Fragilities



Example for Illustration Only

Compliance of Event Sequences

Event Sequence	SSC ITS	Event Sequence Frequency	Probability Criteria Met ?
3	Crane & HVAC	8.4×10^{-7}	Yes
4	Crane & Shear Wall	3.8×10^{-7}	Yes

Example for Illustration Only

Summary

- This presentation illustrates the application of methodology described in draft ISG for demonstration of compliance to Part 63 for seismically initiated event sequences

- Discussed two examples
  – Methodology to compute annual probability of failure of SSC ITS
  – Methodology for evaluating event sequence frequency

Path Forward

Mysore Nataraja

Path Forward for Draft HLWRS-ISG-01

- Receive public comment: July 6, 2006
- Consider public comments, as appropriate, in the final version of ISG-01
- Issue final ISG-01: September 2006

Key Messages

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