U.S. Department of Energy
Office of Civilian Radioactive Waste Management

YUCCA MOUNTAIN PROJECT

Probabilistic Seismic Hazard Analysis for Yucca Mountain

Presented to:
Nuclear Waste Technical Review Board
Joint Meeting of the Natural System and Engineered System Panels

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Las Vegas, Nevada

Scope of Presentation

- Objective of Yucca Mountain (YM) Probabilistic Seismic Hazard Analysis (PSHA)
- PSHA Methodology and Guidance
- Project Implementation
- Ground Motion Hazard Results
- Fault Displacement Hazard Results
- Summary

Objective of Yucca Mountain PSHA

- **Obtain ground motion and fault displacement hazard results for preclosure seismic design and for postclosure performance assessment**
- **Quantify uncertainty in hazard results based on current uncertainty of the informed scientific community about:**
  - **Seismic source interpretations**
  - **Earthquake recurrence and maximum earthquakes**
  - **Engineering estimation of ground motion**
  - **Assessment of fault displacement potential**

Objective of Yucca Mountain PSHA

(Continued)

- **Minimize unquantified data uncertainty by using a common, uniform database for all evaluations**
- **Quantify uncertainty by conducting a formal expert elicitation for all evaluations input to hazard computations**

PSHA Methodology and Guidance

- **Level 4 PSHA, as defined by the Senior Seismic Hazard Analysis Committee (SSHAC): NUREG/CR-6372**
  - **Reviewed by the National Academy of Sciences**
  - **Accepted by the NRC for application in nuclear facility licensing**
- **NRC Branch technical position on the use of expert elicitation in the high-level radioactive waste program: NUREG-1563**
- **NRC Staff technical position on investigations to identify fault displacement hazards and seismic hazards at a geologic repository: NUREG-1451**

PSHA Methodology and Guidance
(Continued)

- **NRC Staff technical position on consideration of fault displacement hazards in geologic repository design: NUREG-1494**
- **DOE Seismic Topical Report #1: *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain, Rev. 1***
  - **Reviewed and provisionally accepted by NRC for application at Yucca Mountain**
- **DOE Seismic Topical Report #2: *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain, Rev. 2***
  - **Reviewed and provisionally accepted by NRC for application at Yucca Mountain**

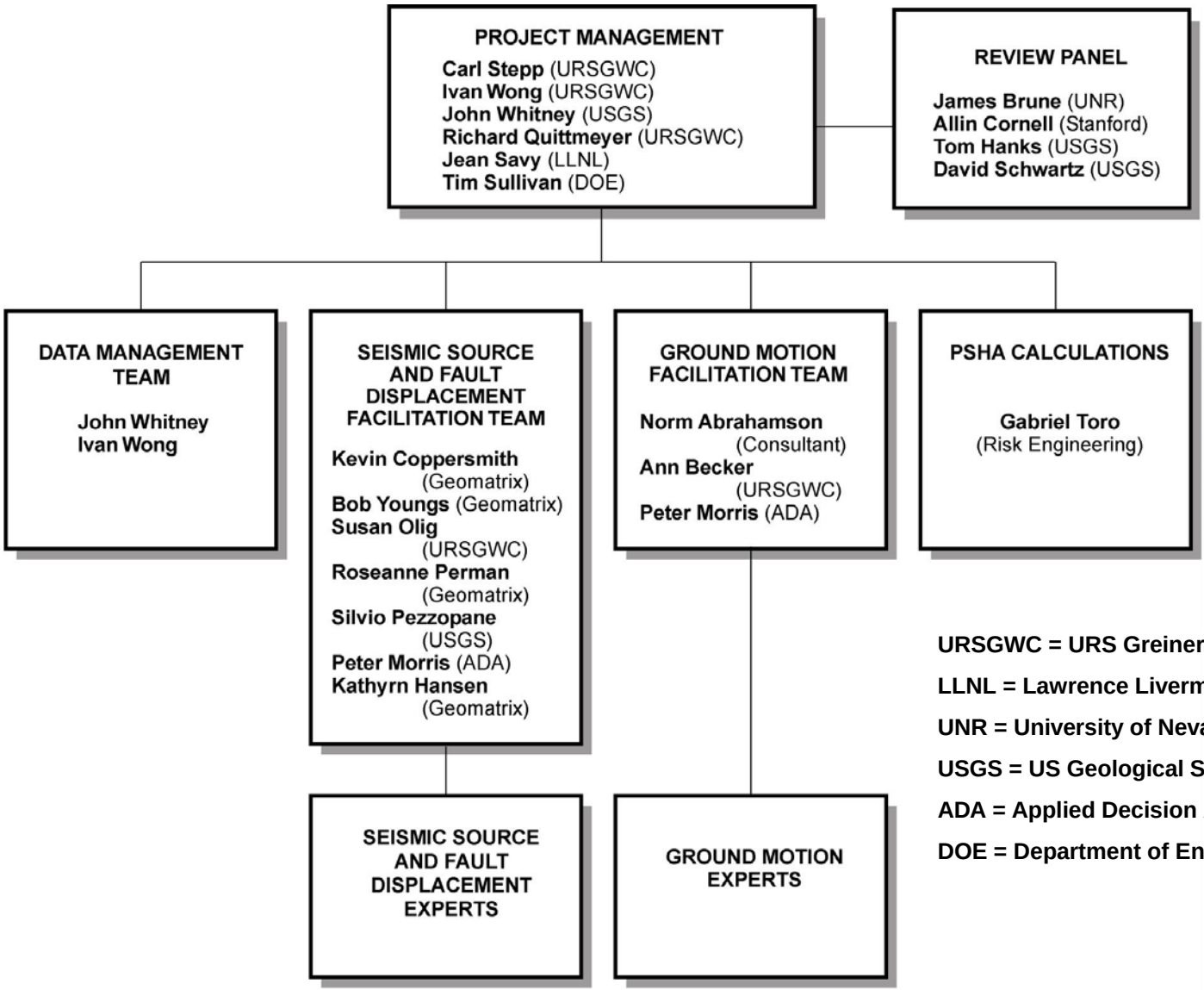
Project Implementation

- **SSHAC Level 4 Methodology**
  - **Focus on quantification of epistemic (knowledge) uncertainty with alternative interpretations by multiple experts**
  - **Six teams of three experts performed seismic source and fault displacement (SSFD) assessments**
    - **Basin and Range tectonics expert**
    - **Seismology expert**
    - **Quaternary fault expert**
  - **Seven ground motion experts – representing credible ground motion modeling approaches and empirical ground motion estimation**
  - **Common database for all expert evaluations**

Project Implementation
(Continued)

- Structured expert interactions in multiple workshops and field trips
- Comprehensive Identification of issues to be addressed in the evaluations
- Presentation of alternative viewpoints and conceptual models – challenge, defense, feedback
- Participatory Peer Review
- Integration of expert evaluations to represent state of knowledge of larger informed technical community

PSHA Project Organization



URSGWC = URS Greiner Woodward Clyde

LLNL = Lawrence Livermore National Laboratory

UNR = University of Nevada at Reno

USGS = US Geological Survey

ADA = Applied Decision Analysis

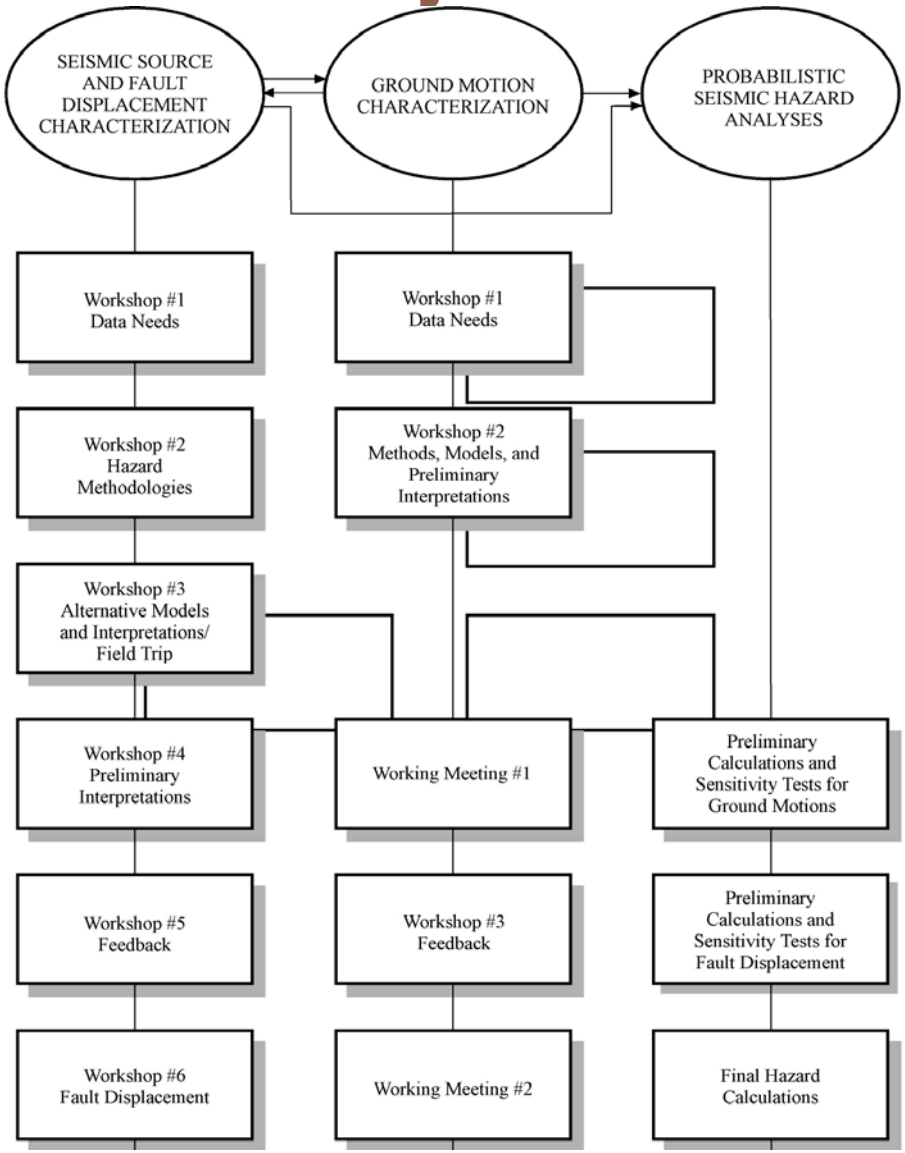
DOE = Department of Energy

PSHA Experts

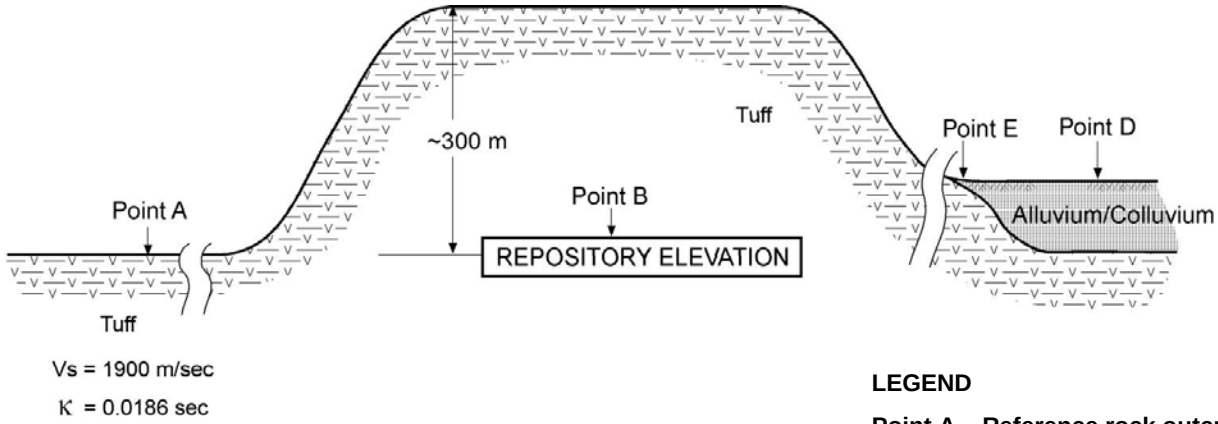
SSFD Expert Teams	*Affiliation*
Walter J. Arabasz (AAR)	University of Utah
R. Ernie Anderson	U.S. Geological Survey
Alan R. Ramelli	Nevada Bureau of Mines & Geology
Jon P. Ake (ASM)	U.S. Bureau of Reclamation
D. Burton Slemmons	Consultant
James McCalpin	GEO-HAZ Consulting, Inc.
Diane I. Doser (DFS)	University of Texas, El Paso
Christopher J. Fridrich	U.S. Geological Survey
Frank H. (Bert) Swan	Geomatrix Consultants, Inc.
Albert M. Rogers (RYA)	GeoRisk Associates, Inc.
James C. Yount	U.S. Geological Survey
Larry W. Anderson	U.S. Bureau of Reclamation
Kenneth D. Smith (SBK)	University of Nevada, Reno
Ronald Bruhn	University of Utah
Peter L. K. Knuepfer	Binghamton University
Robert B. Smith (SDO)	University of Utah
Craig dePolo	Nevada Bureau of Mines & Geology
Dennis W. O'Leary	U.S. Geological Survey

GM Experts	*Affiliation*
John G. Anderson	University of Nevada, Reno
David M. Boore	U.S. Geological Survey
Kenneth W. Campbell	EQE International Inc.
Arthur F. McGarr	U.S. Geological Survey
Walter J. Silva	Pacific Engineering & Analysis
Paul G. Somerville	URS Greiner Woodward-Clyde
Marianne C. Walck	Sandia National Laboratories

PSHA Project Process



Ground Motion Hazard Results



LEGEND

Point A – Reference rock outcrop at repository elevation

Point B – Repository elevation

Point D – Soil surface at Surface Facilities

Point E – Shallow soil/rock at Surface Facilities

- **Ground motion hazard computed at control location – Point A**
  - **Rock properties at control location are properties of rock at the waste emplacement level**
- **Aleatory variability of ground motion about median motion for M & D not truncated**

Ground Motion Hazard Results

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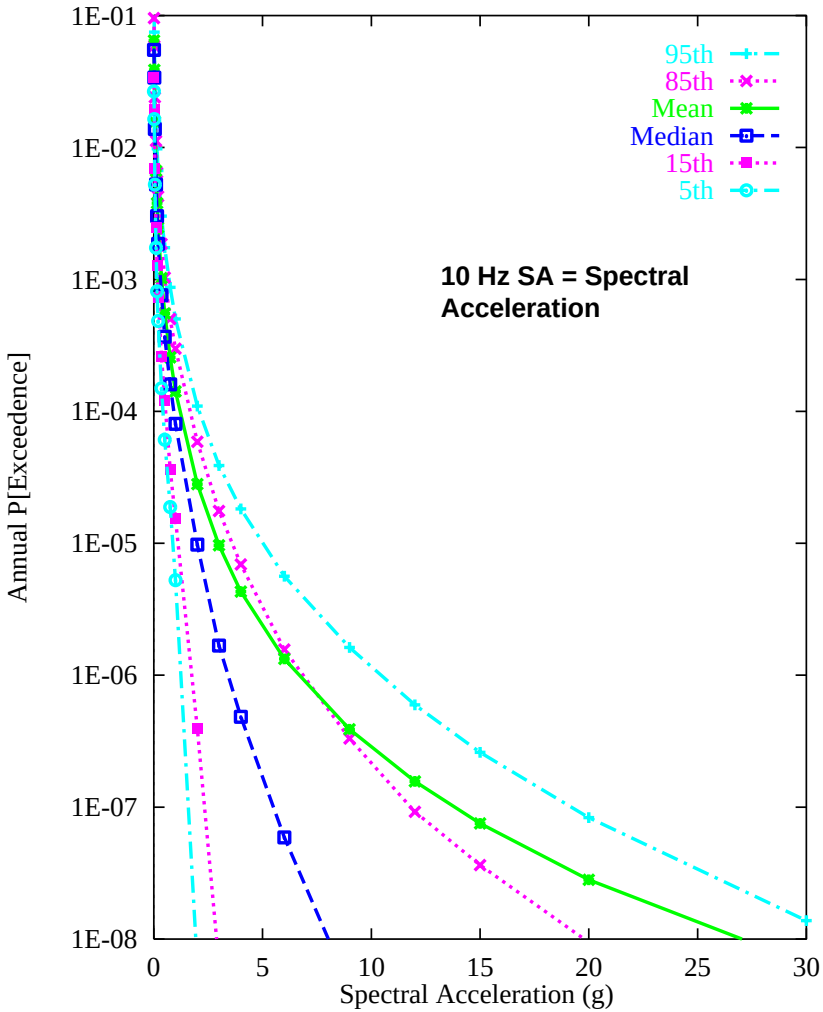

Hazard probability distribution is reasonably symmetric to annual frequency of 1 x 10^{-5}

Ground Motion Hazard Results

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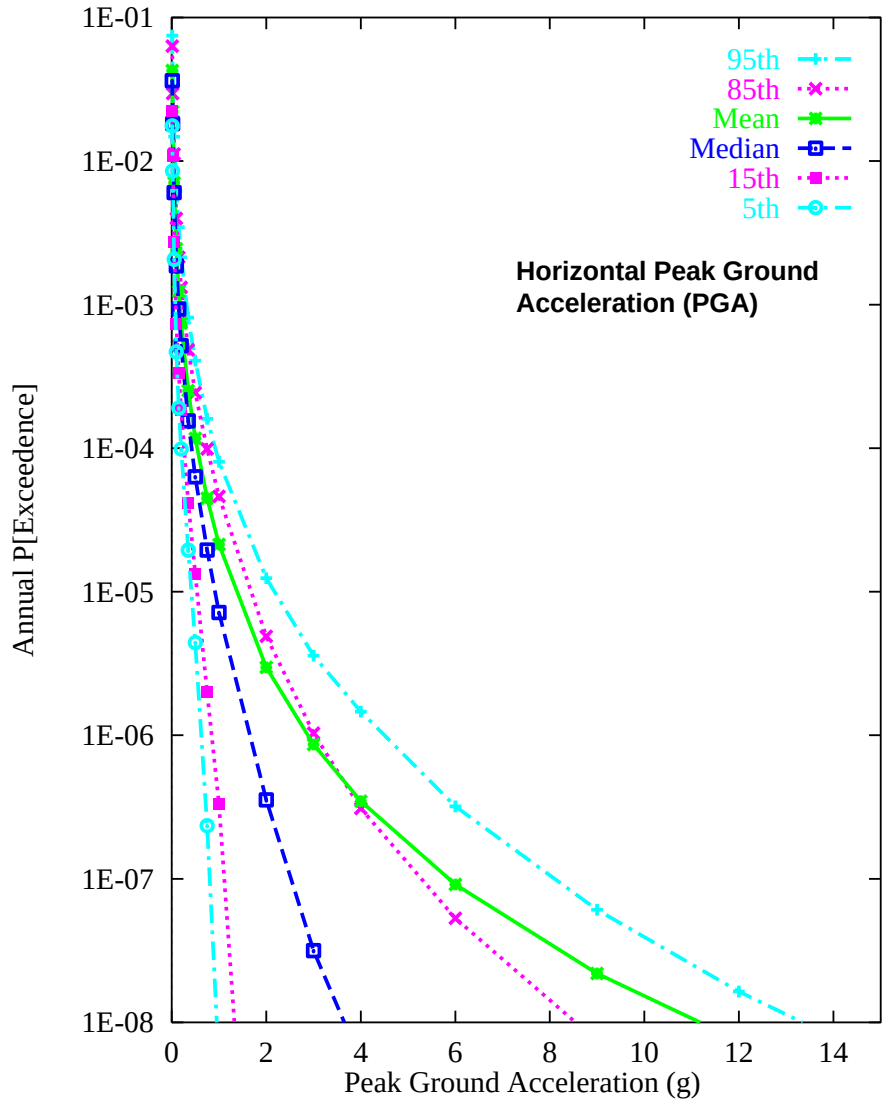

Ground Motion Hazard Results

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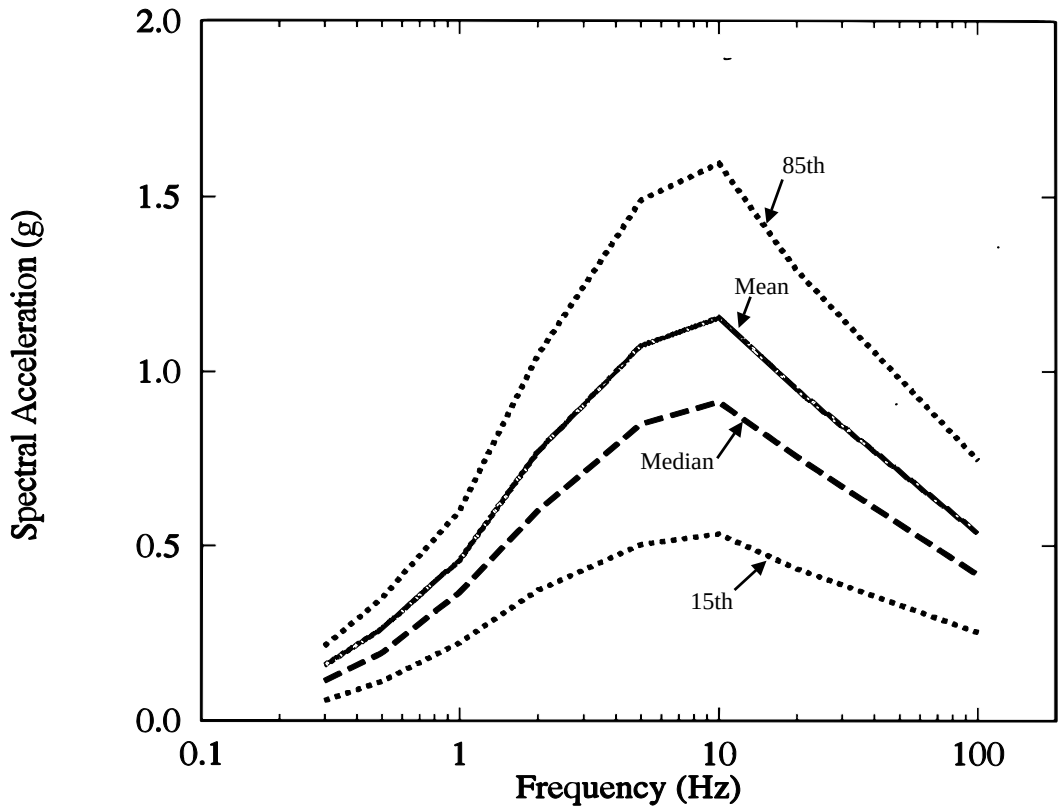
1 x 10^{-3}, 5 x 10^{-4}, and 1 x 10^{-4} uniform hazard spectra to derive hazard-consistent seismic design ground motion spectra at locations of repository facilities – Points B, D, and E



Ground Motion Hazard Results

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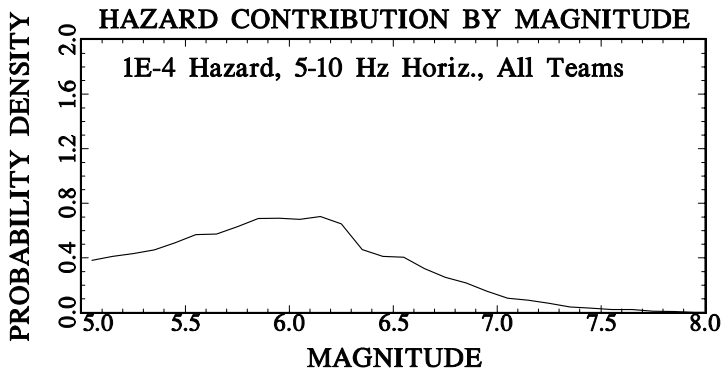

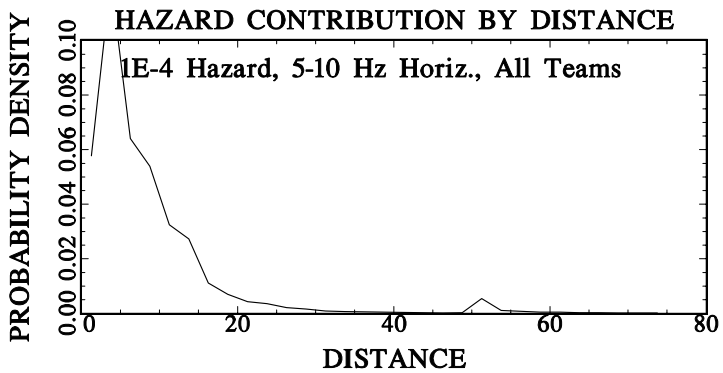

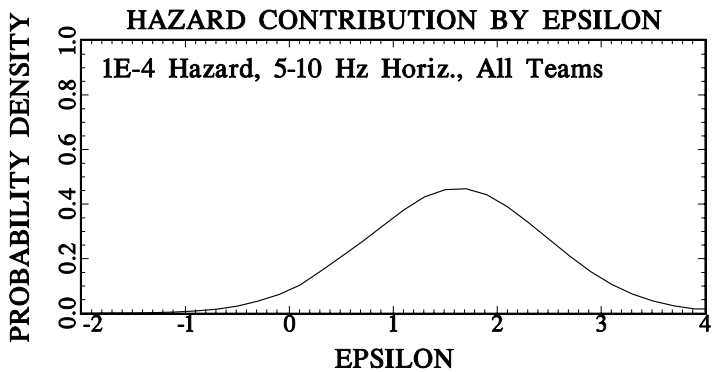

Ground Motion Hazard Results

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- **Ground motions for postclosure seismic analysis derived based on scaled peak ground velocity (PGV)**
- **Hazard probability distribution highly asymmetric for low annual frequencies required to be considered for postclosure performance assessment**
  - **Mean ground motions for lower than about 1×10^{-6} are likely physically unrealistic**
  - **Reflect uncertainty in hazard estimation**
  - **Consistent approach to obtain mean hazard that reflects uncertainties in inputs – no truncation of ground motion uncertainty or ground motion level**

Ground Motion Hazard Results

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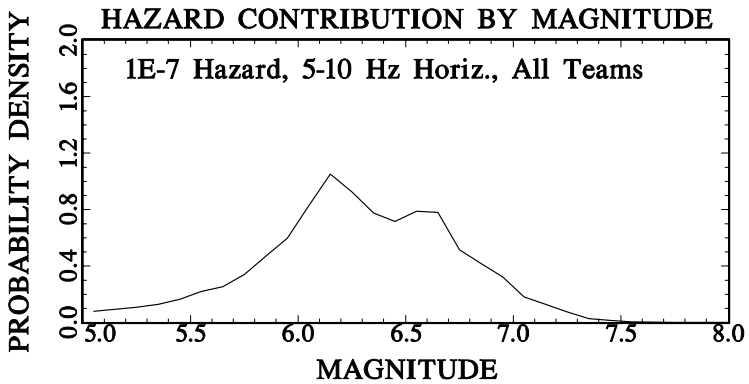
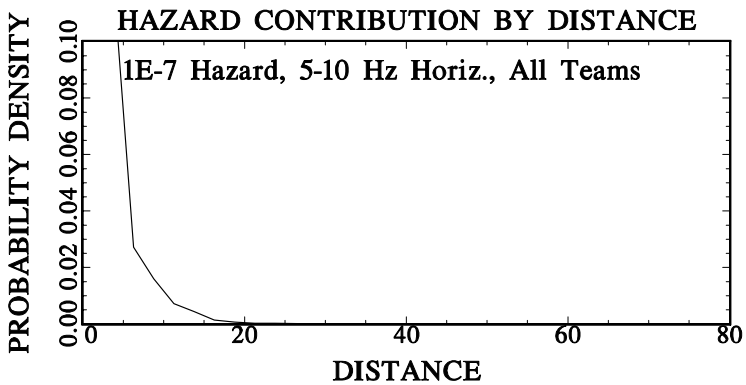
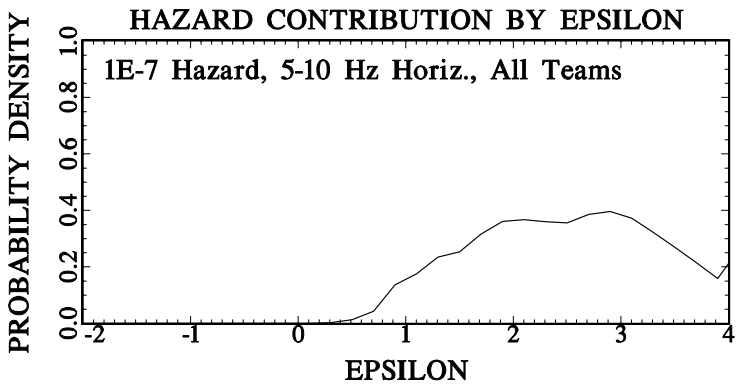
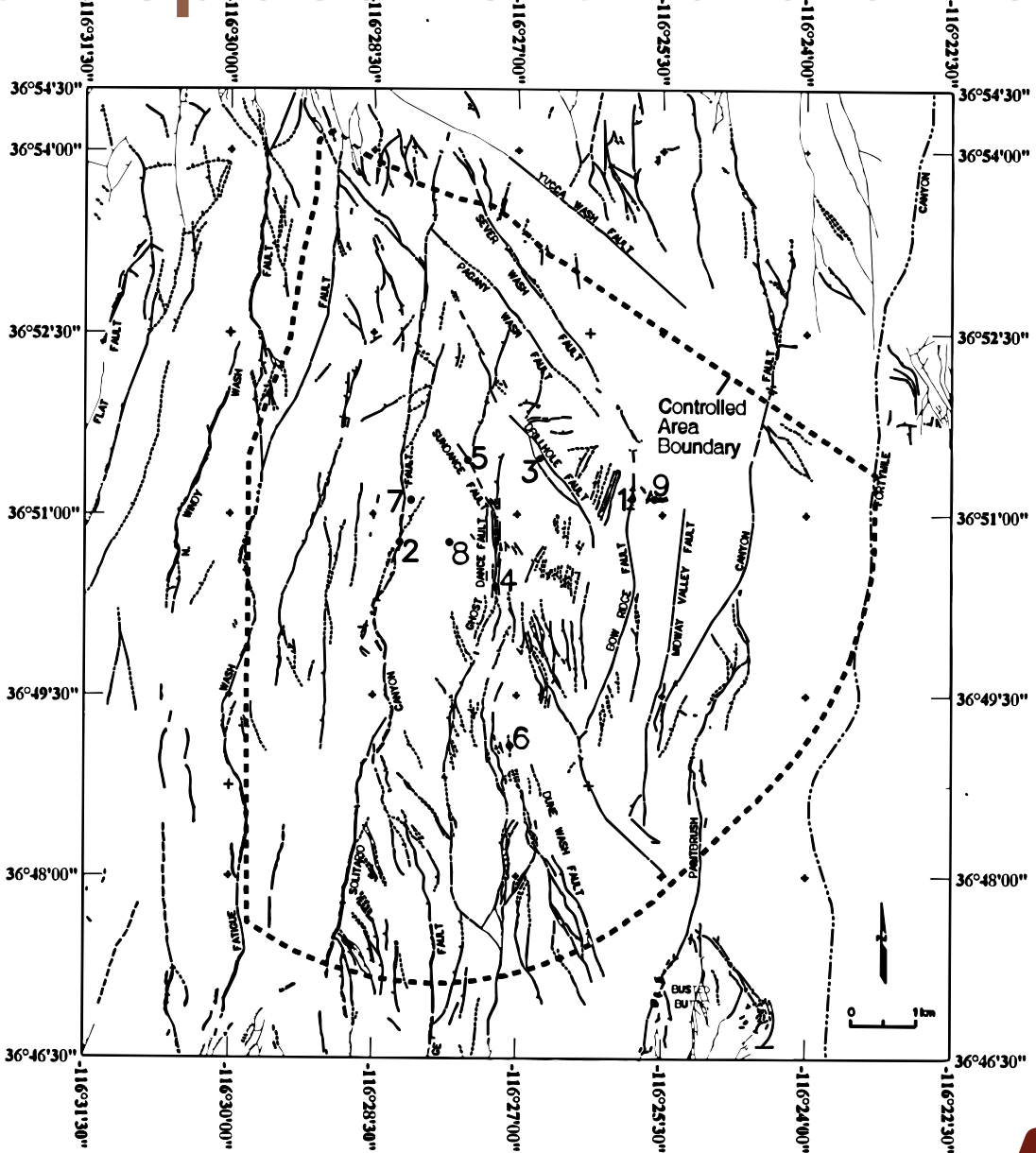






Fault Displacement Hazard Results



Fault Displacement Hazard Results

(Continued)

Fault displacement hazard assessed for a total of 15 faulting conditions known to exist within the Yucca Mountain Controlled Area.

		Displacement (cm)	
		Annual Exceedance Probability	
Case	*Location Description*	10^{-4}	10^{-5}
1	Bow Ridge fault	<0.1	7.8
2	Solitario Canyon fault	<0.1	32
3	Drill Hole Wash fault	<0.1	<0.1
4	Ghost Dance fault	<0.1	<0.1
5	Sundance fault	<0.1	<0.1
6	Unnamed fault west of Dune Wash	<0.1	<0.1
7	100 m east of Solitario Canyon fault		
7a	2-m small fault	<0.1	<0.1
7b	10-cm shear	<0.1	<0.1
7c	Fracture	<0.1	<0.1
7d	Intact rock	<0.1	<0.1
8	Between Solitario Canyon and Ghost Dance faults		
8a	2-m small fault	<0.1	<0.1
8b	10-cm shear	<0.1	<0.1
8c	Fracture	<0.1	<0.1
8d	Intact rock	<0.1	<0.1
9	Midway Valley	<0.1	0.1

Fault Displacement Hazard Results

(Continued)

- **Fault displacement hazard for preclosure design is negligible except for the Bow Ridge and Solitario Canyon faults**
- **Probability distribution for fault displacement becomes increasingly asymmetric with decreasing annual frequency**
- **Fault displacement for mean annual frequency below about 1×10^{-6} are likely unrealistically large considering physical dimensions and observed characteristics of faulting – driven by uncertainty in characterization of fault displacement potential**
- **Analysis of fault displacement for postclosure is currently in progress – effects will likely be screened out of the Total System Performance due to low consequence**

Fault Displacement Hazard Results

(Continued)

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Fault Displacement Hazard Results

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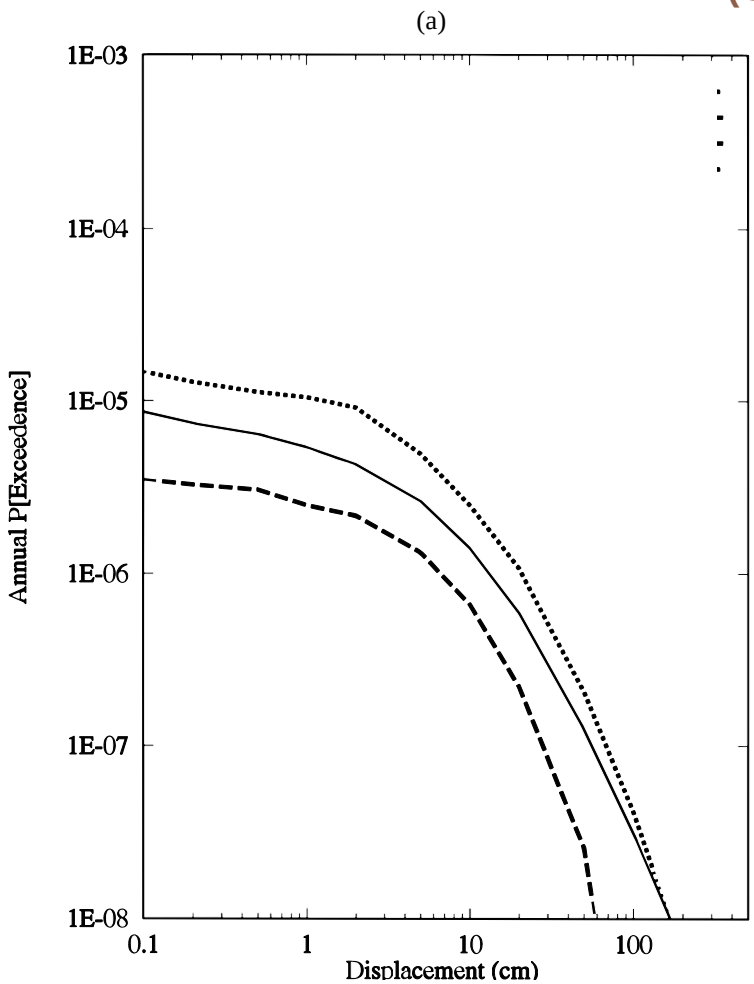
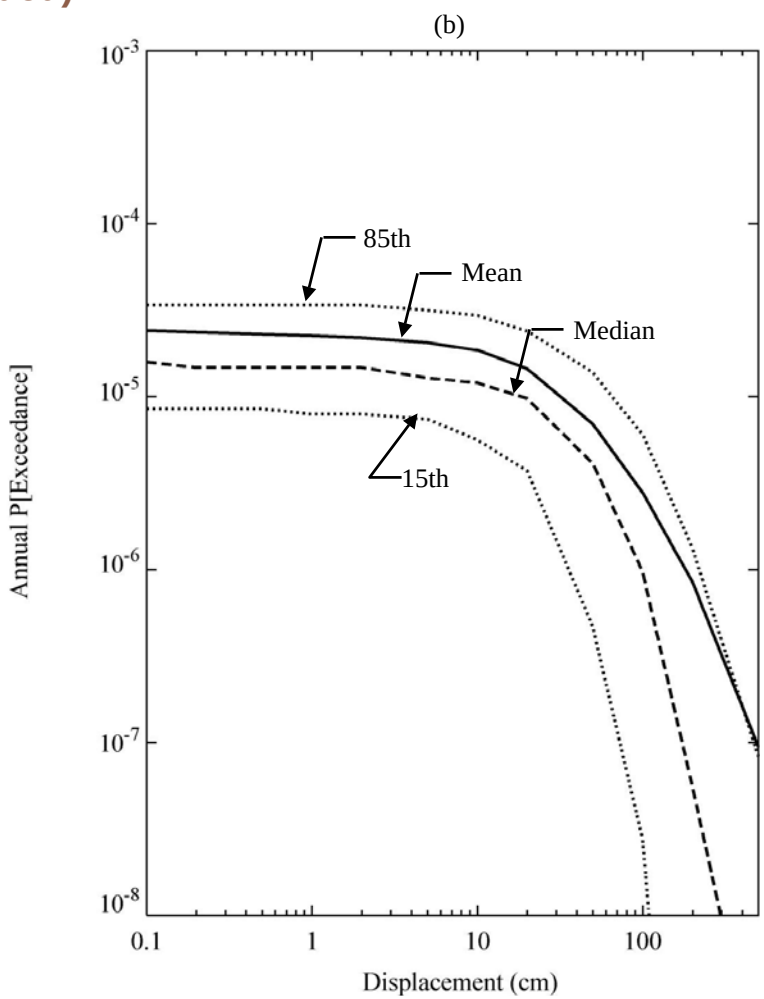


Site 4- Ghost Dance Fault



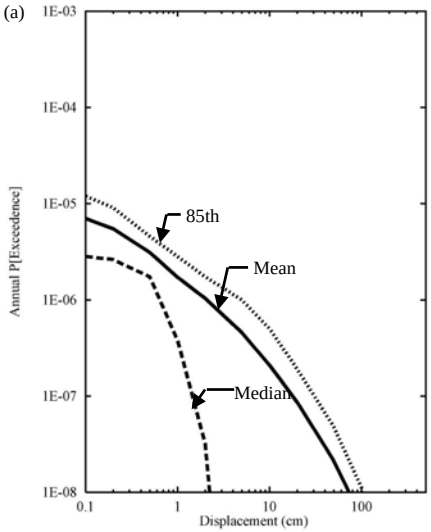
Site 2 - Solitario Canyon Fault

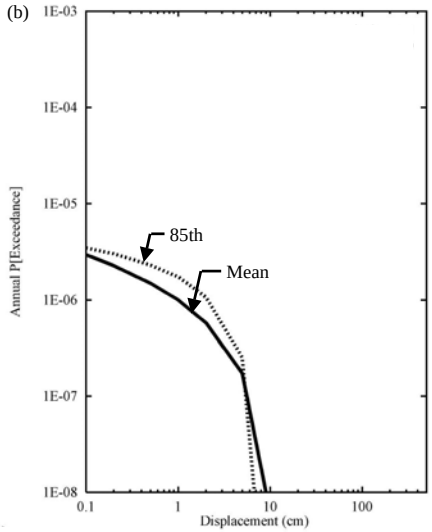
Fault Displacement Hazard Results

(Continued)

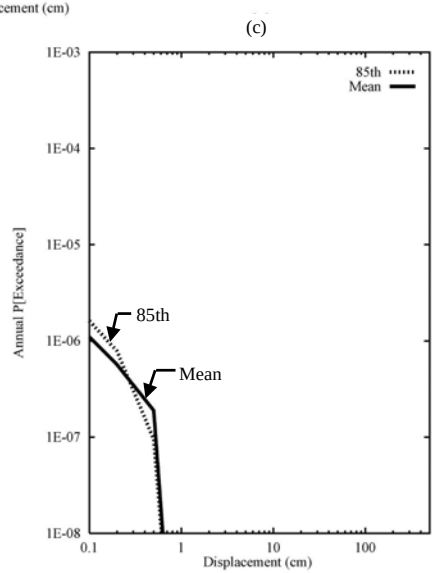
100 m East of Solitario Canyon Fault

Site 7a – 2 m cumulative displacement





Site 7b – 10 cm cumulative displacement



Site 7c – No measurable cumulative displacement

Summary

- **PSHA for Yucca Mountain was conducted in accordance with available guidance for methodologies to perform formal expert elicitation**
- **Focus of elicitation process is the quantification of epistemic uncertainties in seismic source and fault displacement inputs and epistemic and aleatory (random variability) uncertainties in ground motion estimation**
- **Integrated evaluations of all experts and expert teams is representative of the state of knowledge of the informed technical community**
- **Quantification of uncertainties leads to mean ground motion estimates at all annual frequency levels – at very low annual frequencies, ground motions are likely not physically realistic**

Summary
(Continued)

- Ground motions derived from the PSHA are fundamental basis for deriving hazard-consistent ground motions at surface and subsurface facilities
- Fault displacement hazard was quantified for 15 representative faulting conditions identified at Yucca Mountain and can be applied throughout the geologic repository operations area
- Fault displacement hazard is negligible for preclosure design, except for Bow Ridge and Solitario Canyon faults – evaluations for postclosure in progress

Backup

Ground Motion Hazard Results

(Continued)