Preclosure Seismic Design Methodology and Performance Demonstration

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United States Nuclear Regulatory Commission

NRC/DOE Technical Exchange and Management Meeting
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Enclosure 3

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
  - NUREG-0800 criteria
    - DBGM-1 and DBGM-2
  - 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

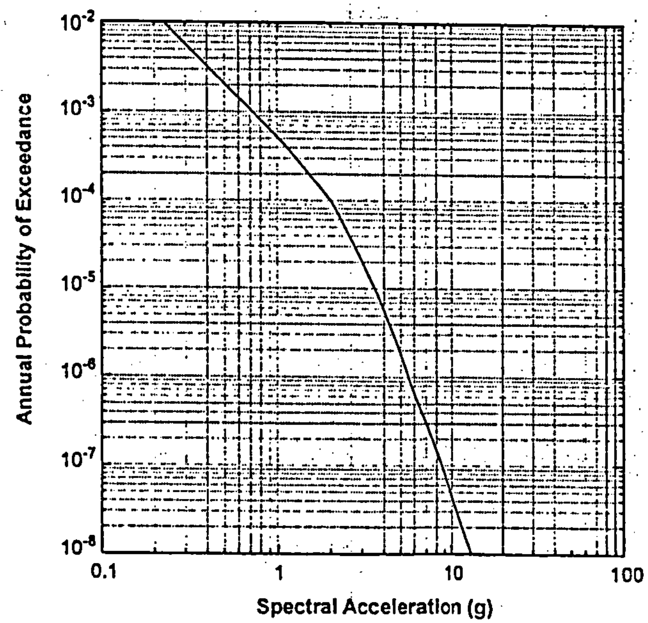
- Section 2.1.1.4.2, *Review Method 2 Categories 1 and 2 Event Sequences*
- Section 2.1.1.4.3, *Acceptance Criterion 2 Categories 1 and 2 Event Sequences are Adequately identified*

Seismically Initiated Event Sequence

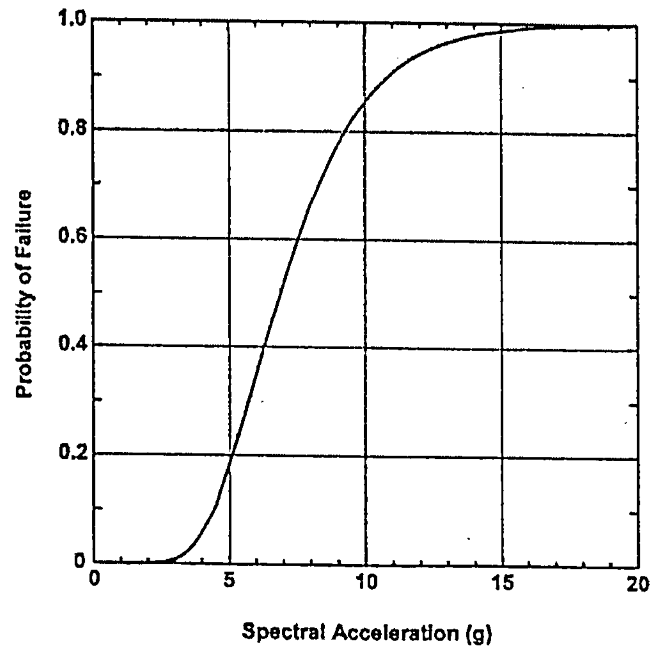
- Seismic hazard curve
- Fragility curve of an SSC ITS
- Probability of failure, P_F, of an SSC ITS can be computed by convolving the hazard curve with the fragility curve (see ASCE 43-05, equation C2-6)

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

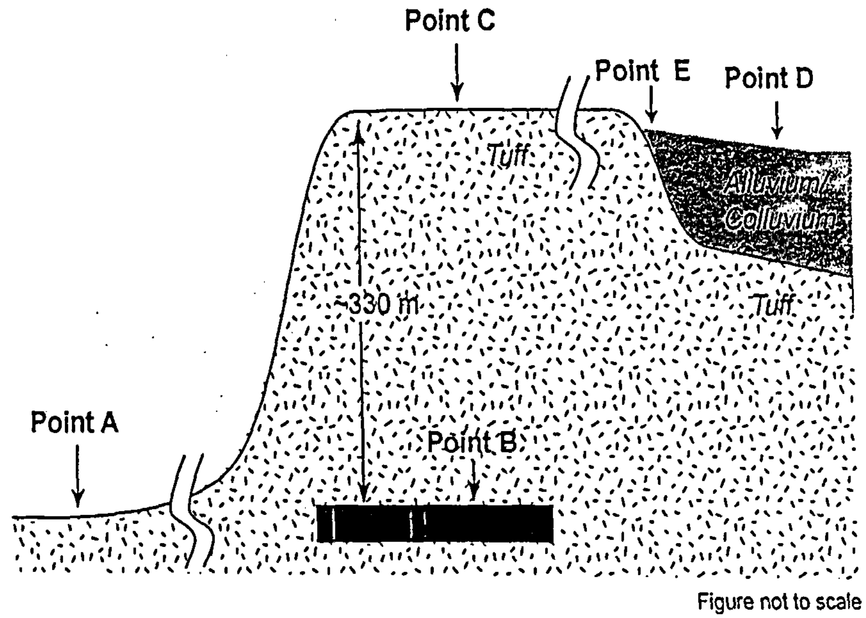
- Discuss YM seismic hazard curves developed by DOE todate

- 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

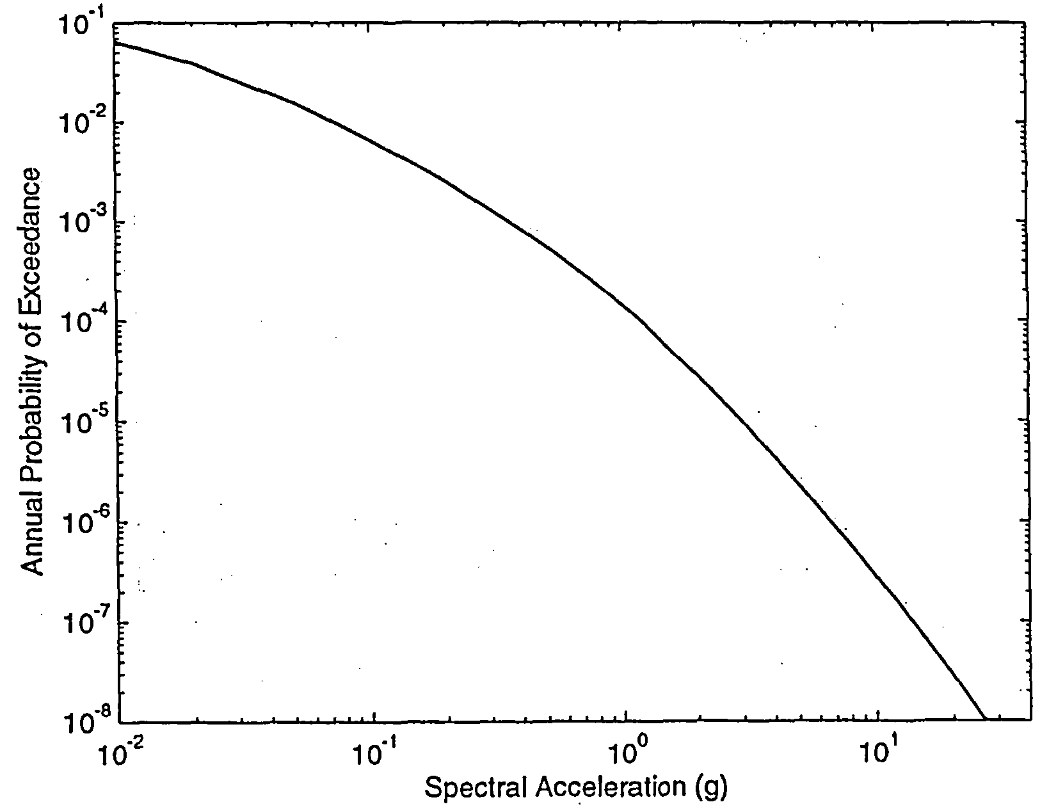
Point D - Soil site at surface facilities area

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)

10 Hz Horizontal Spectral Acceleration



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

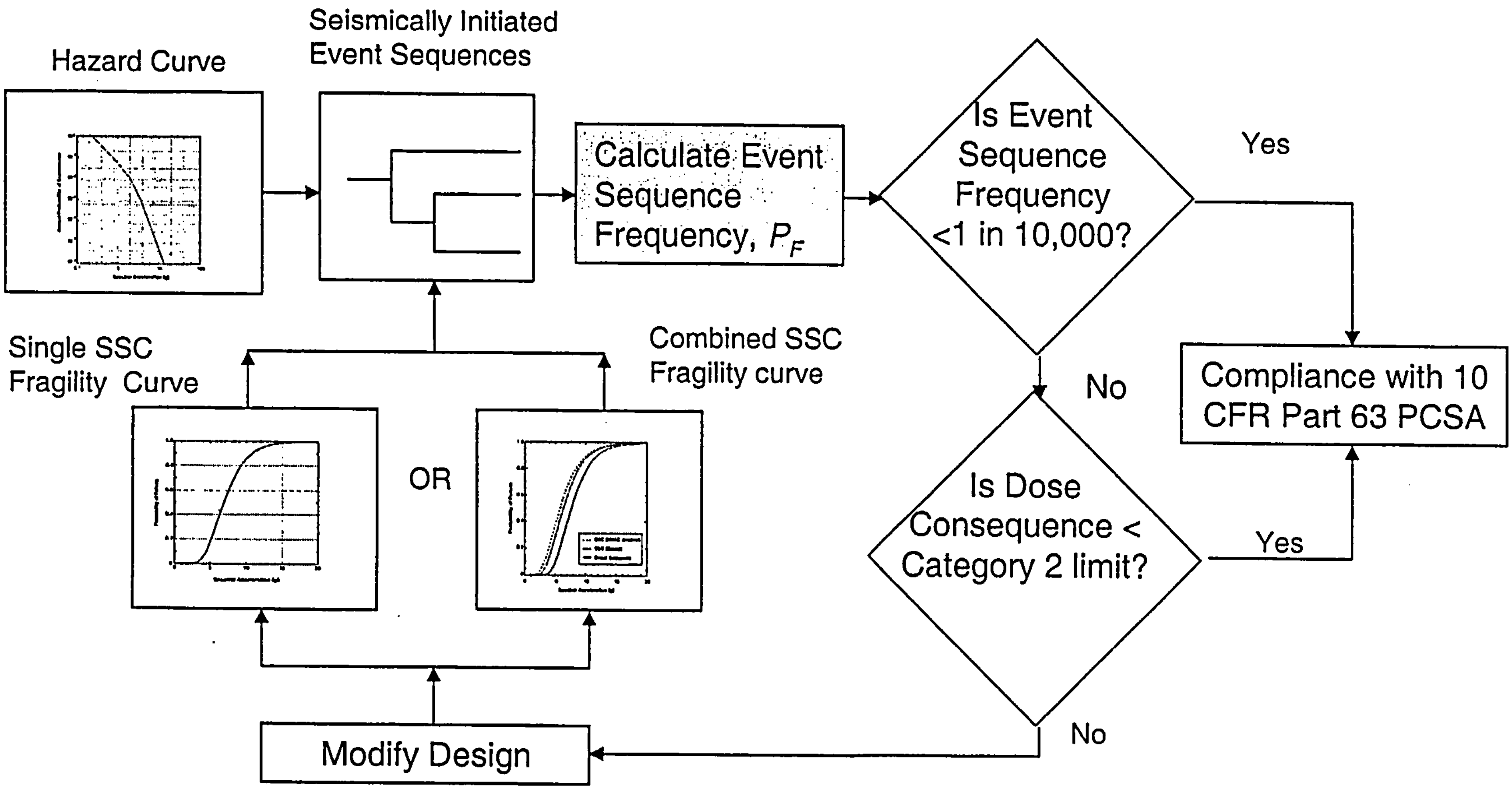
Biswajit Dasgupta

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

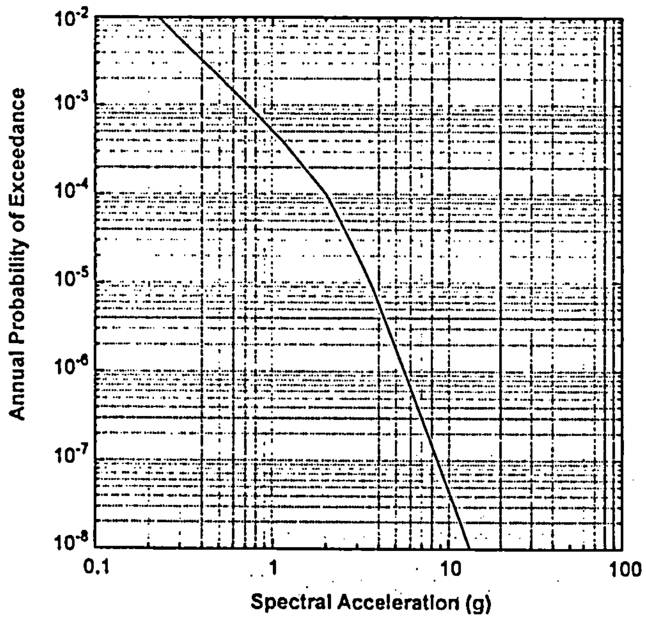
$$P_F = -\int_0^\infty P_F(a)\left(\frac{dH(a)}{da}\right) da \quad \text{or} \quad P_F = \int_0^\infty H(a)\left(\frac{dP_F(a)}{da}\right) da$$

Where

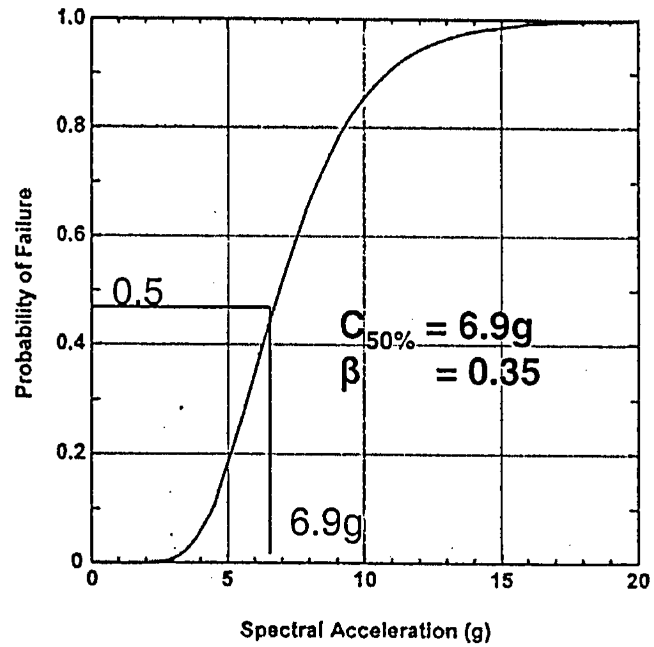
- $H(a)$ is the annual probability of exceedance of ground motion level, a
- $P_F(a)$ is the conditional probability of failure given a value of the ground motion level, a

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

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

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.)

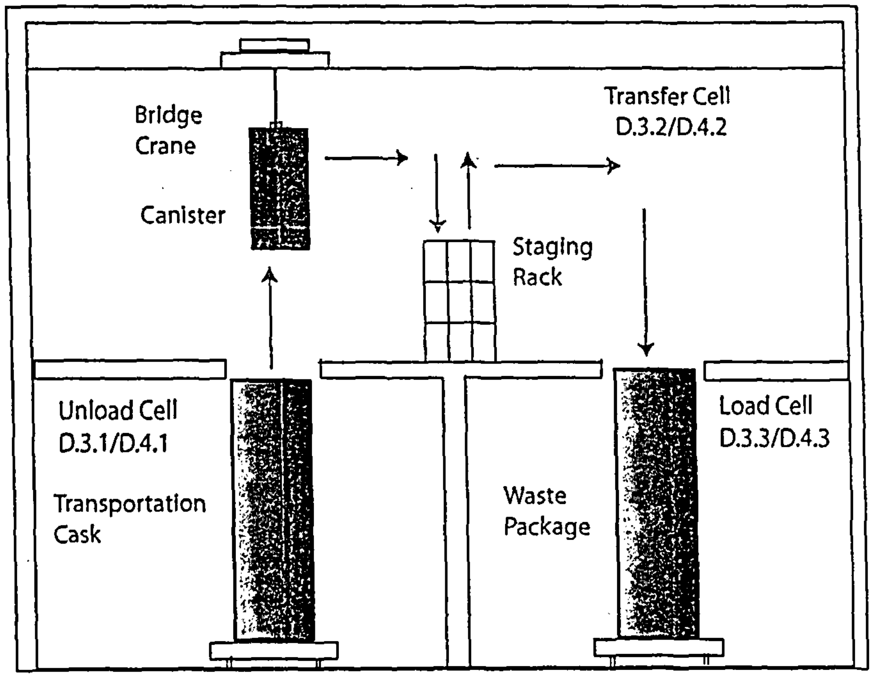
- Annual Probability of Failure of SSC ITS
  - Numerical Integration: 1.5×10^{-6}
  - Closed form solution: 1.8×10^{-6}

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



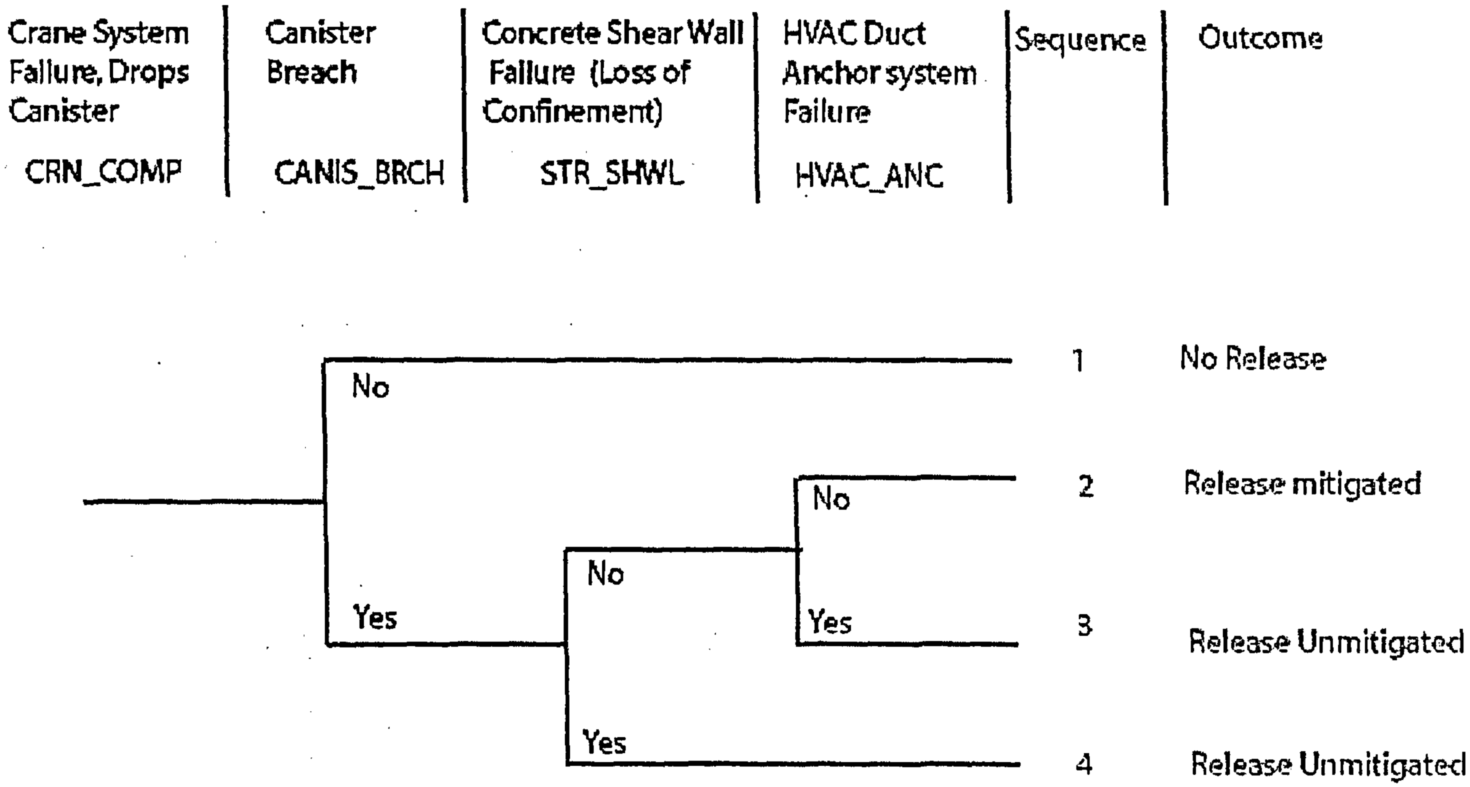
Example for Illustration Only

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.)

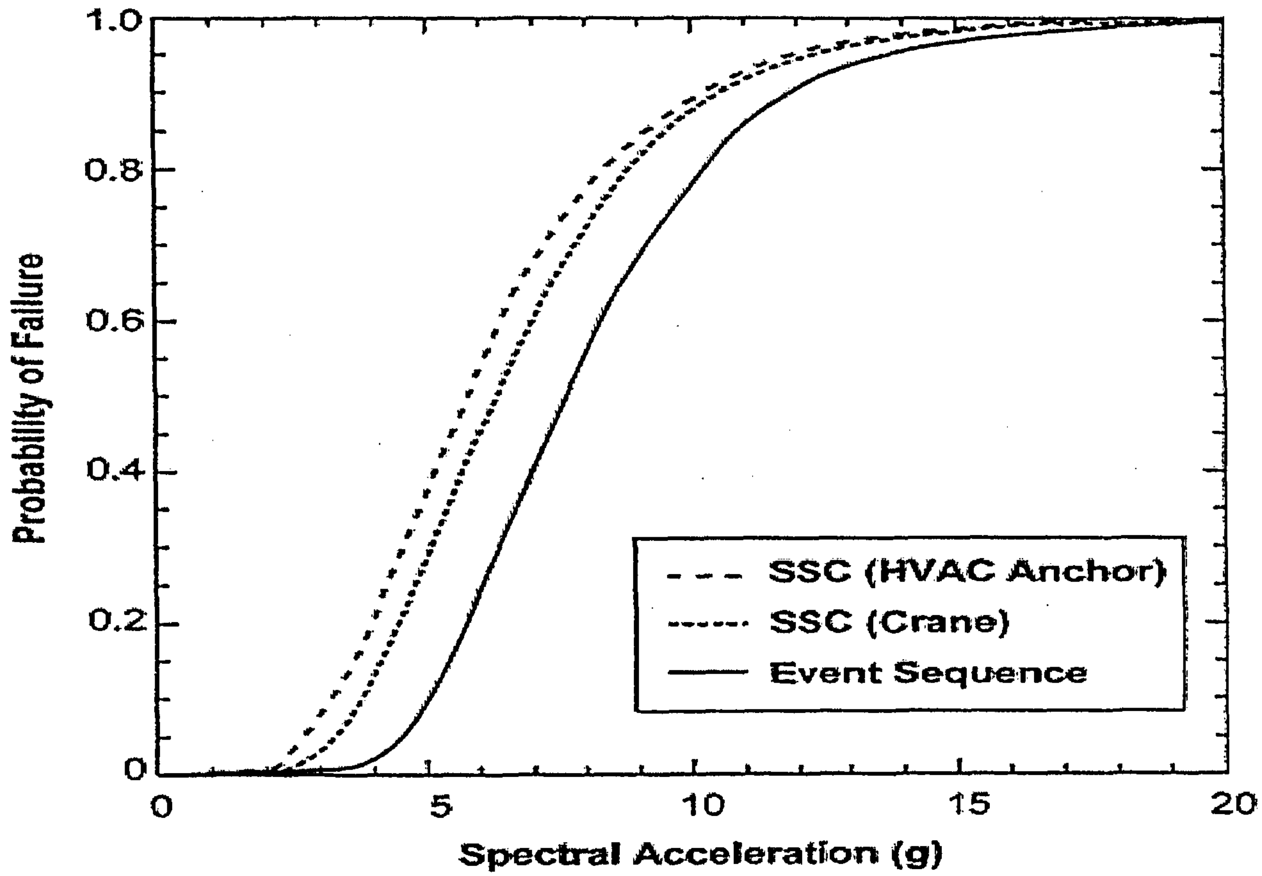
- **Event Sequence 3**
  - Failure of the crane system + HVAC duct anchor system → potential consequence
- Event Sequence 4
  - Failure of the crane system + concrete shear wall → potential consequence

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

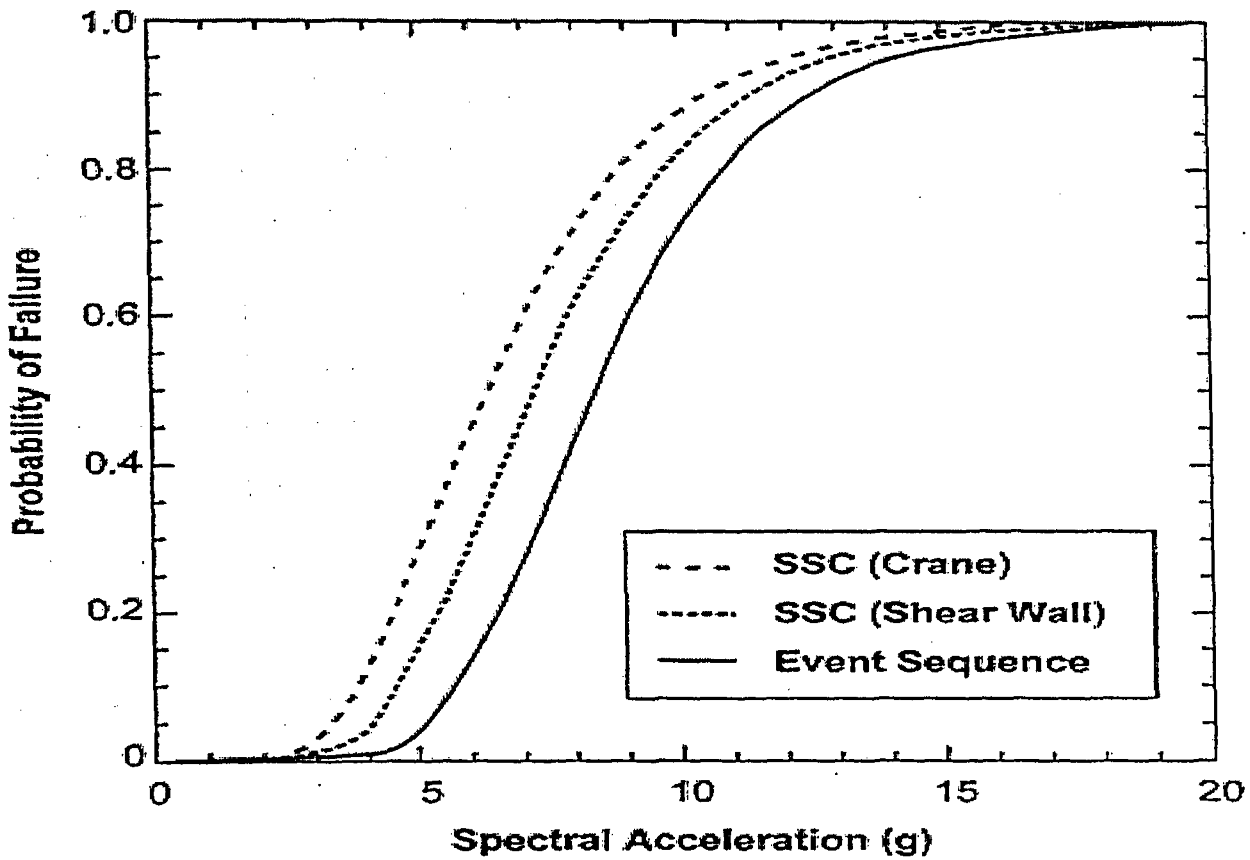
Example for Illustration Only

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	$8.4x10^{-7}$	Yes
4	Crane & Shear Wall	$3.8x10^{-7}$	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

- 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

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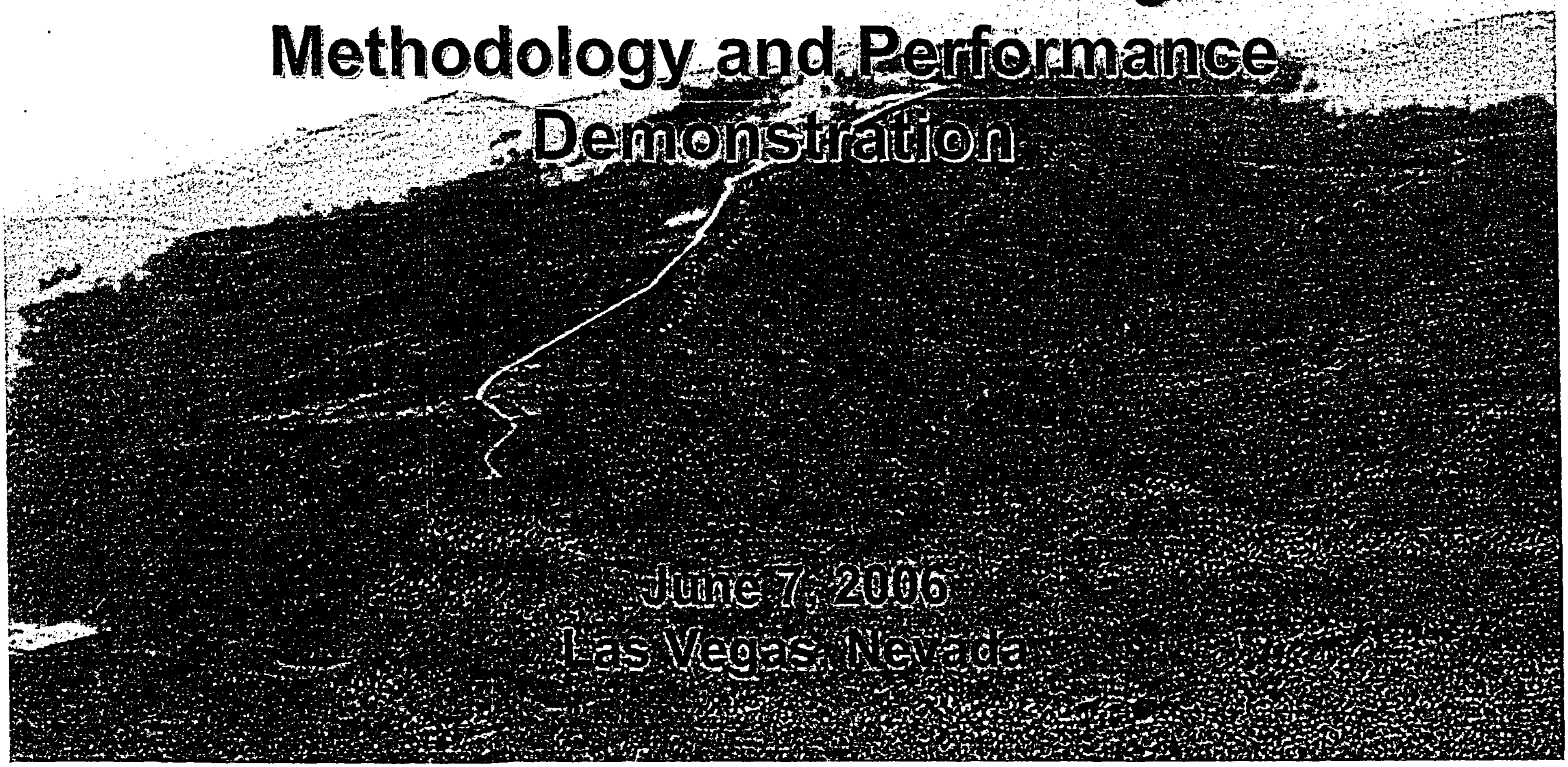
DOE/NRC Technical Exchange on Preclosure Seismic Design Methodology and Performance Demonstration



June 7, 2006
Las Vegas, Nevada

U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Seismic Probability Analyses Overview

Presented to:
NRC/DOE Technical Exchange/Management Meeting on Preclosure Seismic Design Methodology and Performance Demonstration

Presented by:
Mark Wisenburg
Preclosure Safety Analyses, Manager
Bechtel SAIC Company, LLC

Jon Ake
Department of Energy/U.S. Bureau of Reclamation

June 7, 2006
Las Vegas, Nevada

Introduction

- Overview
  - Discussion of NRC letter of January 24, 2006
  - DOE path forward
  - Seismic probability analyses
- Seismic Hazard Analyses
- Fragility Analyses
- Systems Analyses
- Summary

NRC January 24, 2006 Letter

- States the following:
  - Seismic design bases, and design codes and standards, appear consistent with regulatory requirements of §63.112(f)(2)
  - Seismic Margins Analysis (SMA) approach is useful but is not a substitute for demonstrating compliance with the performance objectives in §63.111(b)(2)

NRC January 24 Letter
(Continued)

- **Additional supporting analyses required to demonstrate compliance**
  - Develop probability of occurrence of event sequences through convolution of hazard curves and fragility curves
  - Reference to mixed oxide fuel fabrication facility at the Savannah River Site analyses and American Society of Civil Engineers Standard 43-05 approaches
  - The preclosure safety analysis requirements are met if the calculated probability of unacceptable seismic performance values of individual SSC ITS is less than 1 in 10,000 over the preclosure period, as defined in §63.111(b)(2)

ITS =Important to Safety
SSCs = Structures, Systems, and Components

NRC January 24 Letter

(Continued)

- If probability of occurrence of unacceptable seismic performance of individual SSCs ITS is greater than or equal to 1 in 10,000 over the preclosure period, DOE may demonstrate compliance with § 63.111(b)(2) by:
  i. Showing that dose consequence is within 5 rem;
  ii. Showing that probability of complete event sequence is less than 1 in 10,000 over the preclosure period; or
  iii. Modifying the design

DOE Path Forward

- DOE understands the letter is limited to seismically-initiated events
- DOE believes that elements of the SMA approach in addition to probabilistic seismic analysis will demonstrate compliance with regulations
- DOE will perform additional supporting evaluations and seismic probability analyses to demonstrate compliance for risk-significant SSCs
- Seismic approach will be documented in revised seismic methodology report

DOE Path Forward

(Continued)

- **Continue to use two-levels of seismic design bases ground motions (DBGM-1 and DBGM-2)**
- **Continue to use Conservative Deterministic Failure Margin (CDFM) method to define seismic HCLPF capacities for structures**

DBGM-1 = Design Basis Ground Motion #1 = 10^{-3} MAPE
DBGM-2 = Design Basis Ground Motion #2 = 5×10^{-4} MAPE
HCLPF = High-Confidence-of-a-Low-Probability-of-Failure
MAPE = Mean annual probability of exceedance

DOE Path Forward

(Continued)

- Modify current seismic approach to incorporate elements of probabilistic risk technology to demonstrate compliance for risk-significant SSCs
  – probabilistic seismic analyses
- Screening analysis will be used to focus analyses on risk-significant SSCs

Seismic Probability Analyses

- **Apply to risk-significant structures and equipment, having DBGM-2 design basis**
- **Demonstrate probability of unacceptable seismic performance is:**
  - **Less likely than one-chance in 10,000 during the preclosure period for individual ITS SSCs or for complete event sequences**

Otherwise

  - **Dose consequence is less than 5 rem; or**
  - **Modify the design**

Seismic Probability Analyses Clarification

- **Probabilistic seismic analyses are not a full probabilistic risk assessment (PRA)**
  - Analyses based on individual event sequences and individual ITS SSCs
  - Failure of individual ITS SSCs or individual event sequences will be shown to have probabilities of less than 1 in 10,000 over the preclosure period and therefore below the regulatory threshold or consequences of the event sequences will be shown to be less than 5 rem
  - Consistent with the NRC Letter of January 24, 2006, DOE will not sum the failure probabilities of individual ITS SSCs or probabilities of individual event sequences

ITS = Important to Safety
SSCs = Structures, Systems, and Components

Integration

- Screening and quantification will require coordination of various technical inputs:
  - Seismic hazard analyses
  - Fragility (vulnerability) evaluations
  - System analyses

Additional Slides

Performance Objectives Table

Performance Objectives Applied to Seismic Preclosure Safety	Dose Receptor	Consequences of Loss of SSC Safety Function Single Sequence Dose Limit (TEDE)	DBGM Assigned to ITS SSCs
Category 1 Event Sequences 10 CFR 63.111(b)(1) 10 CFR 20.1201-1204 10 CFR 20.1207-1208 10 CFR 20.1301-1302 10 CFR 20.1101	Radiation Worker	>5 rem (0.05 Sv)	DBGM-1
	Controlled Area Worker Beyond the Geologic Repository Operations Area Or Member of the Public Onsite and Beyond the Geologic Repository Operations Area Or Nevada Test Site and Nellis Workers in an Unrestricted Area	>100 mrem (1.0 mSv) or >2 mrem (0.02 mSv) in one hour Or >10 mrem (0.1 mSv) from air emissions	DBGM-1
	Member of the Public Beyond the Site Boundary in the General Environment	>15 mrem (0.15 mSv)	DBGM-1
Category 2 Event Sequences 10 CFR 63.111(b)(2)	Individual at or Beyond the Site Boundary	=>5 rem (0.05 Sv)	DBGM-2
Criticality Condition 10 CFR 63.112(e)(6)	N/A	N/A	DBGM-2

NOTE: Values are for TEDE (a measure of body dose). Higher dose equivalents for the lens of the eye, skin, and extremities are not included in the table, but are subject to separate limits per 10 CFR 63.111(b)(2), 10 CFR 20.1101, 10 CFR 20.1201 to 1204, 10 CFR 20.1207 to 1208, and 10 CFR 20.1301 to 1302.

Definition – Basic Terms

Seismic Risk:

- The probability that the undesirable consequences, harm or unacceptable performance due to a seismic event (earthquake) will be realized

Definition – Basic Terms

(Continued)

Probabilistic Seismic Analysis:

- The development of a quantitative estimate of unacceptable seismic performance based on engineering evaluation and mathematical techniques for combining estimates of incident likelihood and consequences for risk-significant SSCs

Risk-Significant SSCs:

- *Risk-significant* SSCs are SSCs that are credited to mitigate/prevent seismically-initiated event sequences that potentially could result in a dose from unmitigated release that exceeds the performance objective of 10 CFR 63.111(b)(2)

Definition – Event Sequence

Event sequence (10 CFR 63.2):

"***Event sequence*** means a series of actions and/or occurrences within the natural and engineered components of a geologic repository operations area that could potentially lead to exposure of individuals to radiation. An event sequence includes one or more initiating events and associated combinations of repository system component failures, including those produced by the action or inaction of operating personnel. Those event sequences that are expected to occur one or more times before permanent closure of the geologic repository operations area are referred to as Category 1 event sequences. Other event sequences that have at least one chance in 10,000 of occurring before permanent closure are referred to as Category 2 event sequences"

Definition – Convolution

Convolution:

In functional analysis, convolution is a mathematical operator that (in effect) represents the amount of overlap of one function, f, as it is shifted over another function, g. It therefore "blends" one function with another. If X and Y are two independent random variables with probability distributions f and g, respectively, then the probability distribution of the sum X + Y is given by the convolution f * g.

For seismic analyses, the convolution can be expressed as:

$$\bar{f} = \int_0^\infty \left| \frac{d\overline{H}}{da} \right| P_{f:a} da$$

$\frac{d\overline{H}}{da}$ = *derivative of hazard curve*

$\overline{P}_{f:a}$ = *fragility given a*

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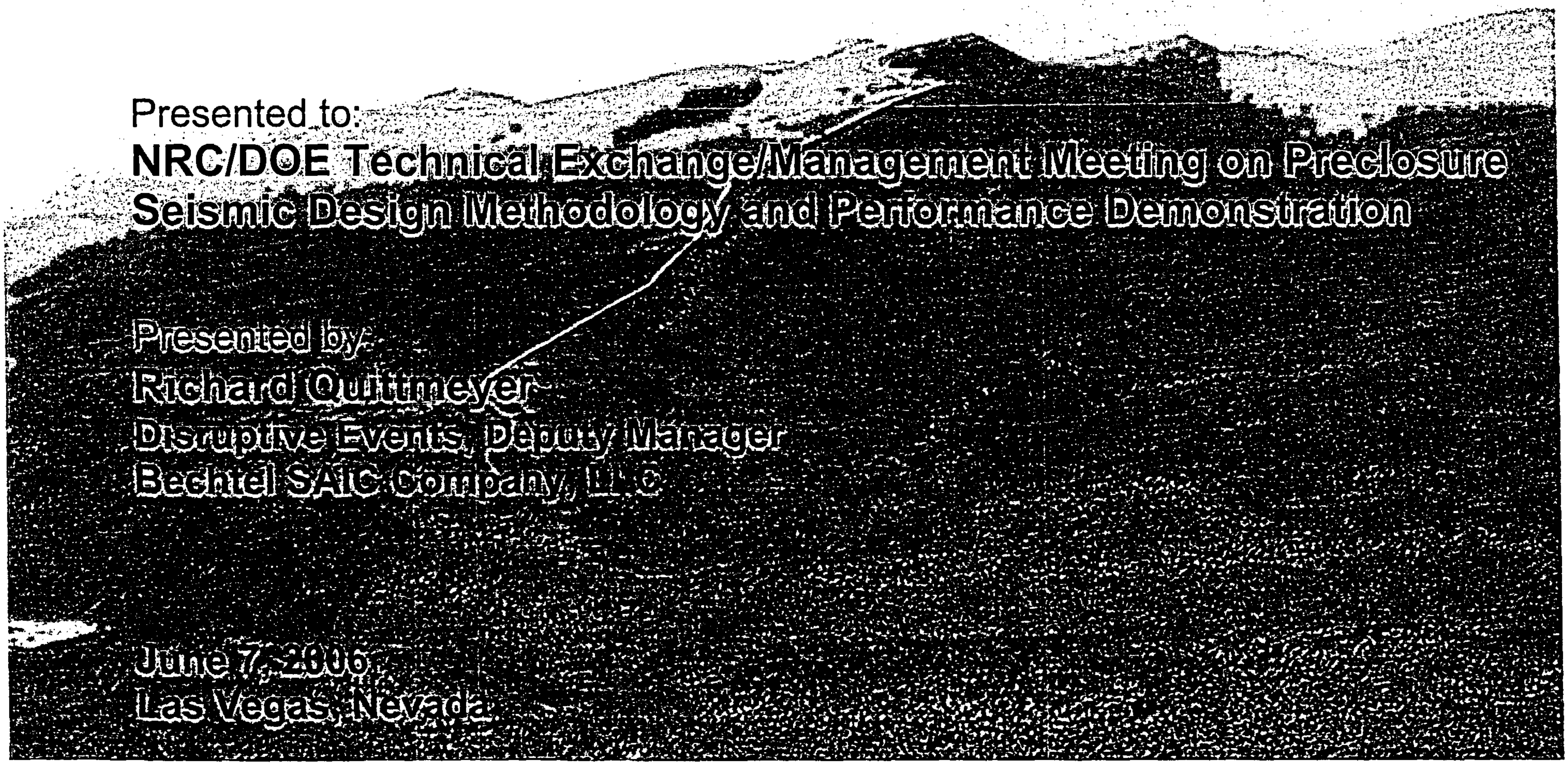
Preclosure Seismic Hazard



Presented to:
NRC/DOE Technical Exchange/Management Meeting on Preclosure Seismic Design Methodology and Performance Demonstration

Presented by:
Richard Quittmeyer
Disruptive Events, Deputy Manager
Bechtel SAIC Company, LLC

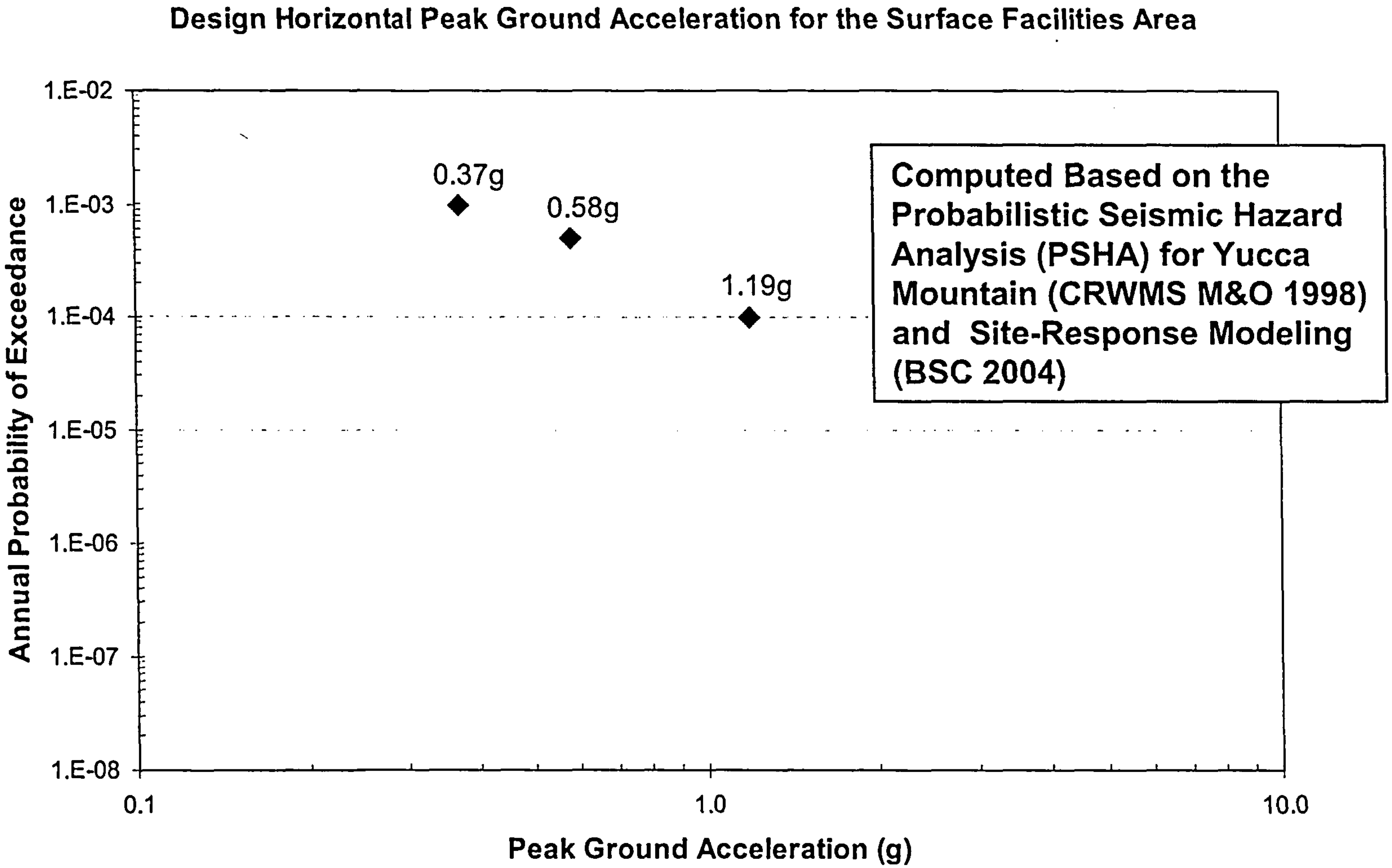
June 7, 2006
Las Vegas, Nevada

Site-specific Seismic Hazard

- **Three values of ground motion currently used for preclosure design analyses:**
  - Design Basis Ground Motion #1 (DBGM-1): MAPE 10^{-3} or 1,000 year return period
  - Design Basis Ground Motion #2 (DBGM-2): MAPE 5×10^{-4} or 2,000 year return period
  - Beyond Design Basis Ground Motion (BDBGM): MAPE 10^{-4} or 10,000 year return period
    - Equivalent to a Review Level Earthquake
- **Design ground motions, developed per NUREG-6728 Approach 2b by enveloping over epistemic uncertainties in site-response inputs and range of alluvium thickness, contain some unquantified degree of conservatism**

MAPE = Mean Annual Probability of Exceedance

Existing Hazard Points

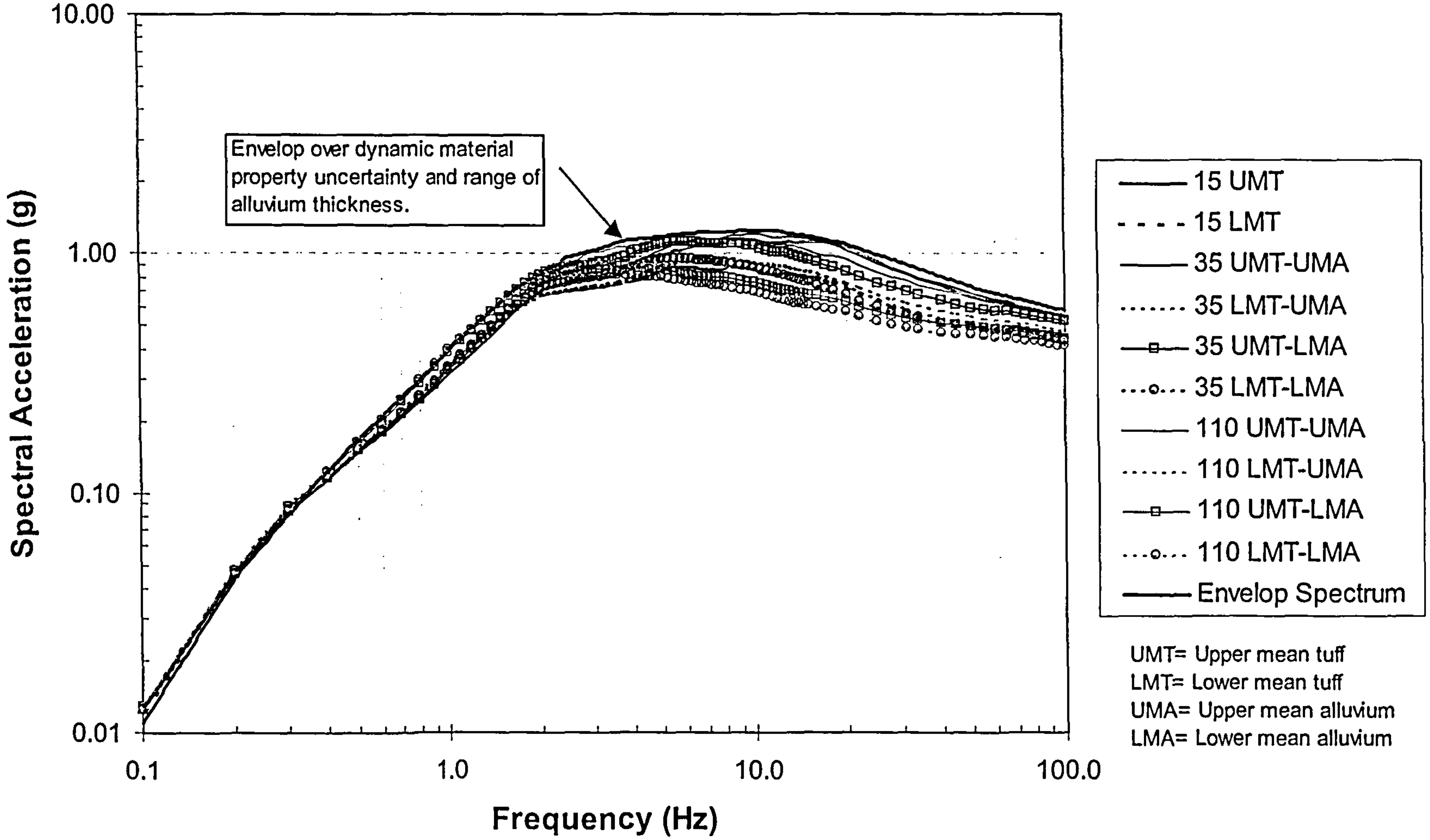


CRWMS M&O 1998. Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada. Milestone SP32IM3, September 23, 1998. Three volumes. Las Vegas, Nevada: CRWMS M&O.

BSC (Bechtel SAIC Company) 2004. Development of Earthquake Ground Motion Input for Preclosure Seismic Design and Postclosure Performance Assessment of a Geologic Repository at Yucca Mountain, NV. MDL-MGR-GS-000003 REV 01. Las Vegas, Nevada: Bechtel SAIC Company.

Spectral Accelerations

5 x 10^{-4} MAPE



UMT= Upper mean tuff
LMT= Lower mean tuff
UMA= Upper mean alluvium
LMA= Lower mean alluvium

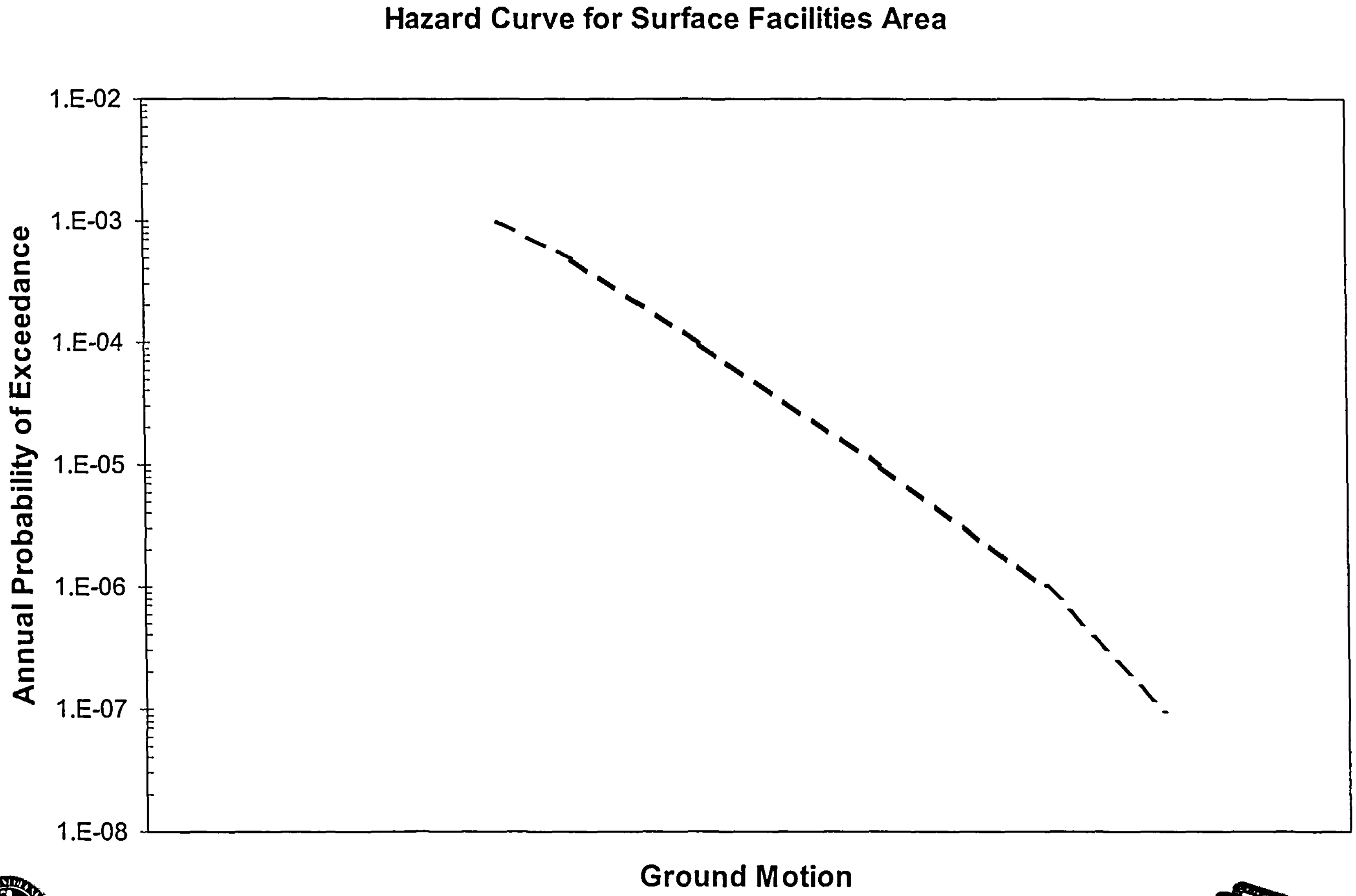
Hz = Hertz (cycles per second); g = Acceleration due to gravity

Site-specific Seismic Hazard

(Continued)

- **DOE will develop a mean hazard curve for surface facilities area for annual probability of exceedance down to approximately 10^{-7} for quantification of probabilistic seismic analyses**
  - Incorporate results of ongoing geotechnical investigations
  - Develop mean ground motion (i.e., without conservative bias)
  - Incorporate knowledge of bounds to ground motion experienced at Yucca Mountain (e.g., geologic observations; seismic observations)

Full Hazard Curve Example



U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Seismic Fragility of Structures, Systems and Components

Presented to:
NRC/DOE Technical Exchange/Management Meeting on Preclosure Seismic Design Methodology and Performance Demonstration

Presented by:
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June 7, 2006
Las Vegas, Nevada

Fragility Evaluation

- Determines conditional probability of unacceptable seismic performance (failure) vs. appropriate ground motion parameter (e.g., spectral acceleration)
- Unacceptable performance (failure) is:
  - The inability of an SSC to perform or provide its intended safety function
  - Defined in terms of Limit States per ASCE 43-05

SSCs = Structures, Systems and Components

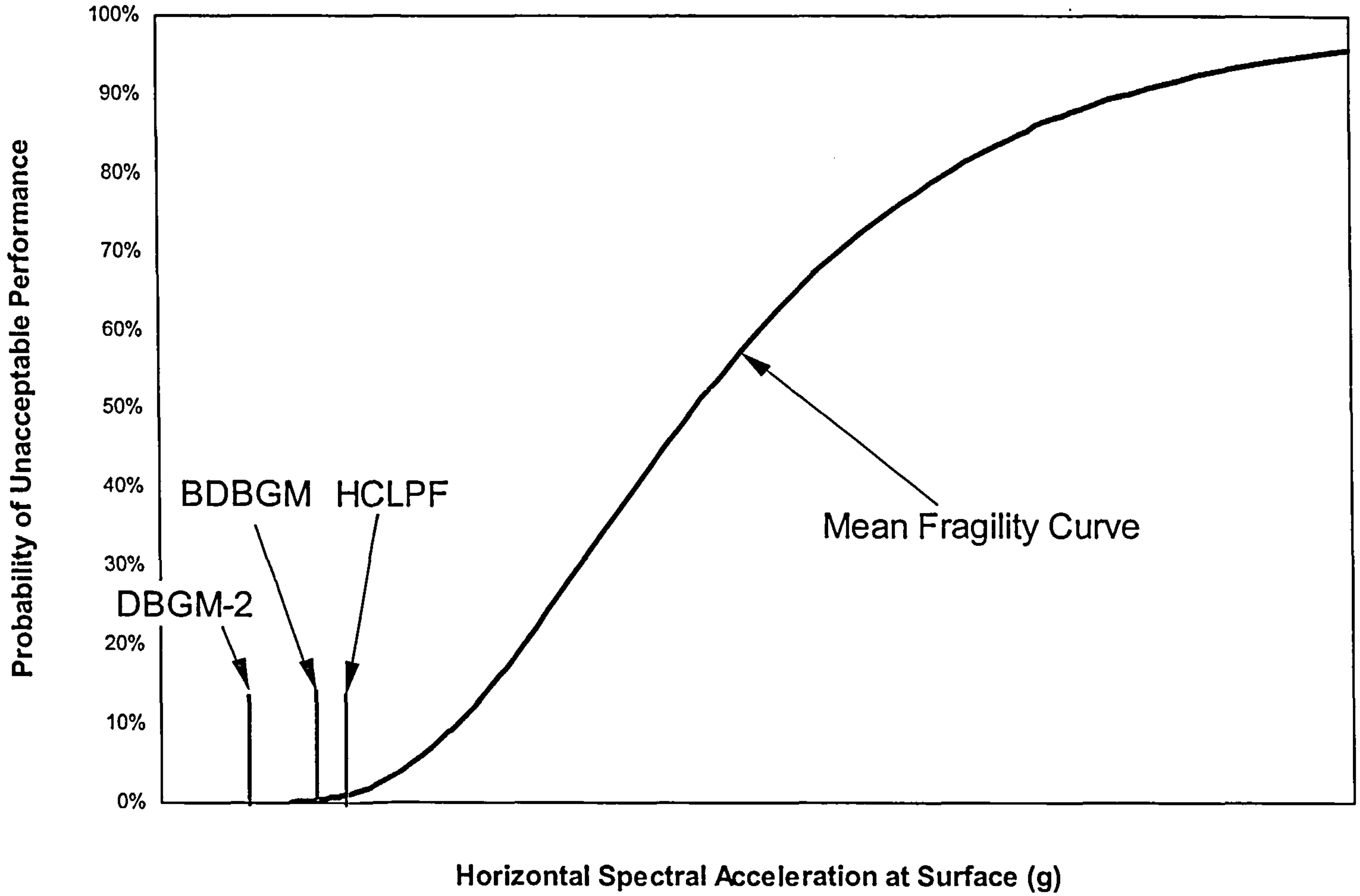
ASCE 43-05 = American Society of Civil Engineers, Standard 43-05

Hybrid Method

Mean Fragility Curve defined by:

- High-Confidence-of-Low-Probability-of-Failure (HCLPF) capacity
- β - fragility logarithmic standard deviation

Example – Mean Fragility Curve



DBGM-2 = Design Basis Ground Motion 2; g = acceleration due to gravity
BDBGM = Beyond Design Basis Ground Motion
HCLPF = High-Confidence-of-Low-Probability-of-Failure

Definition of HCLPF

High-Confidence-of-Low-Probability-of-Failure (HCLPF)

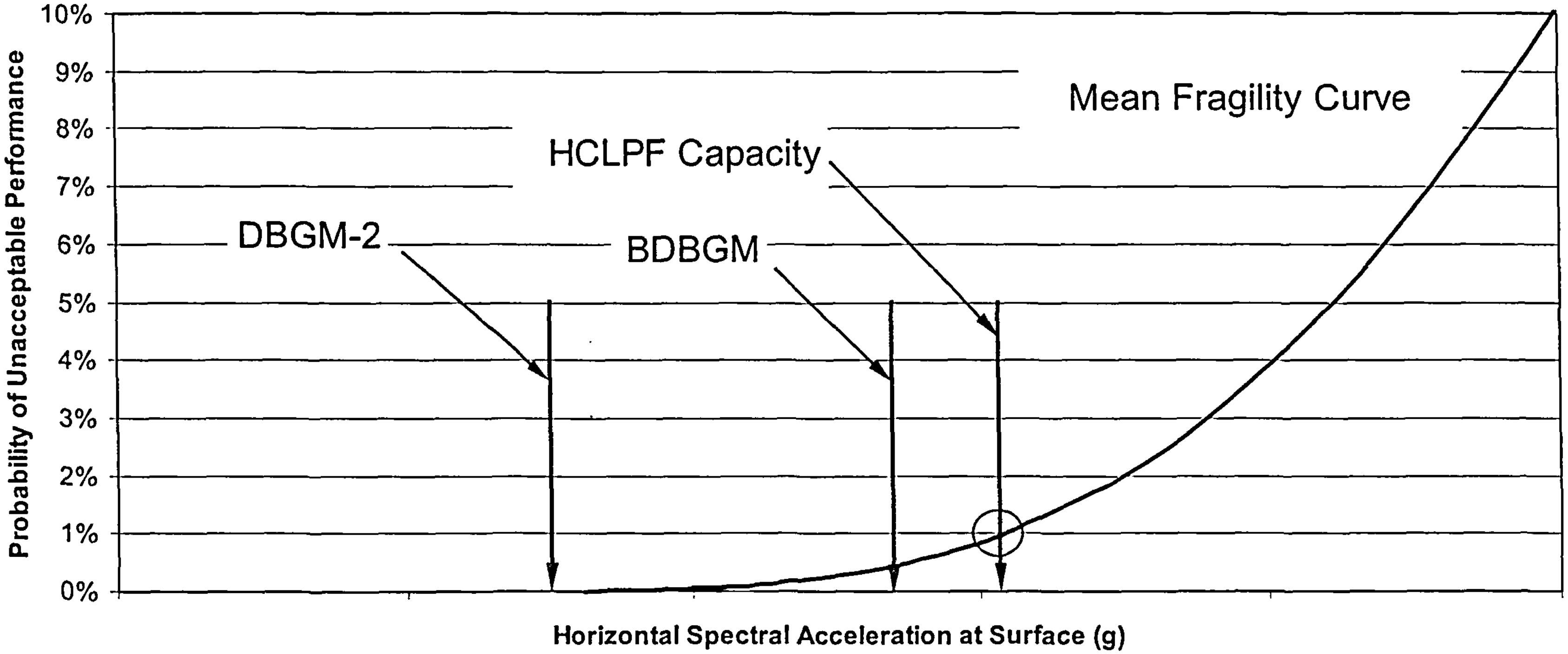
- Seismic capacity of SSC described in terms of a specified ground motion parameter (e.g., spectral acceleration) corresponding to 1% probability of unacceptable performance on a mean fragility curve
- Deterministically computed using Conservative-Deterministic-Failure-Margin (CDFM) methodology

CDFM References

Conservative-Deterministic-Failure-Margin (CDFM) Methodology described in the following:

- EPRI (Electric Power Research Institute) 1991. A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1). EPRI NP-6041-SL, Rev. 1. Palo Alto, California: Electric Power Research Institute.
- Budnitz, R. J., et al., An Approach to the Quantification of Seismic Margins in Nuclear Power Plants, NUREG/CR-4334, U. S. Nuclear Regulatory Commission, August 1985
- NRC (U.S. Nuclear Regulatory Commission) 2004. Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design, Docket No. 52-006, NUREG-1793, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation.
- ASCE 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

HCLPF Factor



Uncertainty Parameter, β

β - Fragility Logarithmic Standard Deviation

- Estimated based on published information, e.g.,
  - ASCE 43-05 Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities
  - *Methodology for Developing Seismic Fragilities*, EPRI TR-103959, Electric Power Research Institute, June 1994
- β ranges from 0.3 to 0.5 for structures and equipment mounted at ground level
- β ranges from 0.4 to 0.6 for equipment mounted high in a structure

Results

Fragility Curves for Seismic Probabilistic Analysis

- Structures
  - Calculate specific fragility curves
- Components
  - Analyze for components such as cranes
  - Use "experience-based" (generic) information
  - Future qualification testing if required

Structural Margin

For Risk Significant Structures, Margin Demonstrated by:

- DBGM-2 Demand significantly less than Code Capacity
  - DBGM-2 PGA: 0.58g horizontal and 0.52g vertical
- BDBGM Demand < HCLPF Seismic Capacity
  - BDBGM PGA: 1.19g horizontal and 1.49g vertical
- Structural Capacity that ensures that the probability of unacceptable seismic performance of the structure (or complete event sequence) is less than 1 in 10,000 over the preclosure period

PGA = Peak Ground Acceleration

MAPE = Mean Annual Probability of Exceedance

Additional References

- Chen, J.T.; Chokshi, N.C.; Kenneally, R.M.; Kelly, G.B.; Beckner, W.D.; McCracken, C.; Murphy, A.J.; Reiter, L.; and Jeng, D. 1991. *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities.* NUREG-1407. Washington, D.C.: U.S. Nuclear Regulatory Commission.
- Kennedy, R.P. 2001. "Overview of Methods for Seismic PRA and Margin Analysis Including Recent Innovations." *Proceedings of the OECD/NEA Workshop on Seismic Risk, Committee on the Safety of Nuclear Installations PWG3 and PWG5, Hosted by the Japan Atomic Energy Research Institute under the Sponsorship of the Science Technology Agency, 10-12 August,1999, Tokyo, Japan. NEA/CSNI/R(99)28, 33-63.* Paris, France: Organization for Economic Cooperation and Development, Nuclear Energy Agency.

U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Preclosure System Analyses and Quantification

Presented to:
NRC/DOE Technical Exchange/Management Meeting on Preclosure Seismic Design Methodology and Performance Demonstration

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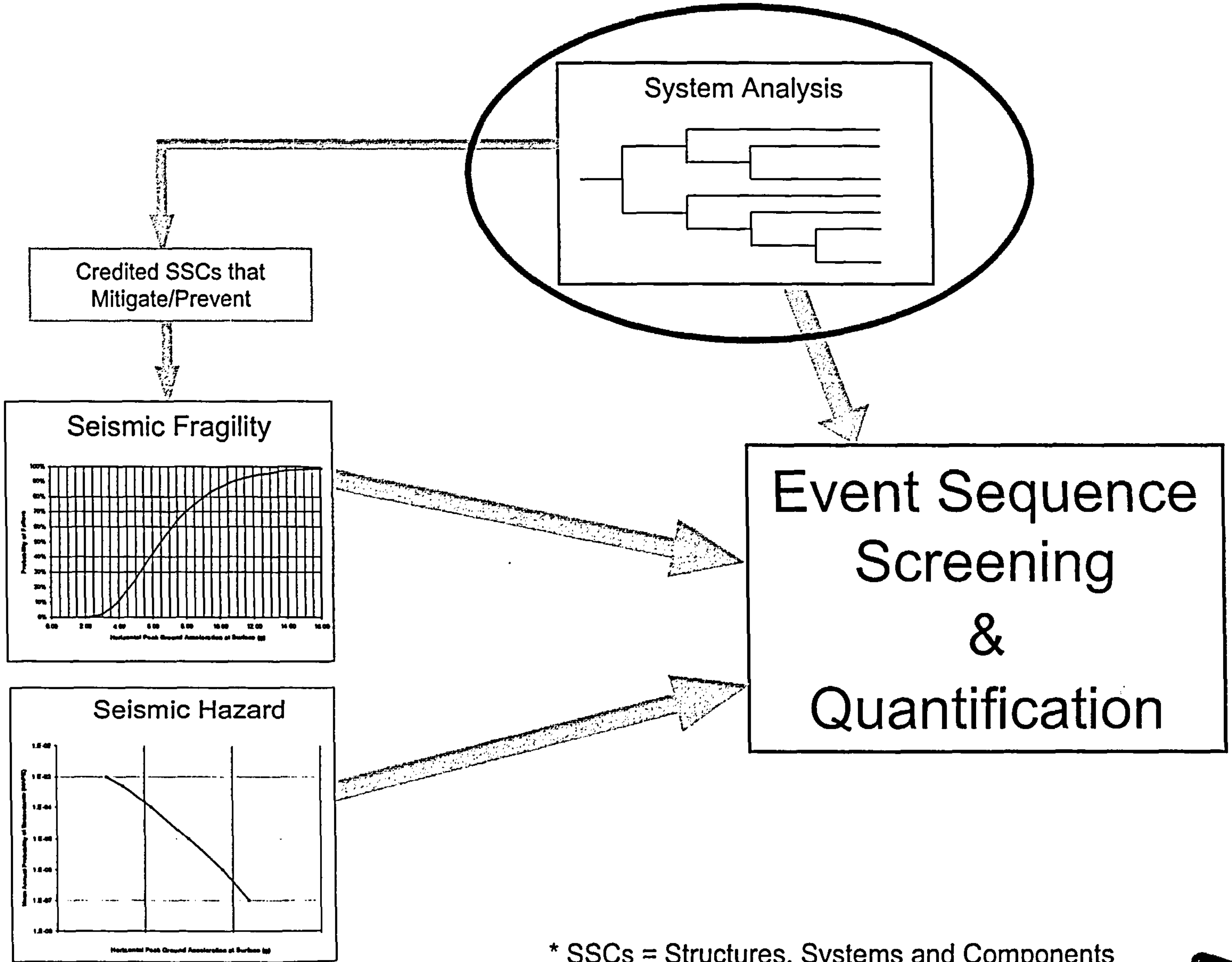
Las Vegas, Nevada

System Analysis

- Seismic event sequence identification
- Consequence analysis and screening
- Seismic design bases assigned to SSCs
- Event sequence quantification
- Demonstration of compliance

SSCs = Structures, Systems and Components

Schematic of Seismic Probability Analyses



* SSCs = Structures, Systems and Components

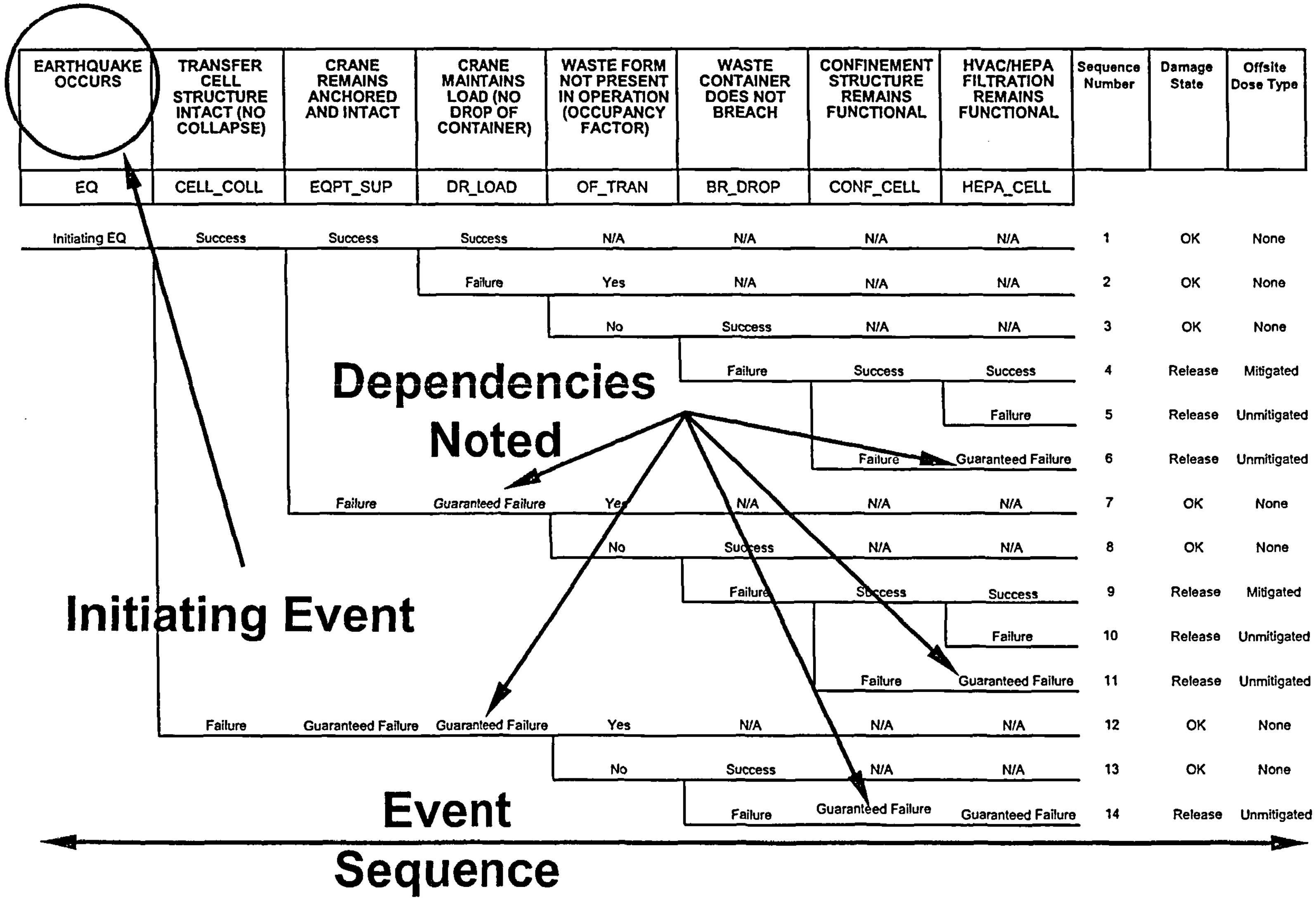
Seismic Event Sequence Identification

- Identify scenarios for potential direct exposure or airborne releases
  - Conduct systematic evaluation
  - Identify seismically-induced failure of SSCs that initiate or affect event sequences
  - Identify amount and type of material at risk
- Typical seismically-initiated scenarios
  - Building damage impacts waste form
  - Heavy object (e.g., crane) falling onto waste form
  - Crane drops waste form
  - Trolleys or transporters tip over with impact to waste form
  - Shield doors or shield windows fail
  - Ducts lose confinement

Seismic Event Sequence Identification
(Continued)

- Identify non-seismic mechanisms or factors that affect potential radiation exposure or release
- Construct seismic event trees
- Apply screening doses to assign Design Basis Ground Motions (DBGM-1 or DBGM-2)
- Simplify event tree

Example of Seismic Event Tree



Simplifying Event Tree

- Identify individual risk-significant SSCs
- Concentrate on preventing initiation of seismic event sequences
- No credit for active mitigation or confinement
- No credit for non-seismic factors that reduce likelihood of release scenario

Simplifying Seismic Event Tree

EARTHQUAKE OCCURS	TRANSFER CELL STRUCTURE INTACT (NO COLLAPSE)	CRANE REMAINS ANCHORED AND INTACT	CRANE MAINTAINS LOAD (NO DROP OF CONTAINER)	WASTE FORM NOT PRESENT IN OPERATION (OCCUPANCY FACTOR)	WASTE CONTAINER DOES NOT BREACH	CONFINEMENT STRUCTURE REMAINS FUNCTIONAL	HVAC/HEPA FILTRATION REMAINS FUNCTIONAL	Sequence Number	Damage State	Offsite Dose Type
EQ	CELL_COLL	EQPT_SUP	DR_LOAD	OF_TRAN	BR_DROP	CONF_CELL	HEPA_CELL			
Initiating EQ	Success	Success	Success	N/A	N/A	N/A	N/A	1	OK	None
			Failure	Yes	N/A	N/A	N/A	2	OK	None
				No	Success	N/A	N/A	3	OK	None
					Failure	Success	Success	4	Release	Mitigated
							Failure	5	Release	Unmitigated
						Failure	Guaranteed Failure	6	Release	Unmitigated
		Failure	Guaranteed Failure	Yes	N/A	N/A	N/A	7	OK	None
				No	Success	N/A	N/A	8	OK	None
					Failure	Success	Success	9	Release	Mitigated
							Failure	10	Release	Unmitigated
						Failure	Guaranteed Failure	11	Release	Unmitigated
	Failure	Guaranteed Failure	Guaranteed Failure	Yes	N/A	N/A	N/A	12	OK	None
				No	Success	N/A	N/A	13	OK	None
					Failure	Guaranteed Failure	Guaranteed Failure	14	Release	Unmitigated

Events not credited in simplification process.
Initially, conditional failure probability set equal to 1.0.

Simplified Tree

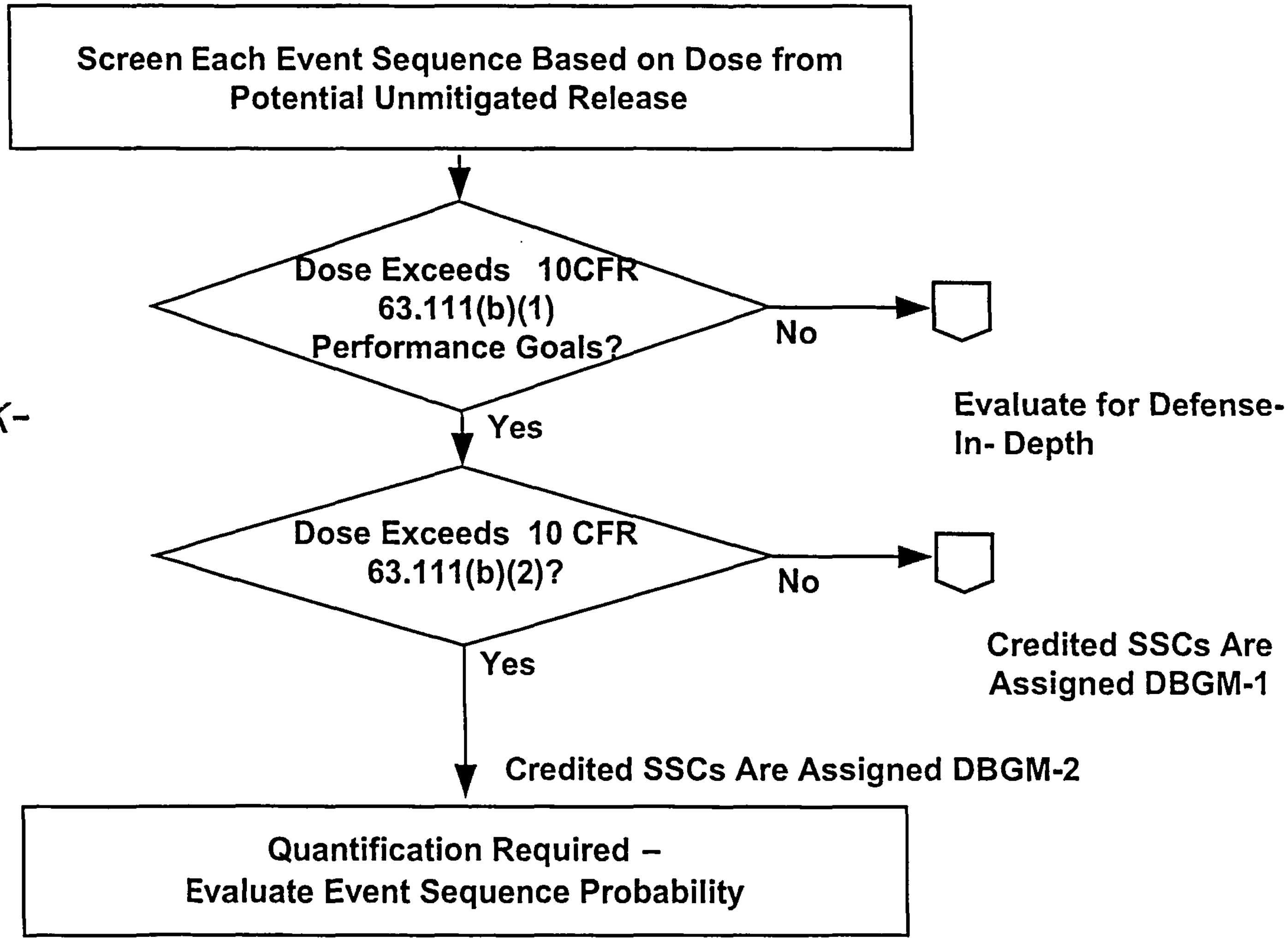
EARTHQUAKE OCCURS	TRANSFER CELL STRUCTURE INTACT (NO COLLAPSE)	CRANE REMAINS ANCHORED AND INTACT	CRANE MAINTAINS LOAD (NO DROP OF CONTAINER)	Sequence Number	Damage State	Offsite Dose Type
EQ	CELL_COLL	EQPT_SUP	DR_LOAD			
Initiating EQ	Success	Success	Success	1	OK	None
			Failure	2	Release	Unmitigated
		Failure	Guaranteed Failure	3	Release	Unmitigated
	Failure	Guaranteed Failure	Guaranteed Failure	4	Release	Unmitigated

Use unmitigated dose associated with material at risk

SSC Safety Functions Credited in Preventing Event Sequence

Screening and Assigning Design Bases

Screen into Groups to Focus on Risk-Significant Event Sequences and SSCs



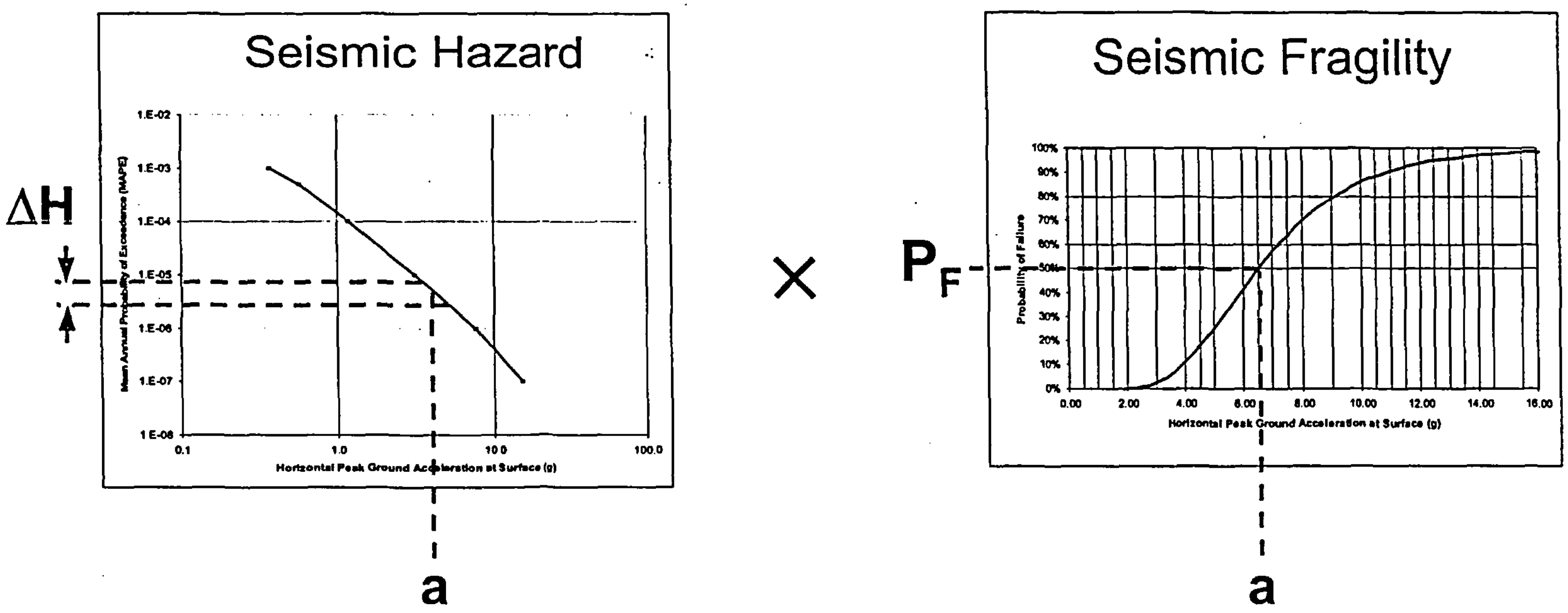
DBGM-1 = Design Basis Ground Motion #1 = 1×10^{-3} MAPE
DBGM-2 = Design Basis Ground Motion #2 = 5×10^{-4} MAPE
MAPE = Mean Annual Probability of Exceedance

Seismic Event Sequence Quantification

- Apply to each event sequence where the dose consequence exceeds 10 CFR 63.111(b)(2)
- Obtain fragility for each SSC credited to prevent or mitigate a sequence; each SSC is
  - Classified as *Important to Safety*
  - Assigned DBGM-2 as seismic design basis
- Quantify the probability of the event sequence using probabilistic analysis including convolution integration of seismic hazard and fragility functions

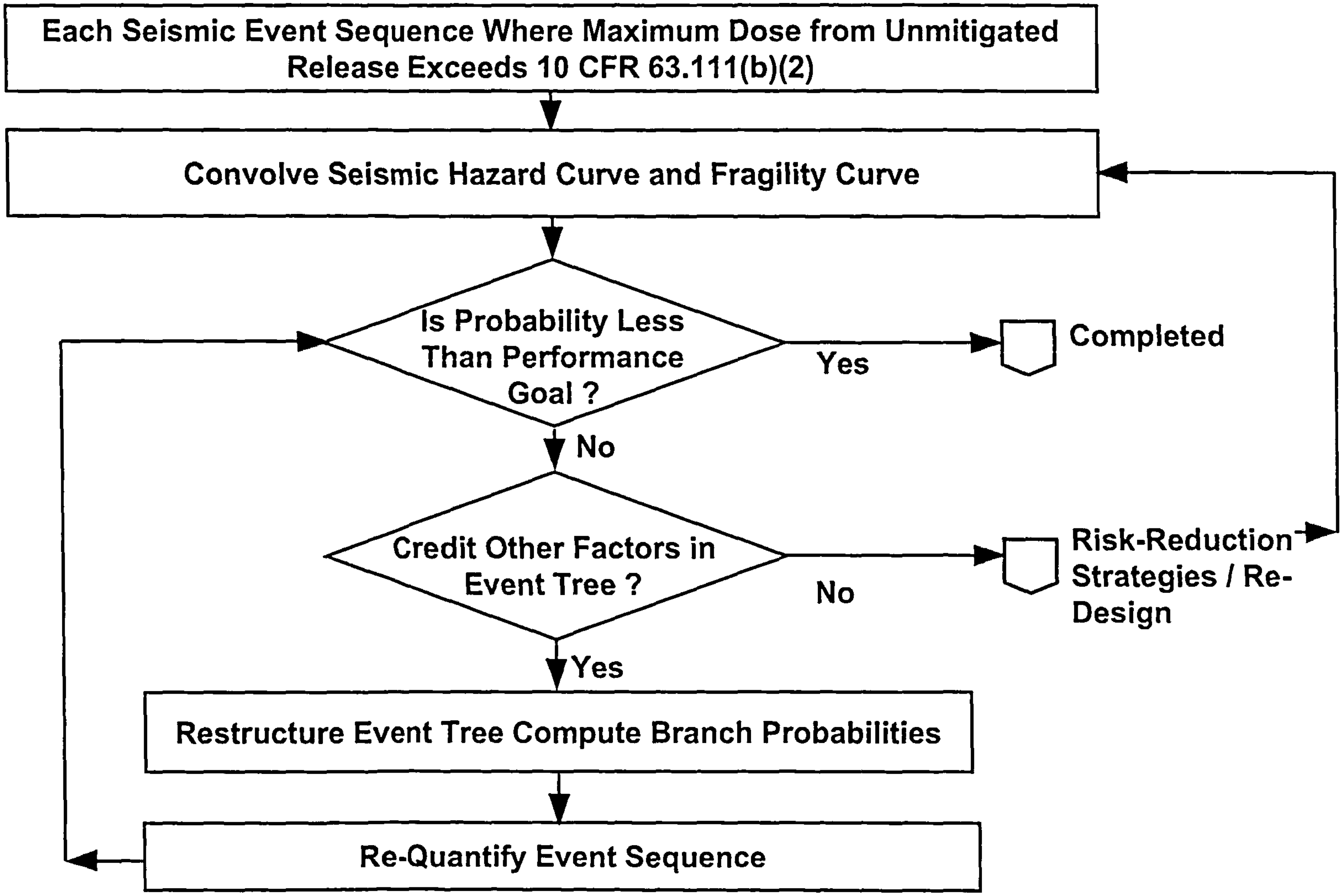
Illustration of Convolution

Example for seismic analyses – using numerical integration:



$$\Sigma\, \Delta H \times P_f$$ = **Probability of Unacceptable Performance**

Quantification Process



Performance Goal = Less than 1 chance in 10,000 before permanent closure.

Results of Preclosure Seismic Analysis

- Identification of credible potential seismically-initiated event sequences and associated consequences
- Assignment of DBGM-1 or DBGM-2 to ITS SSCs credited to prevent or mitigate event sequences, based on potential dose due to unmitigated release
- Quantification of event sequence probability to demonstrate compliance to 10 CFR 63.111(b)(2)

ITS =Important to Safety

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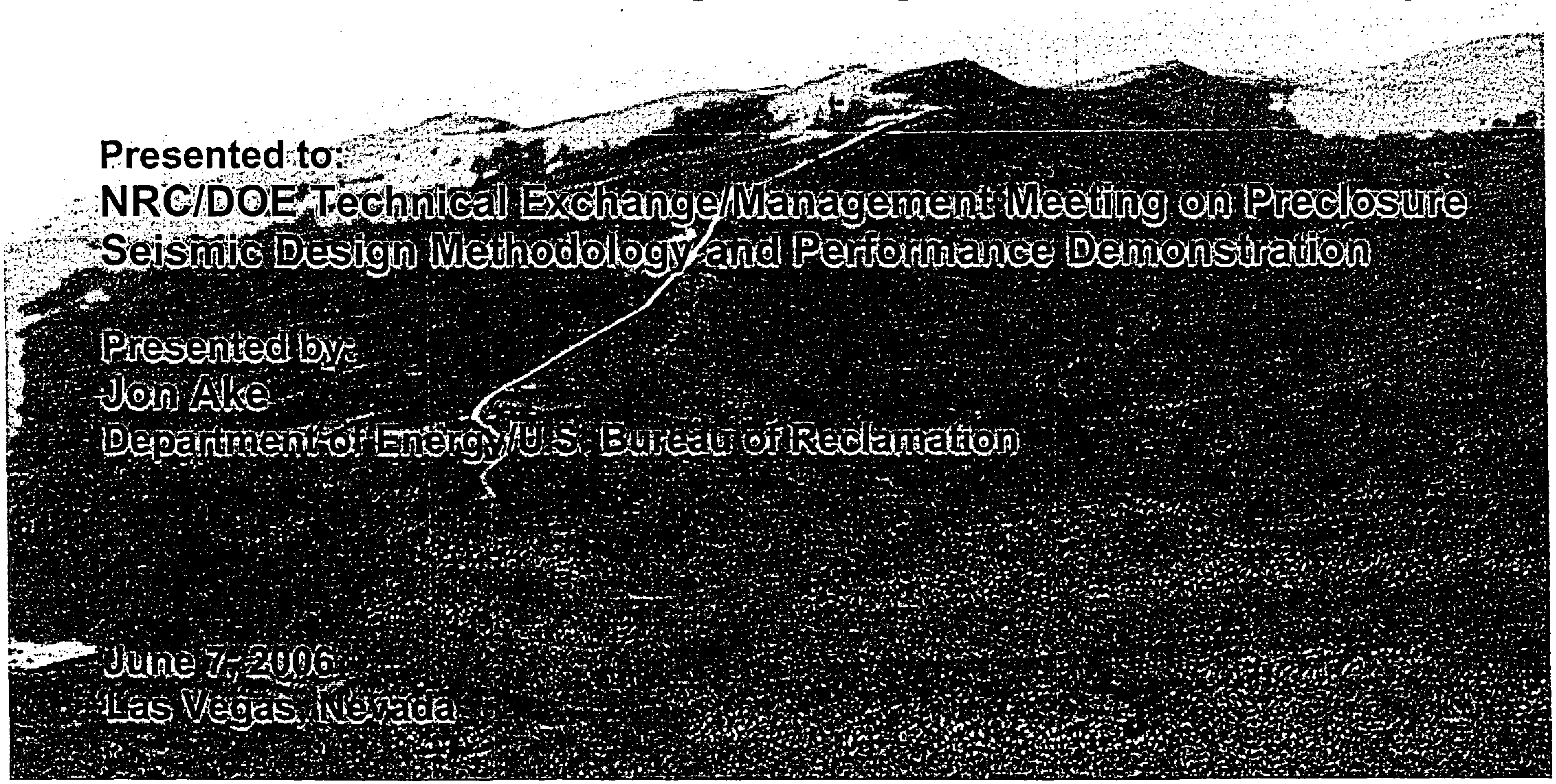
Seismic Probability Analyses – Summary



Presented to:
NRC/DOE Technical Exchange/Management Meeting on Preclosure Seismic Design Methodology and Performance Demonstration

Presented by:
Jon Ake
Department of Energy/U.S. Bureau of Reclamation

June 7, 2006
Las Vegas, Nevada

Seismic Probability Analyses Summary

- Credible potential seismically-initiated event sequences will be identified and associated consequences estimated
- Appropriate design basis ground motions will be assigned to ITS SSCs credited to prevent or mitigate event sequences, based on potential dose due to unmitigated release
- Event tree quantification (including convolution) will be used to demonstrate compliance for individual ITS SSCs or each seismically-initiated event sequence as appropriate

ITS =Important to Safety
SSCs = Structures, Systems, and Components

Seismic Probability Analyses Summary
(Continued)

- The failure probability of each risk-significant SSC or the probability of each seismically-initiated event sequence where dose consequence could exceed 5 rem will be demonstrated to be less than 1 chance in 10,000 over the preclosure period