Overview of New Reactor Seismic Reviews

-Relationship to Research Programs-

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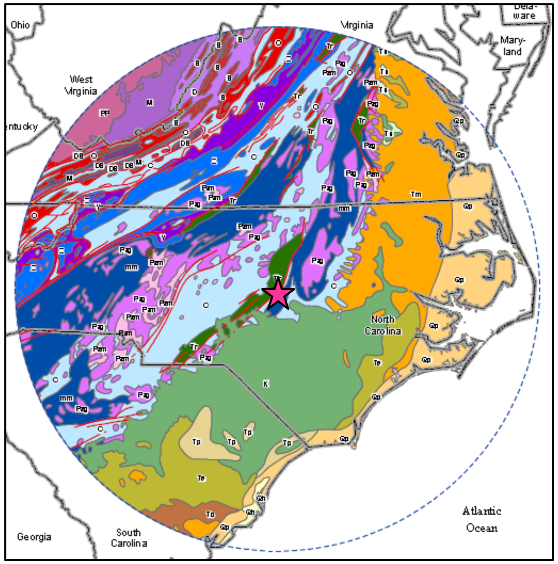
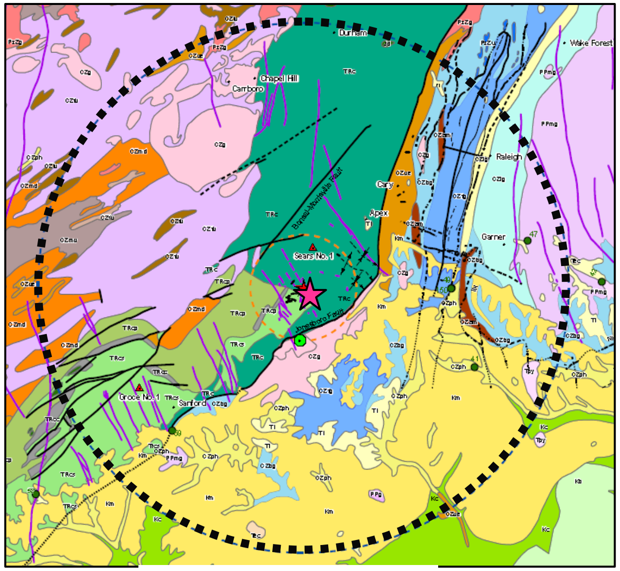
Outline

- **Geology** (RGs 1.206, 1.208)
  - Regional and Local Structures
  - Evidence of Past Earthquakes (Paleoseismology)
- **Seismology** (RG 1.208)
  - Seismic Source Models
  - Ground Motion Prediction at Site
  - Safe Shutdown Earthquake – SSE (GMRS)
- **Geotechnical Engineering** (RGs 1.132, 1.138,1.198)
  - Static and Dynamic Soil/Rock Properties
    - Field Measurements/Lab Tests
  - Foundation Stability (static/dynamic)
    - Liquefaction
- **Engineering Areas of Seismic Review**

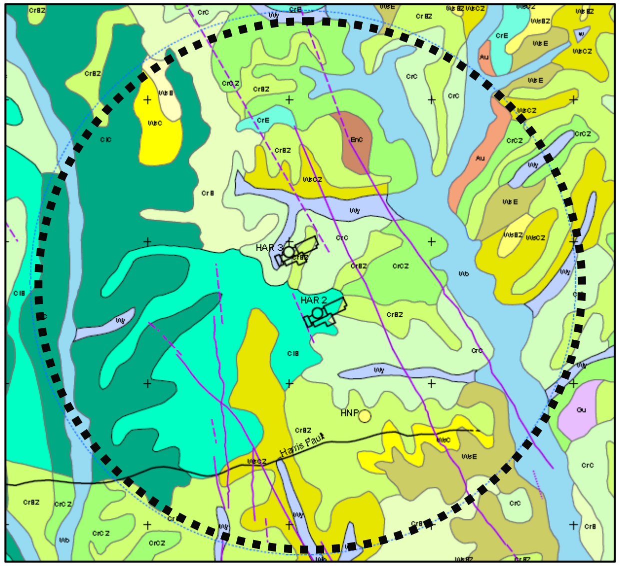
Geology: Regional and Local Structures



320 km radius



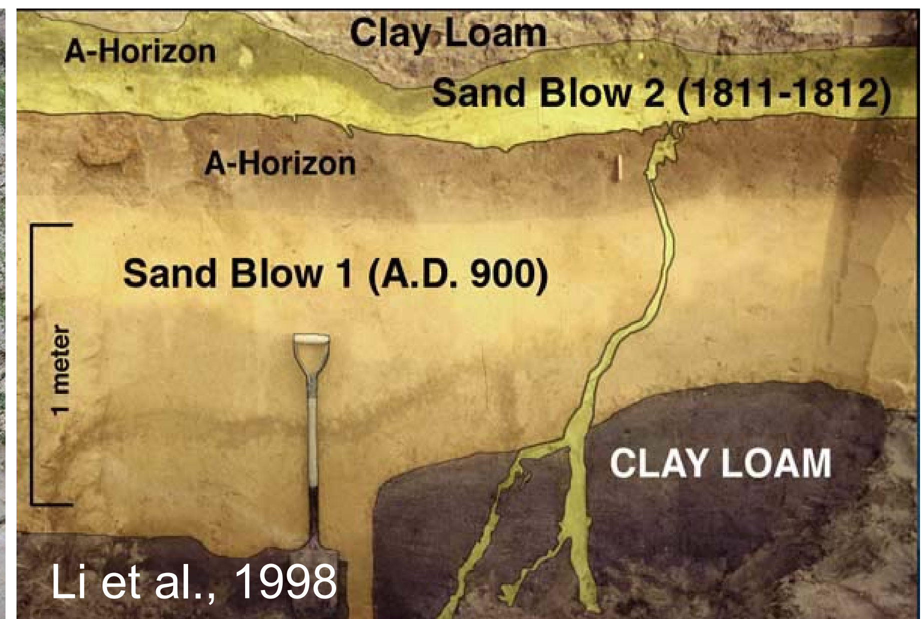
40 km radius



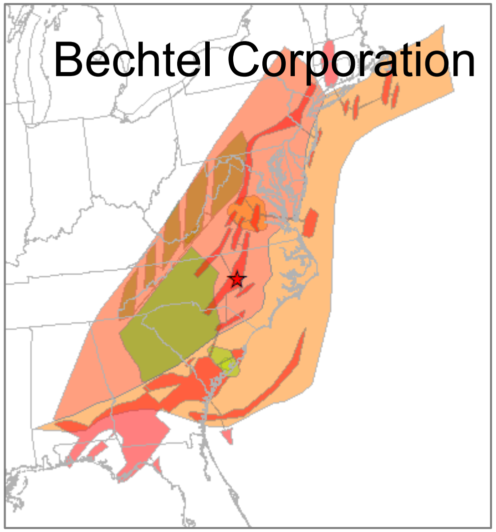
1 km radius

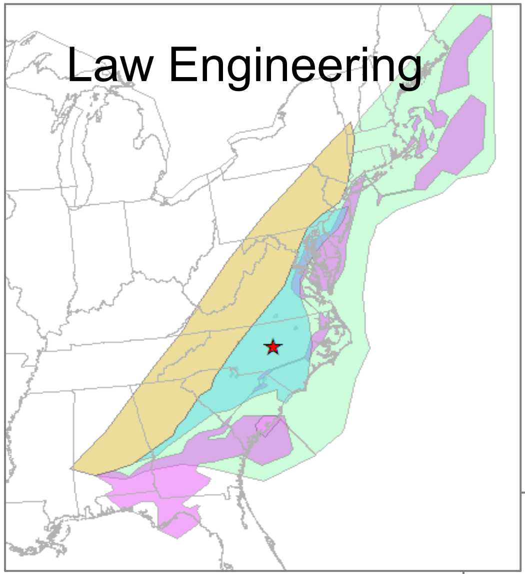
Geology: Past Earthquakes - Paleoseismology

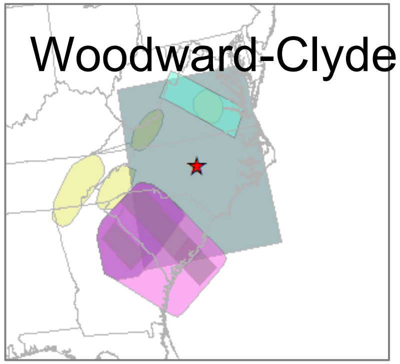
- **Liquefaction**
  - Liquefaction features occur in response to strong ground shaking
  - Liquefaction susceptibility is a function of site characteristics
  - Liquefaction features commonly observed in the form of sand blows

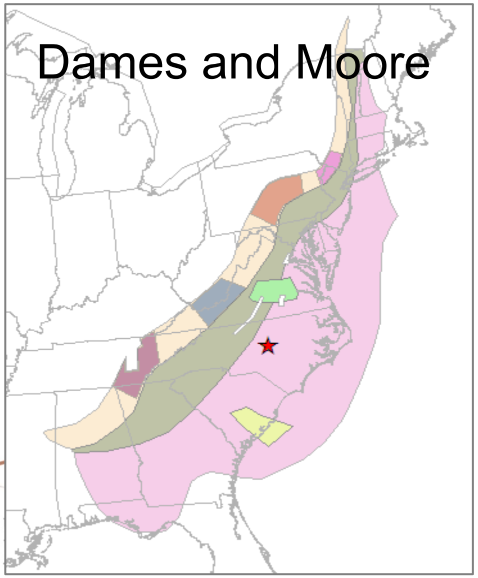


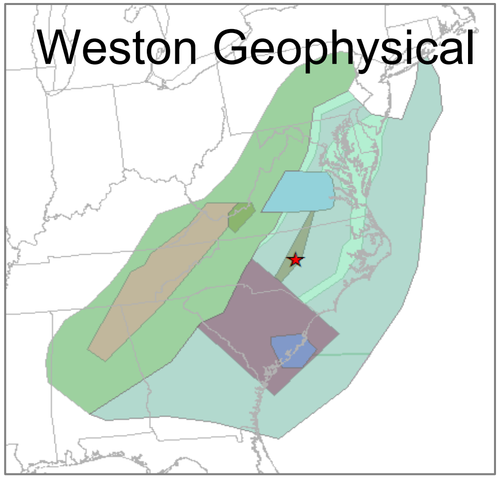
Seismology
1986 EPRI-SOG Source Geometries

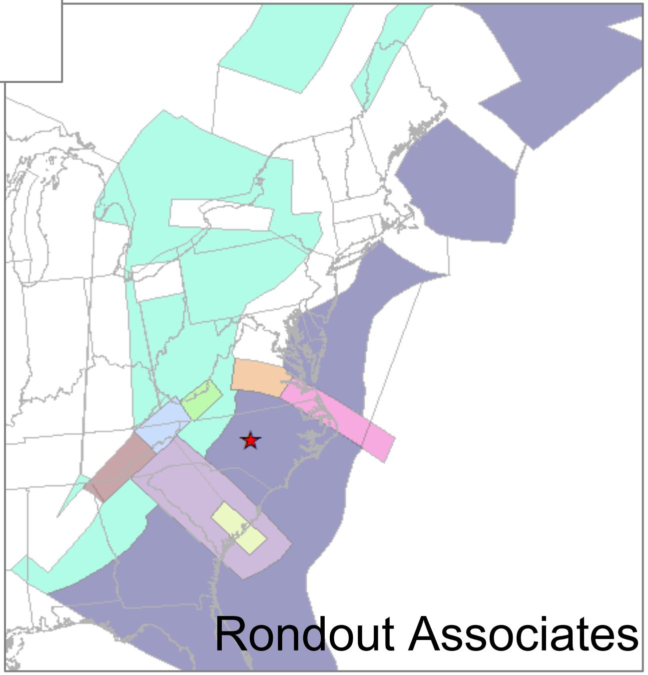






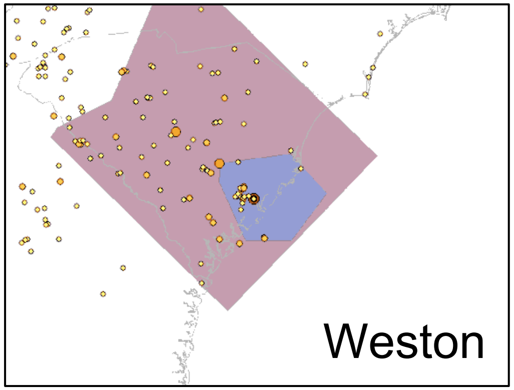


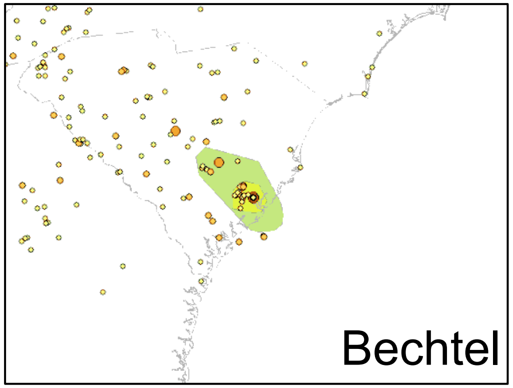


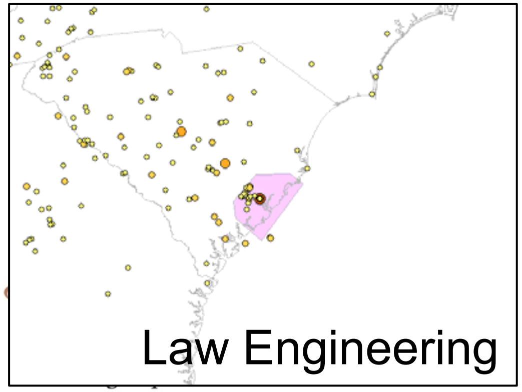


Updated Charleston Seismic Source

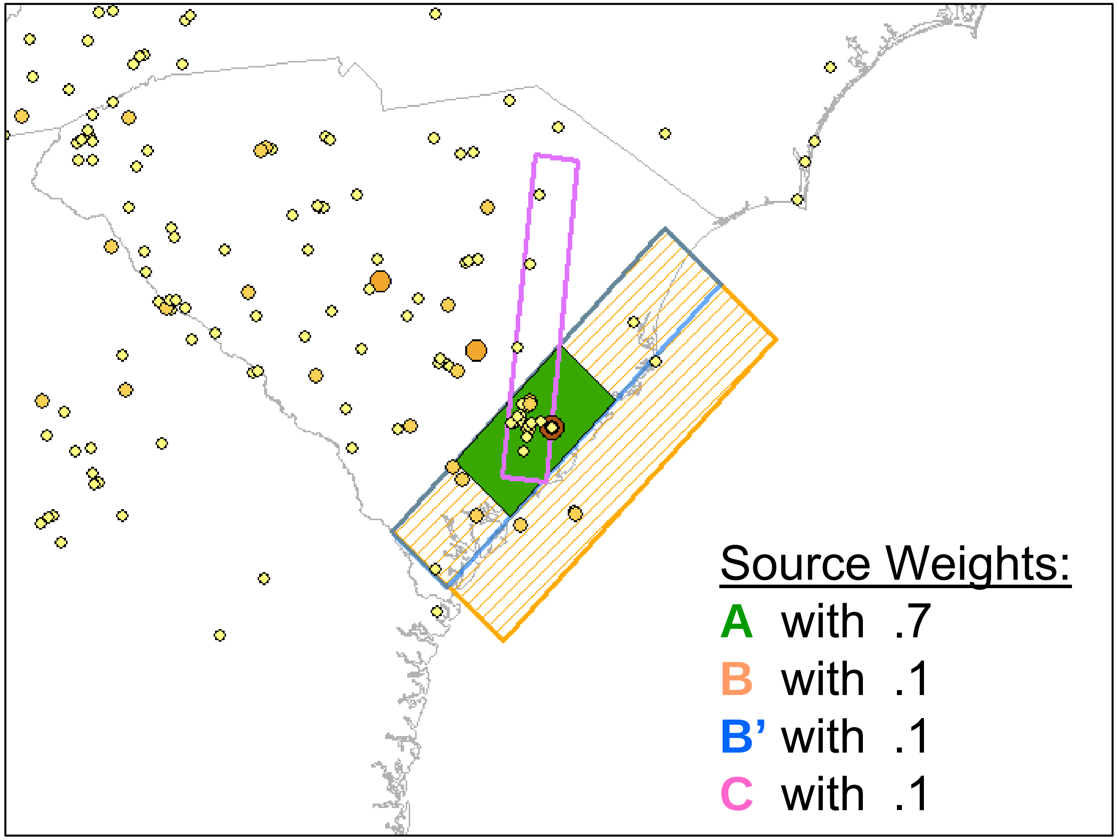
EPRI-SOG, 1989





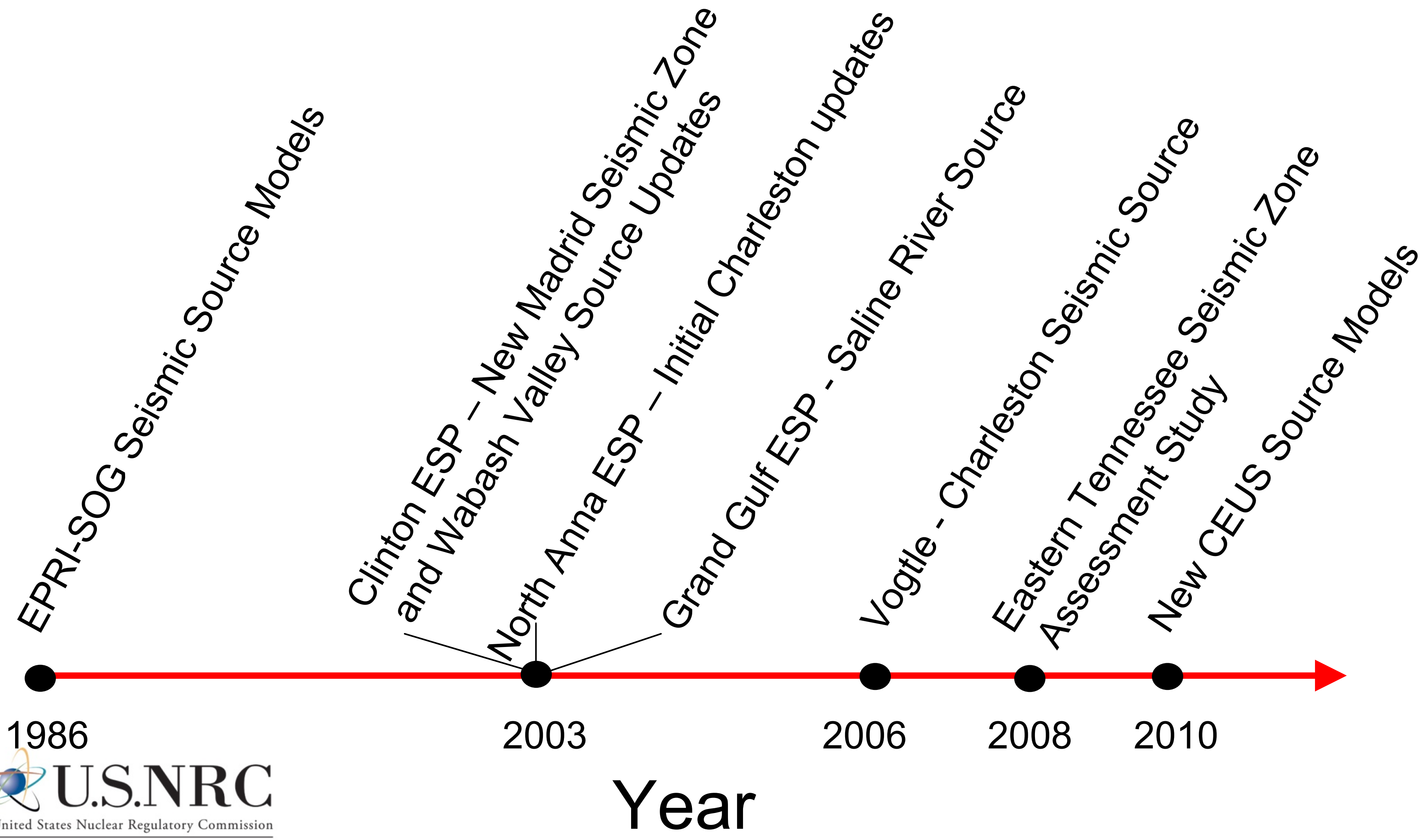


Updated Charleston Seismic Source, 2006



Updates to EPRI-SOG Source Models

Source models are not static, they require updates as our understanding of the geology/tectonics of these sources improves



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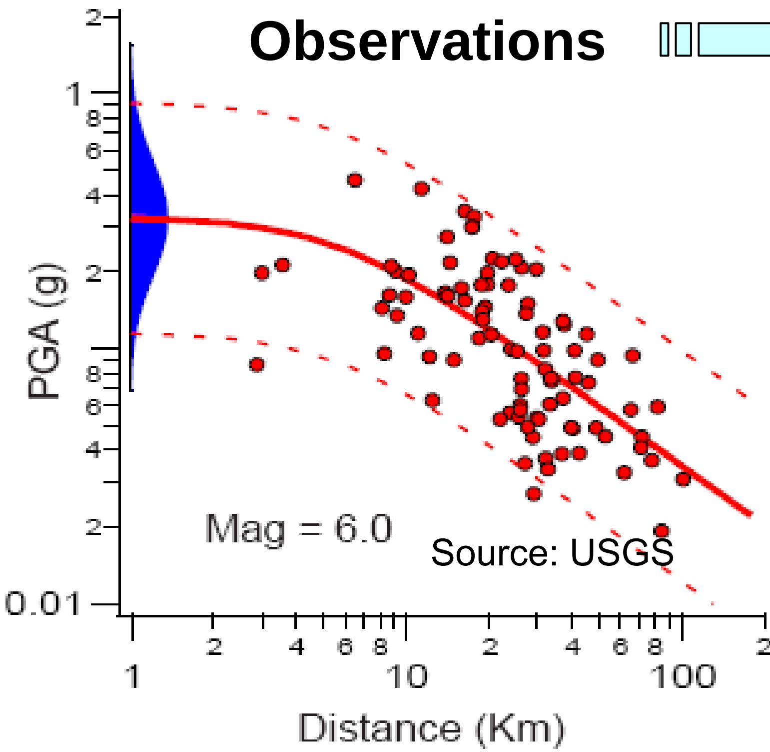
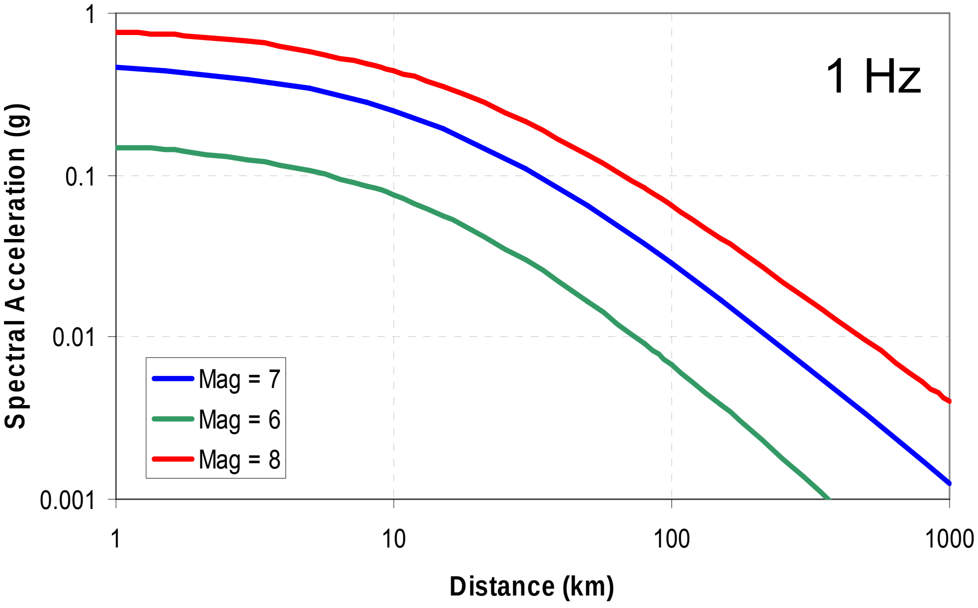
United States Nuclear Regulatory Commission
Protecting People and the Environment

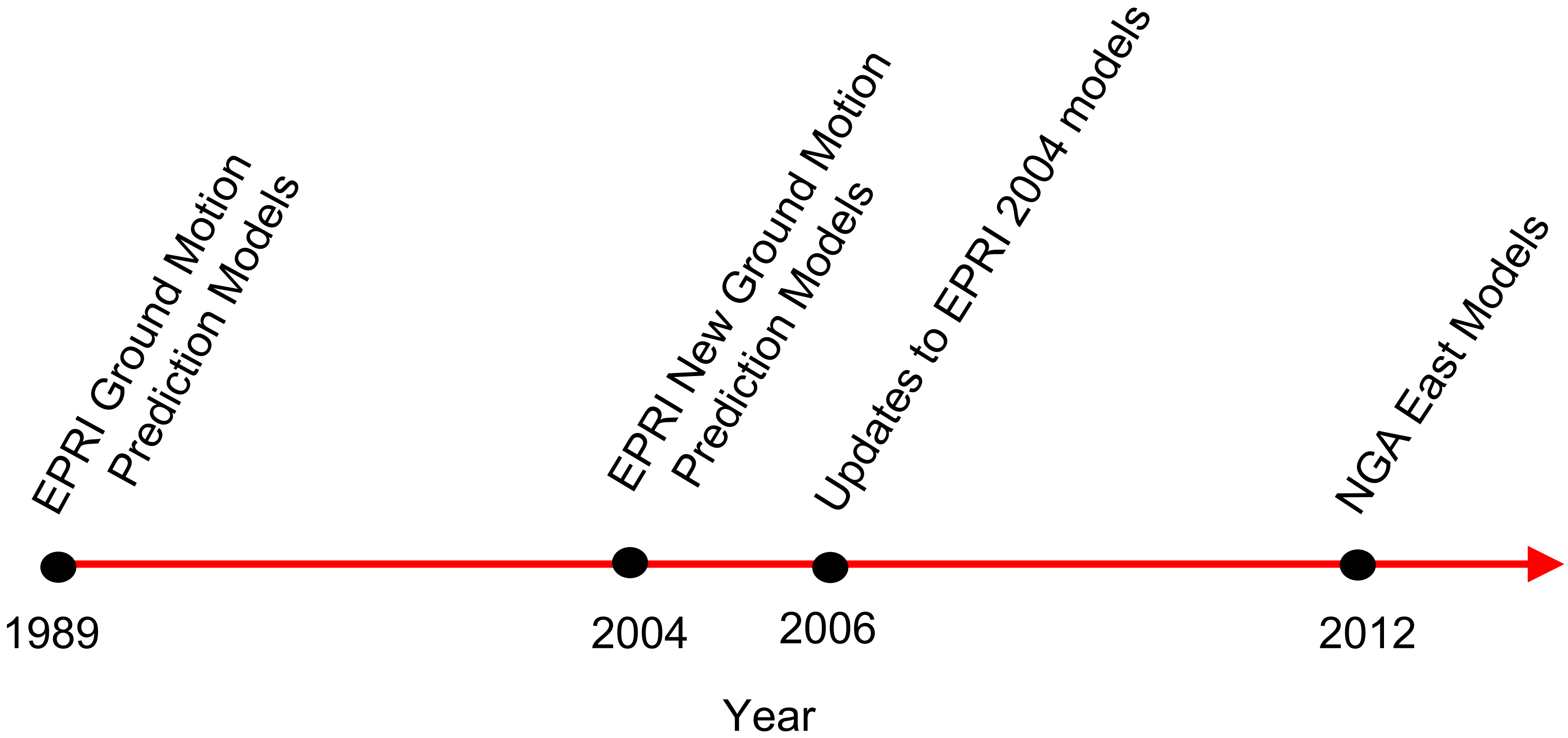
Seismology: Ground Motion

Seismograms

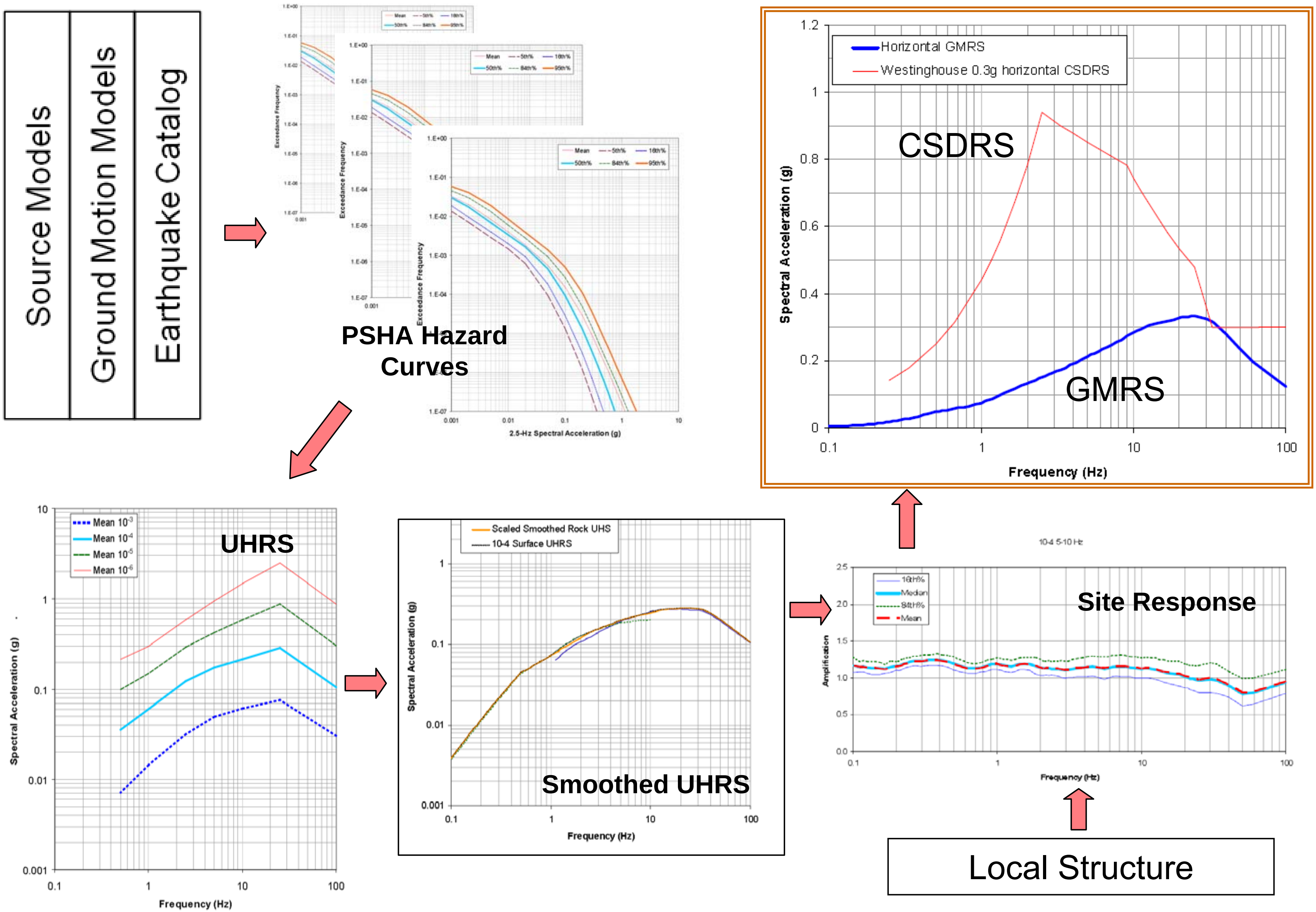




Updates to Ground Motion Prediction Models

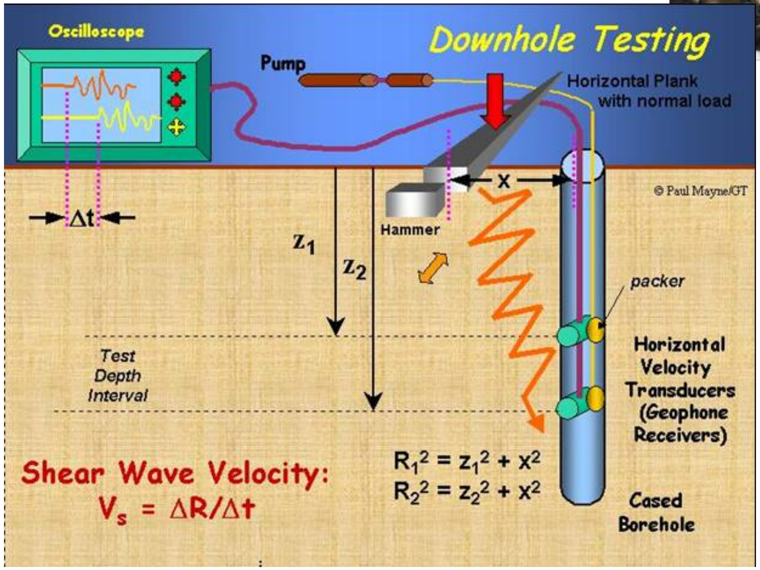


Pathway to GMRS



Geotechnical: Soil & Rock Properties

- **Field Observations**
  - Borings
    - Sampling (Disturbed/undisturbed)
    - Rock Coring
    - In-Situ testing for stress-strain-strength
  - Geophysical Measurements
    - Crosshole
    - Downhole
    - Suspension Logging
    - Spectral Analyses of Surface Waves (SASW)



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Soil/Rock Properties

- **Laboratory Tests**

  Laboratory testing is conducted to identify and classify soils and rocks and to evaluate their physical and engineering properties

- Classification tests
- Engineering properties tests
  - Total mass density
  - Moisture Content
  - Poisson's ratio
  - Shear and compressional wave velocities
  - Dynamic shear modulus and damping ratios

Foundation Stability
Bearing Capacity & Settlement

- **Bearing Capacity (Static/Dynamic)**

  General failure and local failure
  - Rock
  - Soil

- **Settlement**

  Typically a soil foundation problem

  Total & Differential Settlement

  Monitored during and after construction

Earth Pressures, Liquefaction

- **Lateral Earth Pressures (Static/Dynamic)**

  Calculations of lateral earth pressures related to safety related structures

- **Liquefaction**

  Assessments are made to determine whether the site is likely to liquefy in response to earthquake shaking

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Engineering Areas of Seismic Review

- SRP 3.7 Seismic analysis and design parameters
- SRP 3.8 Seismic design of Category I structures and foundations
- SRP 3.10 Seismic qualification of equipment
- SRP 3.12 Seismic design of piping and supports

Summary

Relationship to Research Programs

- Development of New Seismic Source Models for the Central and Eastern USA
- Next Generation Ground Motion Prediction Models
- Identification of Past Earthquakes
- Geotechnical Regulatory Guide Updates
- Seismic Induced Passive Earth Pressure
- Ground Motion Incoherency
- Guidance for PRA-Based SMA

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Protecting People and the Environment

Seismic Research Program 2008-2011

ACRS Meeting
April 2009

Research Activities

- Regulatory infrastructure development
  - Regulatory guidance
  - Development of new approaches and tools
- Evaluation of operating experience
- Confirmatory analysis
- Other regulatory programs
- Codes & Standards
- Assistance in reviews

Program Overview

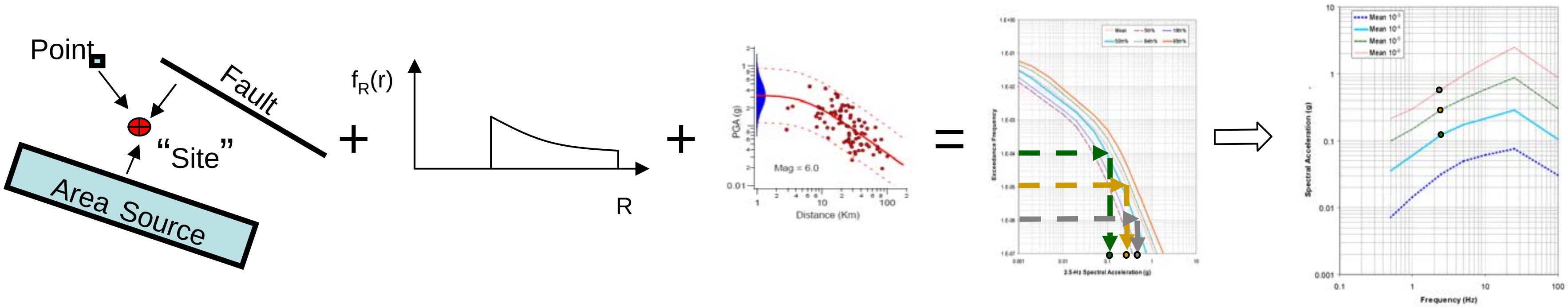
- Publicly available research plan
- Targeted on regulatory needs
- Strong stakeholder interaction
  - Developed with NRO, NRR & NMSS
  - Cooperation with industry, other national & international agencies, and the technical community
- Developed to advance the science and increase regulatory stability
- Short- and long-term projects

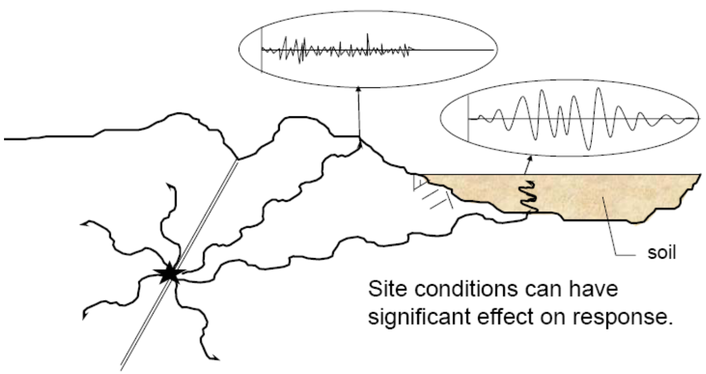
Program Overview

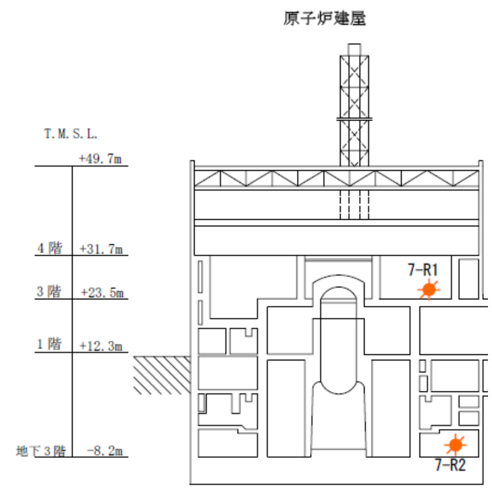
- Systematic & integrated
  - Integrated research planning
  - Focused on issues with highest uncertainties
  - Risk informed plan that fills in gaps
- Cost effective/High Quality
  - Piggy backing and partnering
  - Universities & Federal Agencies
  - "Next-generation" approaches
- Emphasis on performance-based & risk-informed approaches

“Next Generation” Approaches

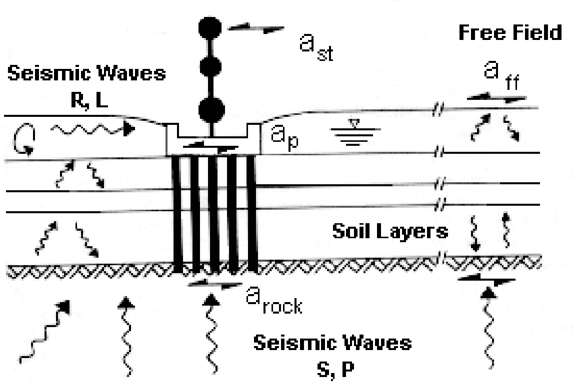
- Emphasis on community cooperation and consensus
- NRC & Industry initiated pioneering seismic research
- Divergence of tools and methods in some areas
  - Different databases, gray literature, proprietary reports, proprietary software
- Now mature field moving toward integration through workshops, working groups and “next generation” approaches
  - Common databases & inputs, all key researchers involved, community consensus or weighting of alternate opinions, documentation of thought processes, outliers better understood, best estimates and estimates of uncertainties


Point
Fault
"Site"
Area Source
+
$f_R(r)$
R
+
PGA (g)
Mag = 6.0
Distance (Km)
=
Frequency (Hz)


soil
Site conditions can have significant effect on response.


原子炉建屋
T. M. S. L.
+49. 7m
4 階 +31. 7m
3 階 +23. 5m
1 階 +12. 3m
地下 3 階 −8. 2m
7-R1
7-R2

SSCs

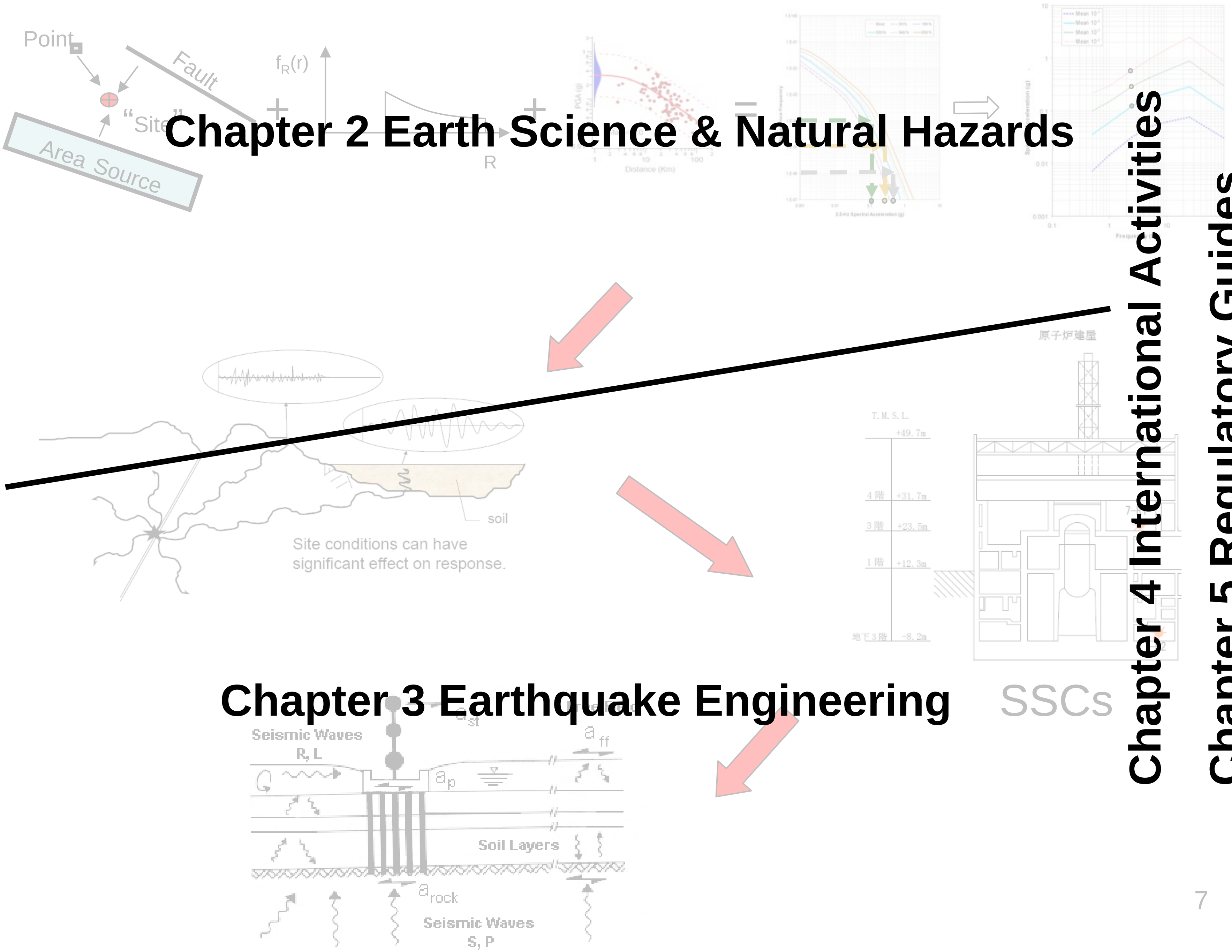

a_{st}
Free Field
Seismic Waves
R, L
a_{ff}
a_p
Soil Layers
a_{rock}
Seismic Waves
S, P

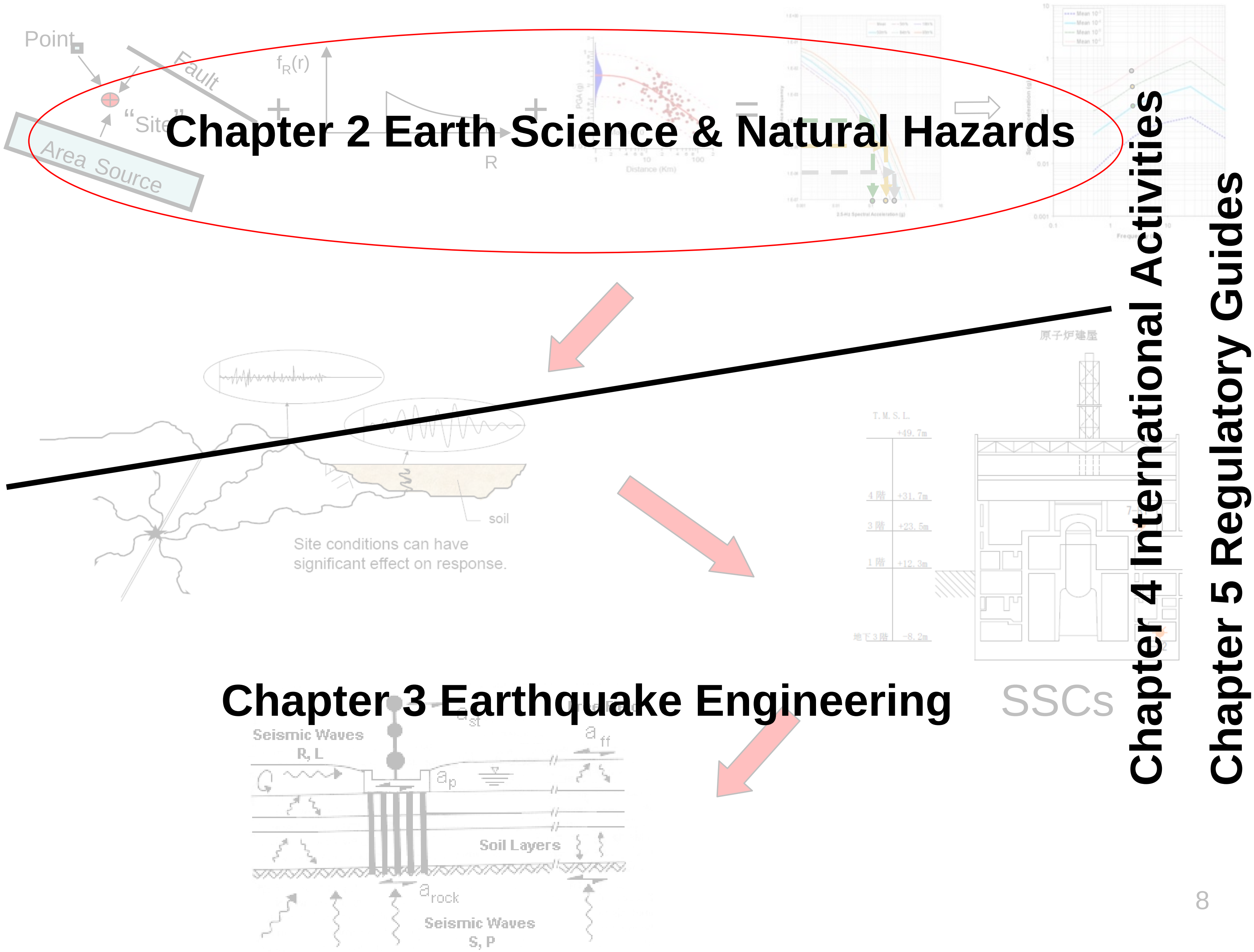
Chapter 2 Earth Science & Natural Hazards

Chapter 3 Earthquake Engineering

Chapter 4 International Activities

Chapter 5 Regulatory Guides





Chapter 2 Earth Science & Natural Hazards
Chapter 3 Earthquake Engineering
Chapter 4 International Activities
Chapter 5 Regulatory Guides
Point
Fault
"Site"
Area Source
R
soil
Site conditions can have significant effect on response.
SSCs
原子炉建屋
Seismic Waves
R, L
Soil Layers
Seismic Waves
S, P

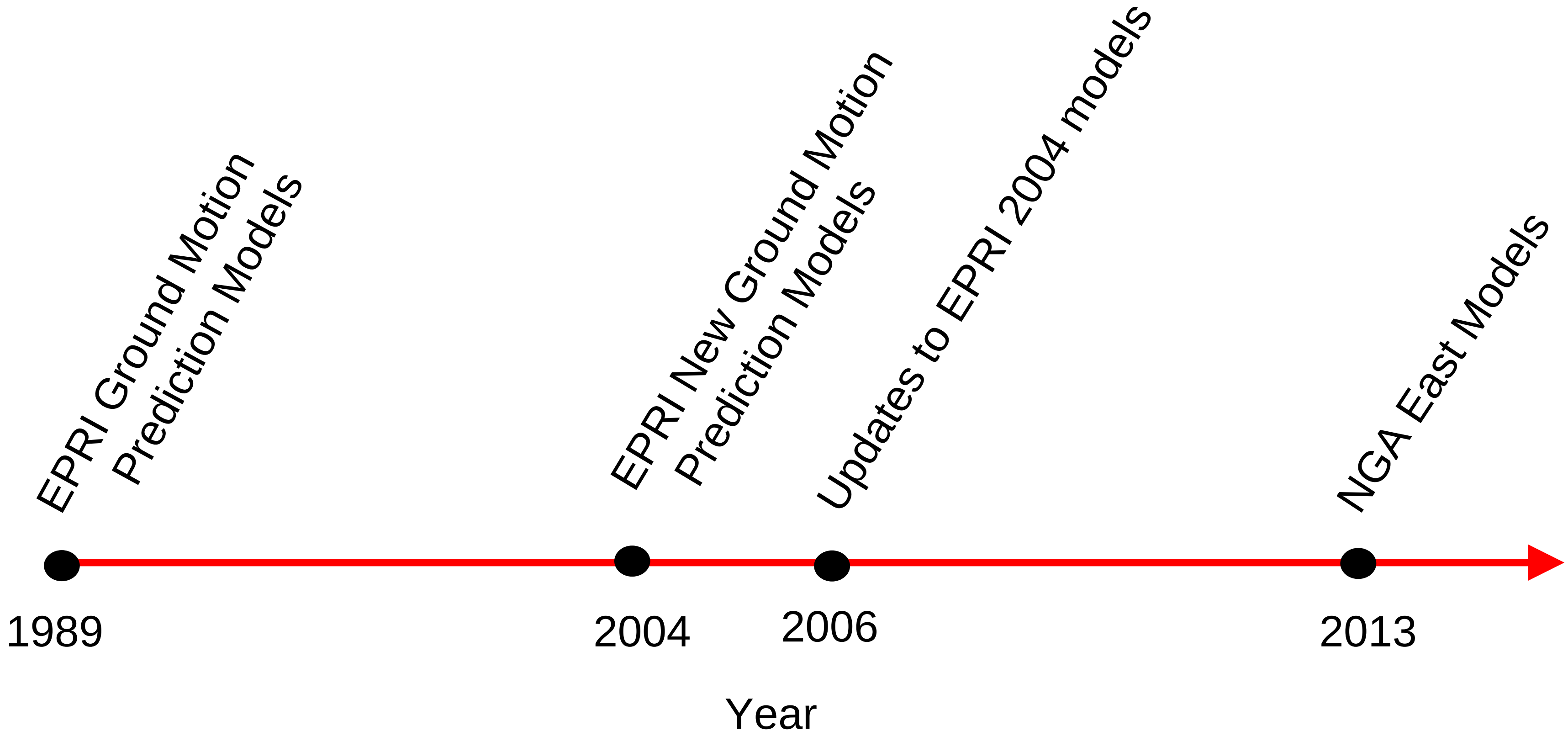
New US NRC Projects to Assess Seismic Hazard in CEUS

Source Characterization → Central and Eastern US Seismic Source Characterization project for Nuclear Facilities (CEUS SSC)

Ground motion prediction equations → Next Generation Attenuation Relationships for the Central and Eastern (NGA-East)

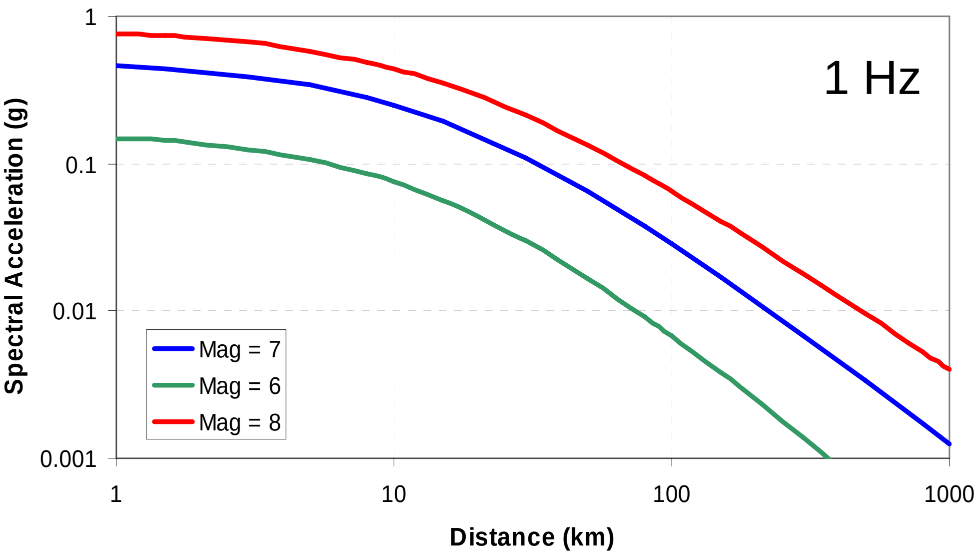
Framework for large PSHA studies → Recommendations for Application of the SSHAC Guidelines

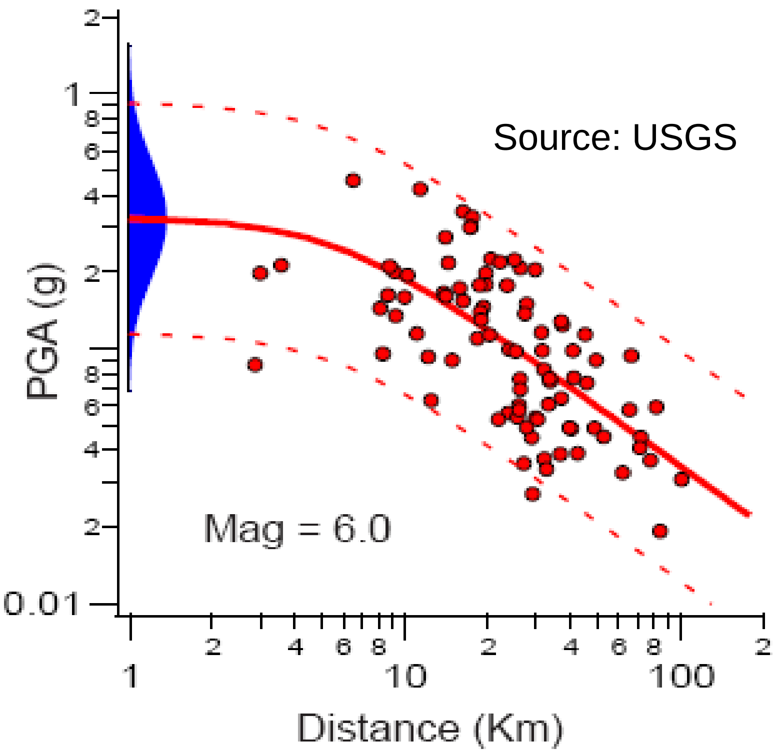
Updates to Ground Motion Prediction Models



Ground Motion Prediction Equations (aka Attenuation Relationships)

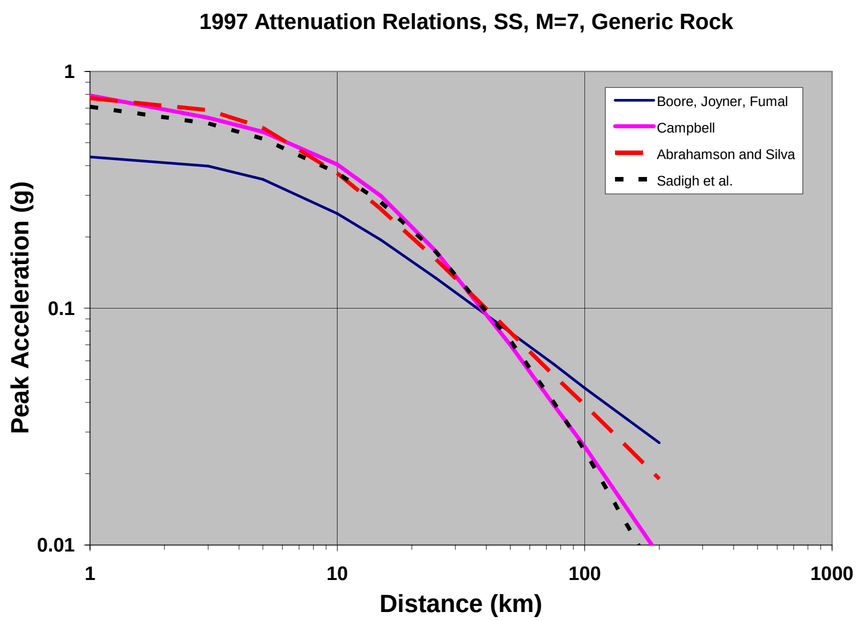
Seismic Wave Amplitudes vs. Distance



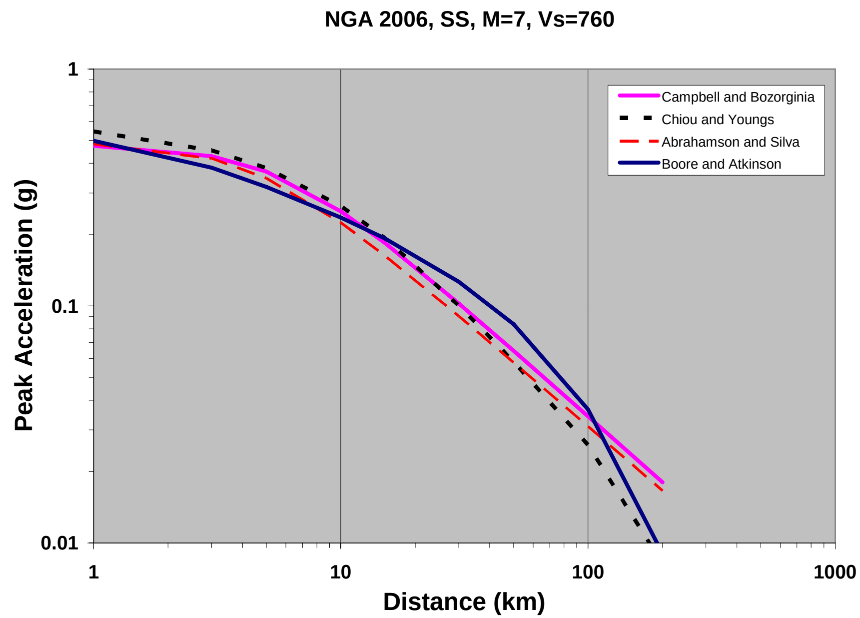


NGA-West

Before



After



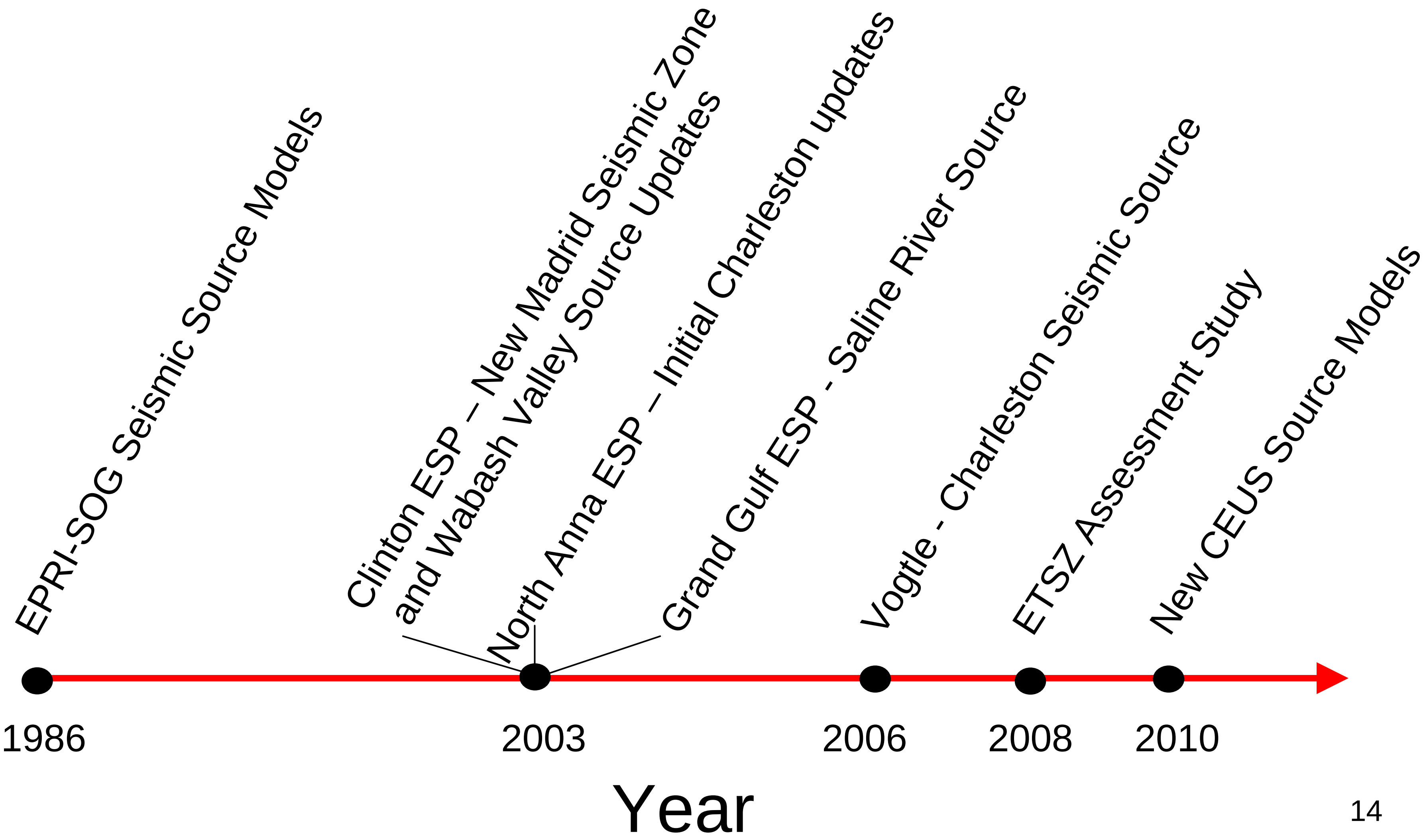
- From ad hoc relationship development to unified approach
- Mutually agreed upon databases, technical bases & assumptions
- Epistemic uncertainties reduced and characterized
- Broad community consensus (removed points of contention)

NGA-East

- **Follows up on original NGA project approach**
  - Standard agreed upon assumptions
  - Standard and complete database
  - Development program undertaken to scope project and bring in multiple agencies
- **Development completed & full project started**
  - Cooperative agreement : DOE, EPRI NEHRP
  - USGS in-kind participation in development project
- **Ongoing preliminary critical path technical work**
  - Technical Basis for assumptions
  - Development of earthquake record database

Updates to EPRI-SOG Source Models

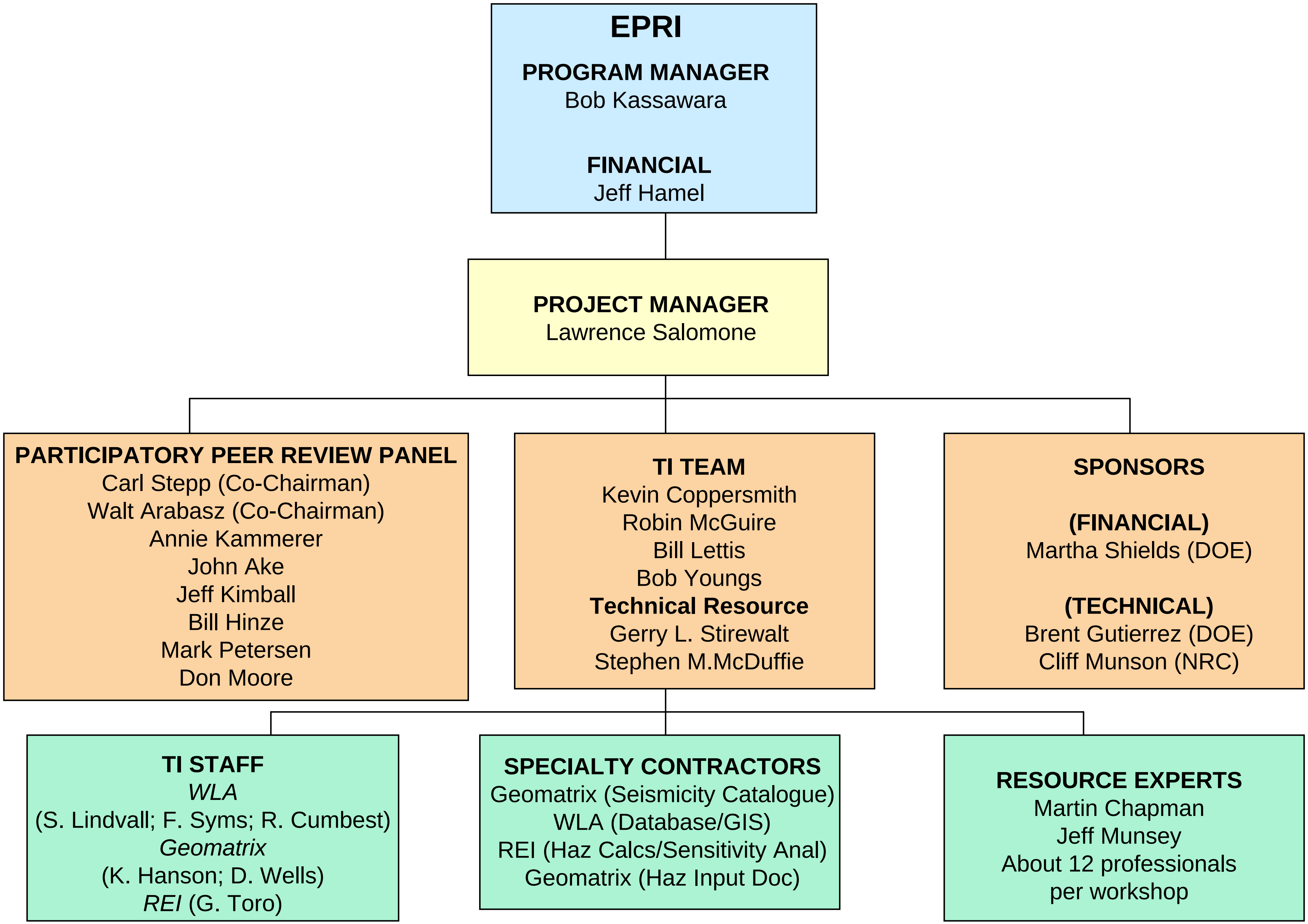
Source models are not static, they require updates as our understanding of the geology/tectonics of these sources improves



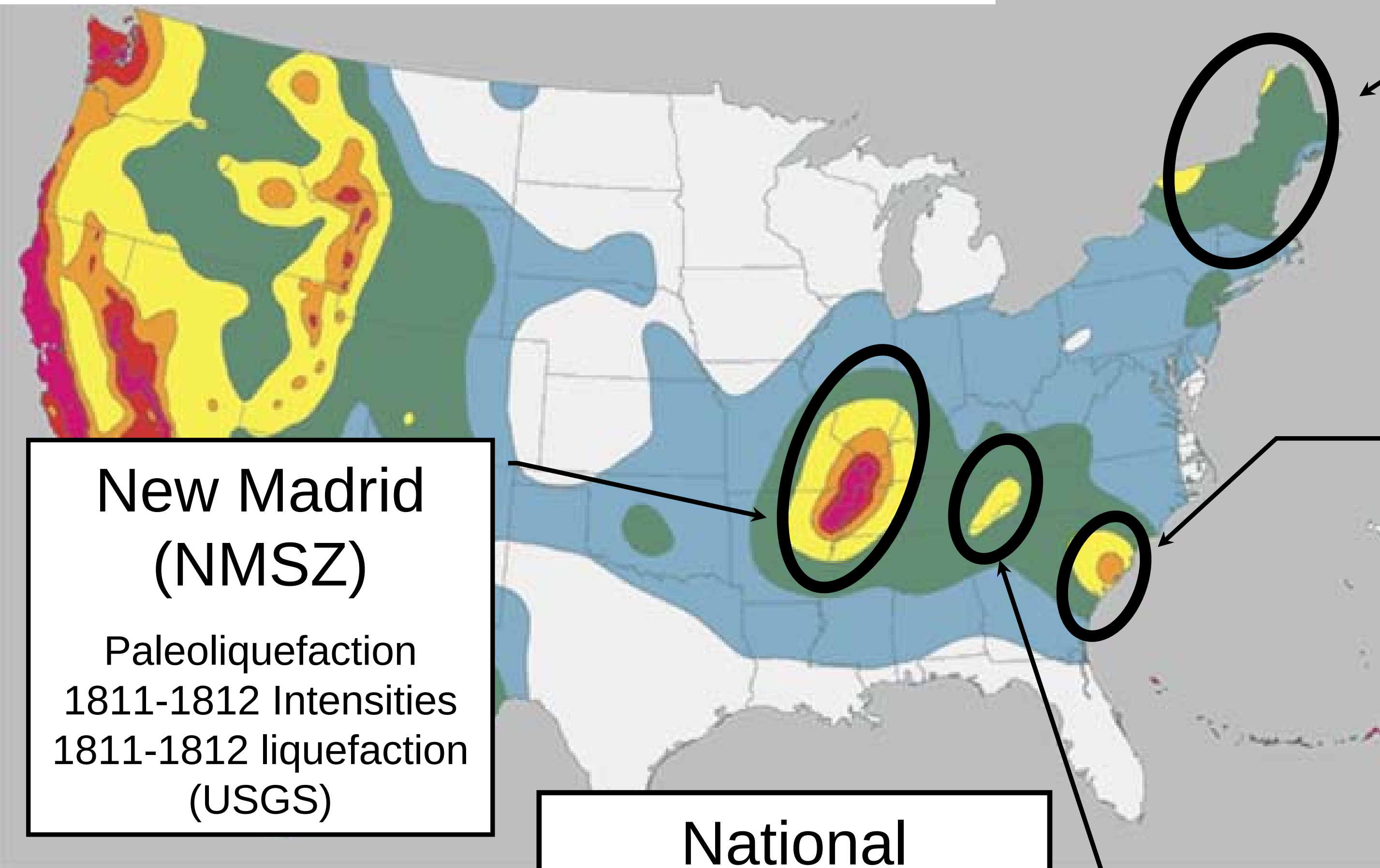
CEUS Seismic Source Characterization project for Nuclear Facilities

- Participation from NRC, DOE, EPRI, USGS, and other US specialists
- SSHAC level-3 study
- Developing a new seismic source database for the CEUS to be used as a regional model
- NPP applications will still study local sources
- CEUS SSC “International Observers Program” to allow international specialists to observe the US project firsthand

Organization Chart



Key Seismic Source Zone Updates



Northeast (NESZ)

Charleston (CSZ)

Seismic reflection reprocessing (Virginia Tech)

New Madrid (NMSZ)

Paleoliquefaction
1811-1812 Intensities
1811-1812 liquefaction
(USGS)

National

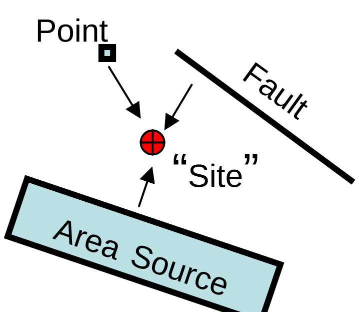
Advanced National Seismic System (USGS)

Paleoliquefaction guidelines (USGS)

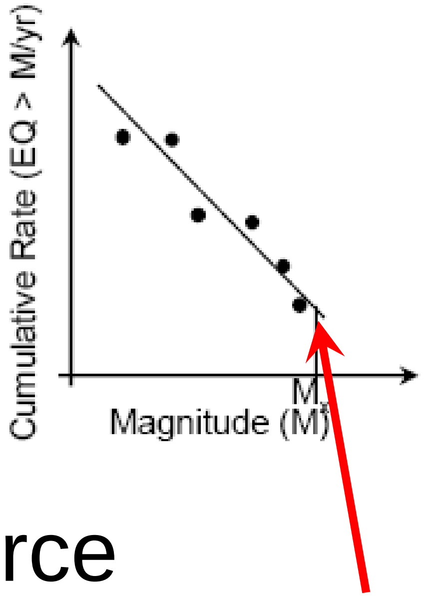
Intensity/Magnitude correlations (USGS)

Eastern Tennessee (ETSZ)

Paleoliquefaction (Univ. of Tenn)
Seismites (speleothems) (USGS)

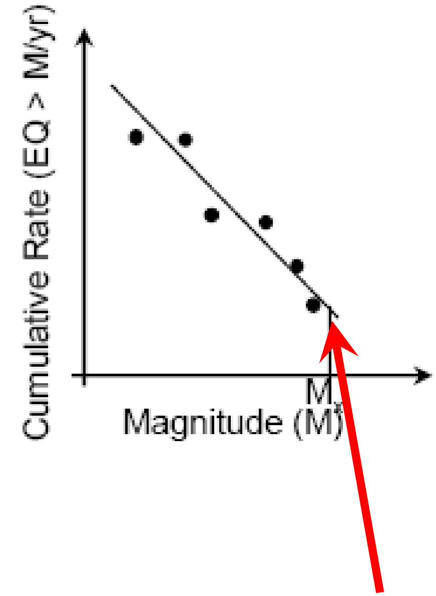


M_{max} Workshop



- M_{max} is largest magnitude for a source
- Issue for area sources in CEUS for long return periods
- Limited technical basis due to lack of systematic, integrated evaluation of existing models and new data
- Results are of interest to both USGS hazard mapping and CEUS SSC Project

M_{max} Workshop

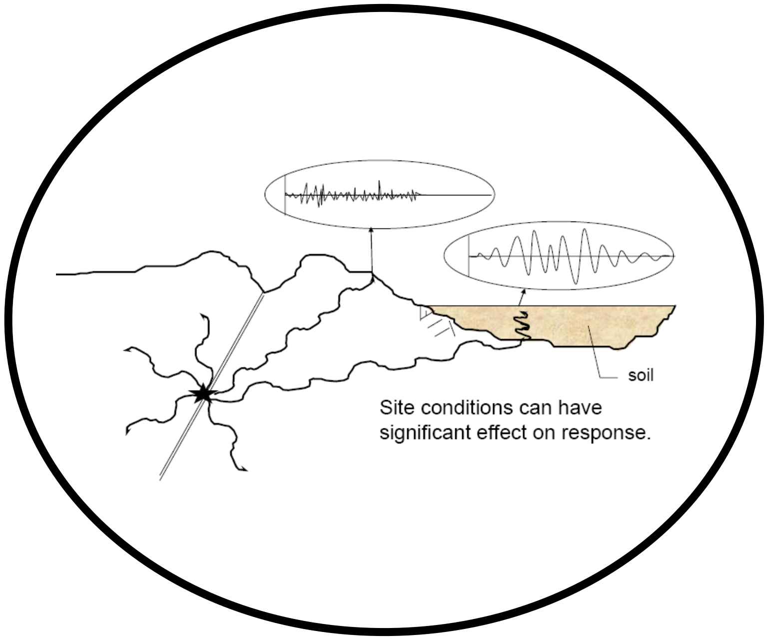


- Foundation document reviewing all past work was developed
- Sensitivity study undertaken by USGS
- M_{max} Workshop held August 08 at USGS
  - Foundation document sent to participants before workshop for review. Also downloadable.
  - Key researchers sponsored, but open to anyone
  - Developed consensus “table”

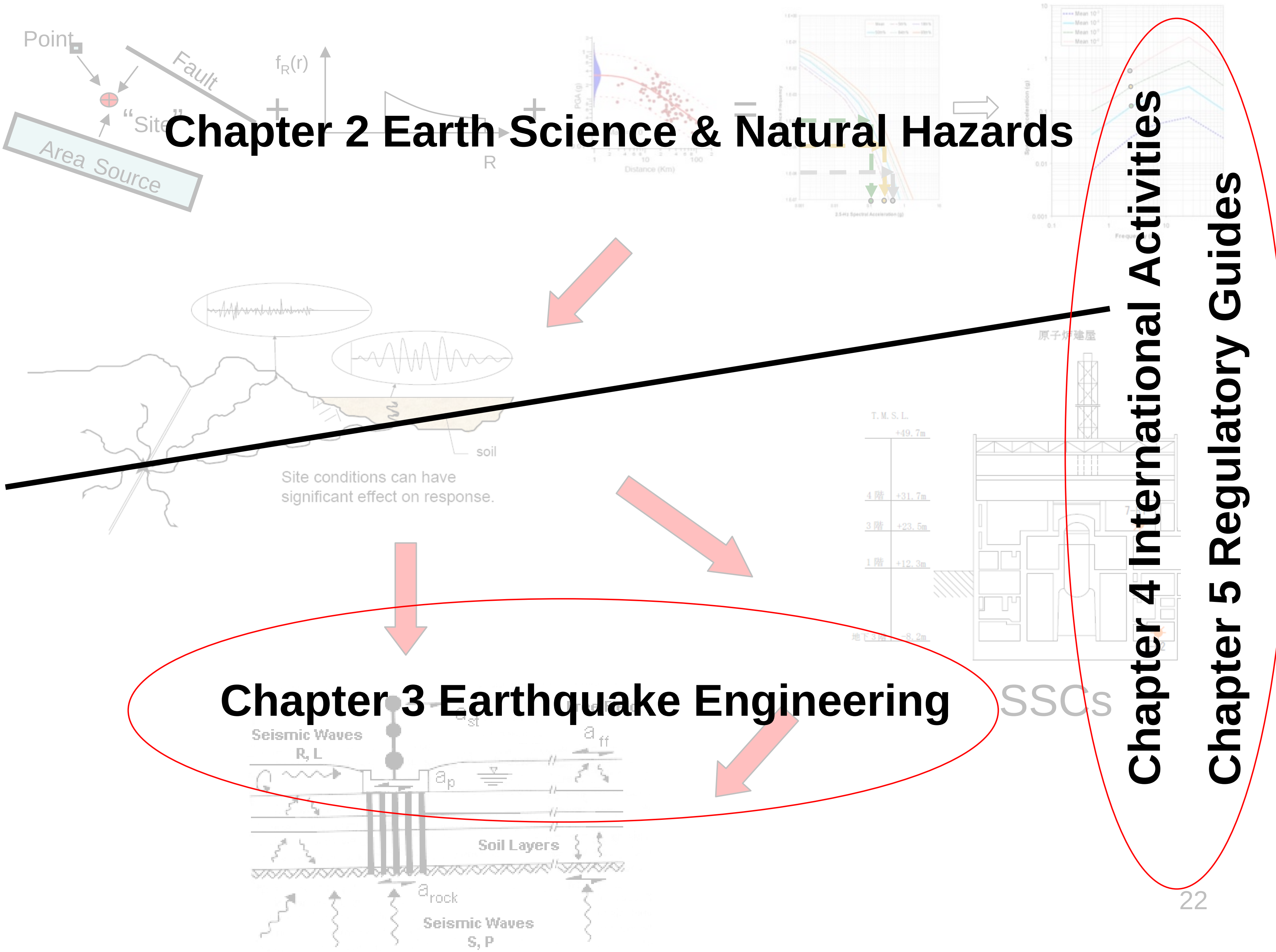
M_{max} Workshop

- Outcome of workshop was a consensus table in which possible methods for determining M_{max} were put into several bins
  - Not an acceptable method
  - Acceptable method
  - Promising, but needs more work
- Accepted 3 overall approaches
  - Global Analogues
  - Bayesian updating
  - Fault dimensions (for well characterized faults)

Random Vibration Theory & Site response methods



- Multiple methods accepted in NUREG 6728
  - Theoretical framework but few details
  - Only recently used and implementation differs
  - Focus on better understanding
- Multiple modeling tools currently in use
  - Non-linear, SHAKE, and RVT
  - Comparison of methods
  - Developing RVT software


Chapter 2 Earth Science & Natural Hazards
Chapter 3 Earthquake Engineering
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Chapter 5 Regulatory Guides
Point
Fault
"Site"
Area Source
fR(r)
R
soil
Site conditions can have significant effect on response.
SSCs
Seismic Waves
R, L
Soil Layers
Seismic Waves
S, P
Distance (Km)

Seismic Engineering

- Performance-based, Risk-informed framework
  - RG 1.208, ASCE 43-05
- Integrated application of seismic PRA in research
- Complex Load Effects in Input & Response
  - Non-vertically propagating waves
  - High frequency & incoherent waves
  - 3-Dimensional effects in structures and soil

Seismic Engineering

- NRO reviews and activities inform research
  - Advanced modeling techniques, incoherency, seismic instrumentation
- Advanced Reactor Designs
  - Aging and degradation of materials under new operating conditions
  - Base isolation technologies
  - Deep foundations and lateral earth pressures
  - New construction techniques (e.g. modular construction)

Seismic Engineering

- In-House Review of SSC Reliability Techniques
  - In-structure correlation coefficient
  - Review of probabilistic reliability methods
- International Projects
  - Joint program with Japan on testing and numerical modeling
  - KK structure and component modeling project with through IAEA
  - Smart 2008 project on numerical modeling
  - International regulatory guidance

Tsunami

- Tsunami source model development with USGS
  - – Phase 1 report used by NRC staff and industry
  - – Phase 2 under development
- Continued development of modeling capabilities with USGS and NOAA
  - – Study of near shore modeling
  - – Hazard mapping for US coasts
  - – Study of Canary Islands slide

Tsunami

- Support to NRO staff
- Regulatory Guidance
  - NOAA report on state-of-the-art analysis (finalized 2006)
  - NUREG on assessments approaches (being finalized)
  - USGS reports in sources (phase 1 report published)
  - NOAA report on global modeling (draft coming summer 09)
  - A & M report on near shore modeling (future)
  - Tsunami Regulatory Guide (future)
  - IAEA Regulatory Guidance (nearing final draft)

Summary

- Seismic Research Plan publicly available
- Key drivers are both the advancement of state of practice AND greater regulatory stability
- Integrated risk-informed approach
- Both short- and long-term planning
- Focus on consensus products
  - Community-wide consensus
  - Multiple stakeholders & sponsors

Insight and Experience with Probabilistic Seismic Hazard Analysis and Performance Based Seismic Design

Jeff Kimball
Technical Staff
Defense Nuclear Facilities Safety Board

Presentation to United States Nuclear Regulatory Commission
Advisory Committee on Reactor Safeguards
Subcommittee Meeting
April 16, 2009

Topics to be Addressed

- Performance Based Seismic Design at the Department of Energy (DOE)
- Probabilistic Seismic Hazard Analysis (PSHA) experience at the Savannah River Site
- PSHA issues relevant to current application of Performance Based Seismic Design
- Thoughts related to addressing current PSHA issues and high priority research needs

Performance Based Seismic Design for Nuclear Facilities

- First published as UCRL-15910, *Design and Evaluation Guidelines for DOE Facilities Subject to Natural Phenomena Hazards,* June 1990.

- Later published as DOE Standard 1020, *Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities,* April 1994.

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

- NRC Regulatory Guide 1.208 established A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion, March 2007.

Performance Based Seismic Design for Nuclear Facilities

- What is common between the documents listed on the previous slide is the concept of Performance Goal expressed as the mean annual frequency of unacceptable performance.

- The mean PSHA is used to establish the design earthquake response spectra.

- The next slide illustrates this concept (ASCE/SEI 43-05)

Performance Based Seismic Design for Nuclear Facilities

ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, 2005.*

Design Response Spectra Parameters				
Seismic Design Category	**Mean Hazard Frequency of Exceedance (HD)**	**Mean Annual Frequency of Unacceptable Performance (PF)**	**Ratio between HD and PF**	**Comments**
SDC3	$4x10^{-4}$	$\sim 1x10^{-4}$	4	The mean annual frequency of unacceptable performance is achieved by following the seismic design procedures contained in the standard. Important factors include; accounting for the slope of the hazard curve, acceptable seismic analysis approaches, load factors, material strength, proper seismic detailing {see ASCE/SEI 43-05 for a complete list}.
SDC4	$4x10^{-4}$	$\sim 4x10^{-5}$	10	
SDC5	$1x10^{-4}$	$\sim 1x10^{-5}$	10	

Performance Based Seismic Design at DOE

- Early PSHA work at DOE Central and Eastern United States sites was based on PSHA work completed by Lawrence Livermore National Laboratory (LLNL)– similar to LLNL work done to support the NRC Systematic Evaluation Program. UCRL-53582, published in 1984.

- Early PSHA work was replaced by EPRI/SOG (1989) and LLNL (1989, 1993); much work went into understanding differences between EPRI/SOG and LLNL leading to a revision of the LLNL work in 1993.

Performance Based Seismic Design at DOE

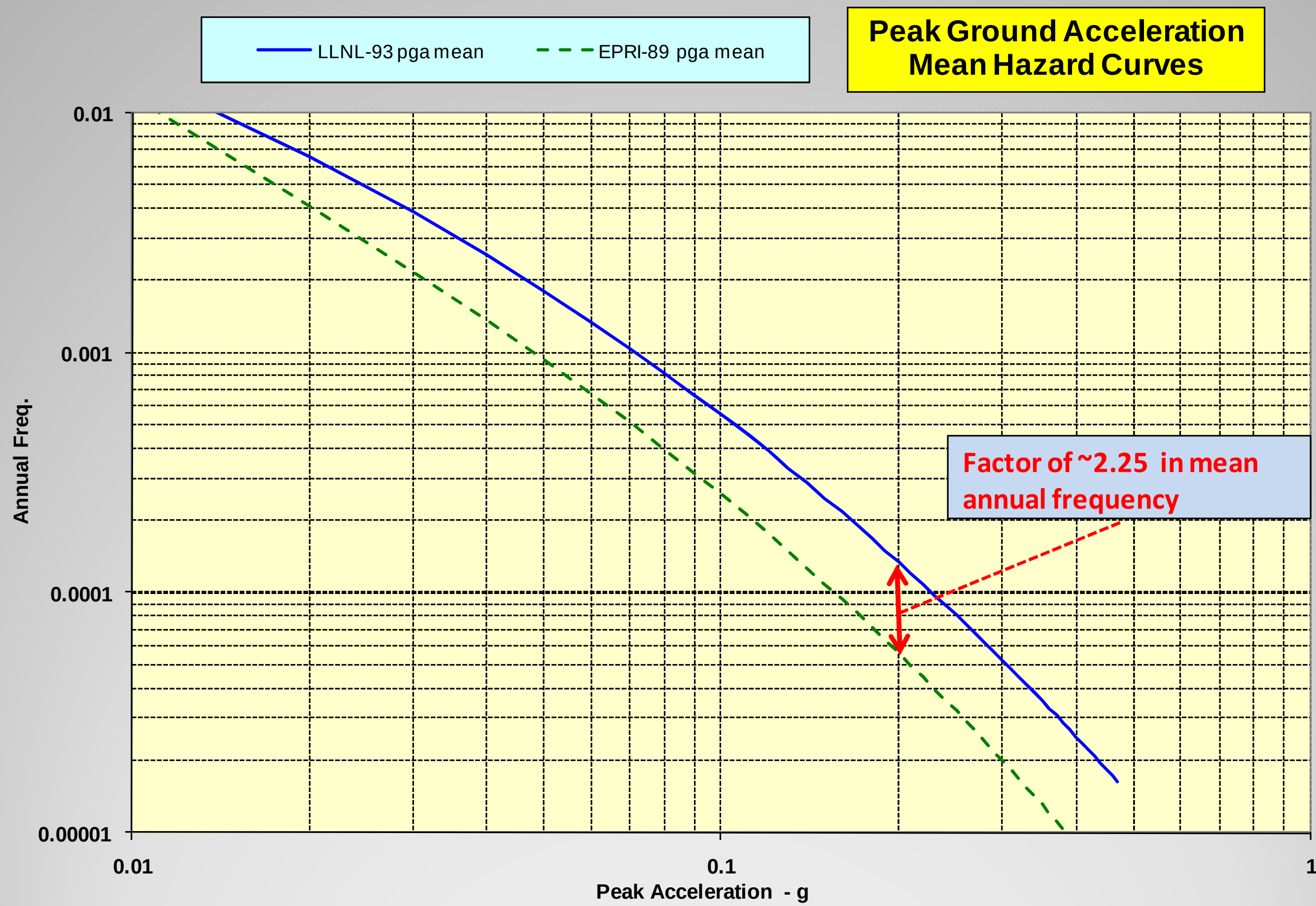
Stability in performance based seismic design depends on stability in PSHA.

In the Central and Eastern United States, DOE directed that LLNL and EPRI mean hazard curves be averaged as part of setting the site specific design motion (neither was preferred over the other). This was documented in DOE Standard 1023, *Natural Phenomena Hazards Assessment Criteria*, March 1995.

DOE supported developing *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts,* NUREG/CR-6372, April 1997 (commonly referred to as the SSHAC report).

PHSA Experience at the Savannah River Site

SRS is a deep soil site but the basic PSHA is run for hard rock site conditions



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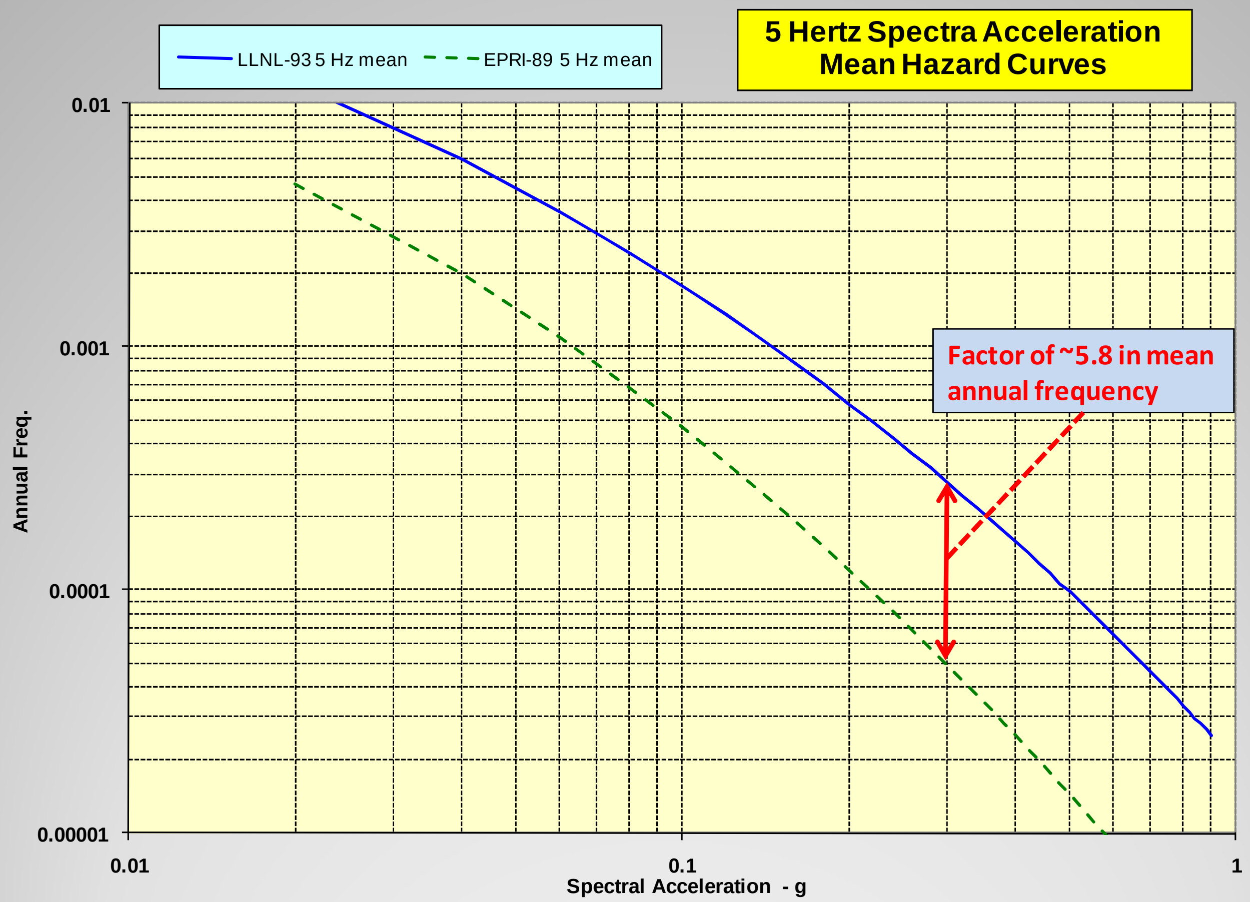

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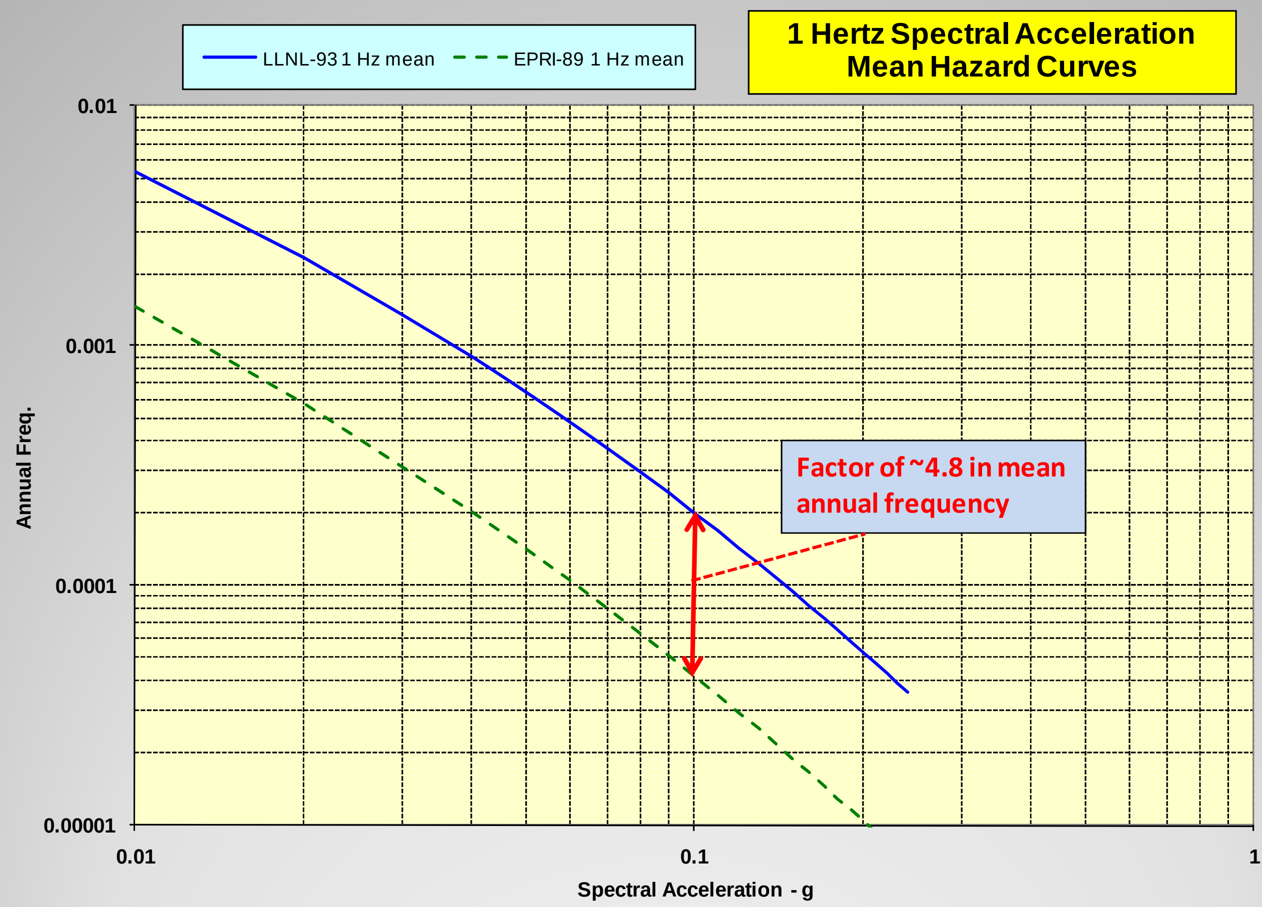


PSHA Issues Relevant to Current Application of Performance Based Design

SSHAC "Guiding Principle"

A PSHA must represent the legitimate range of technically supportable interpretations among the informed technical community and the relative importance or credibility that should be given to the differing hypotheses among the range.

If this Guiding Principle is not followed then there is little confidence that the mean PSHA is supportable.

PSHA Issues Relevant to Current Application of Performance Based Design

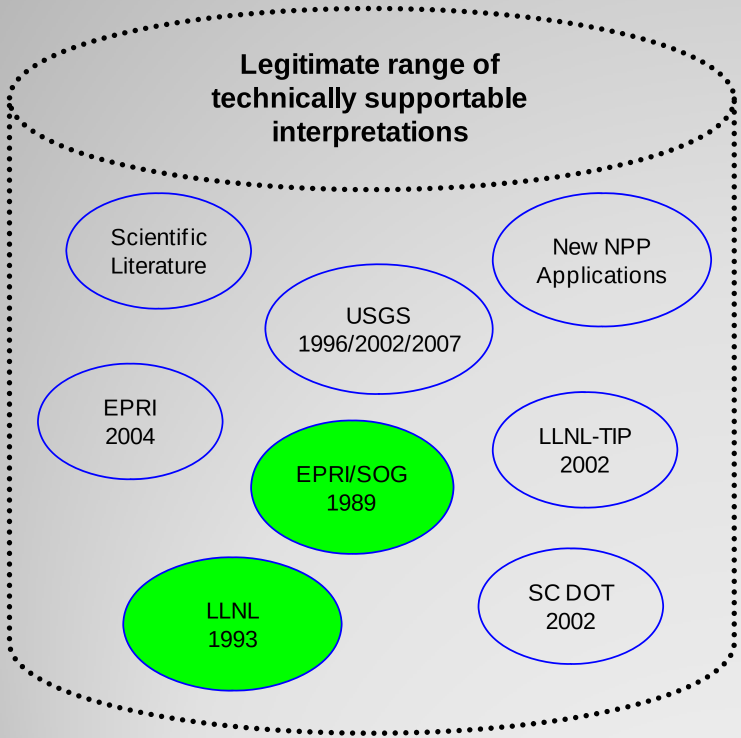
Regulatory Guide 1.208

- The PSHA language provided in RG 1.208 requires that all information be considered when developing the PSHA; this forces an applicant to explicitly consider multiple sources of information when developing the mean PSHA.

- RG 1.208 properly requires that the PSHA be conducted with up-to-date interpretations of earthquake sources, earthquake recurrence, and ground motion attenuation models.

PSHA Issues Relevant to Current Application of Performance Based Design

In CEUS, RG 1.208 allows either EPRI/SOG (1989) or LLNL (1993) PSHAs to be used as starting point.

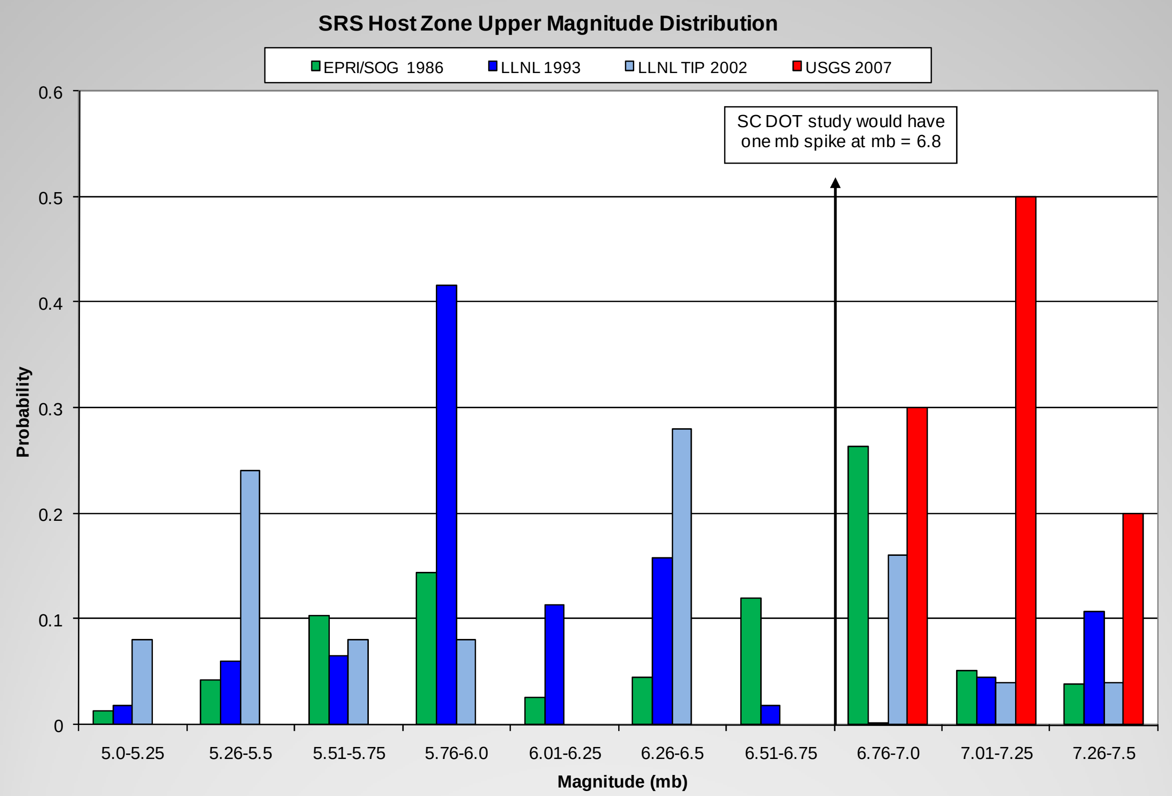


In concept, for RG 1.208 to work properly an applicant should be able to start with either "Accepted PHSA Model" and arrive at a similar mean PSHA. In practice, this is not that easy. The LLNL (1993) computational model has not been maintained.

While having a starting point is good, it is the finishing point that is critical; a mean PSHA that represents the legitimate range of technically supportable interpretations.

PSHA Issues Relevant to Current Application of Performance Based Design

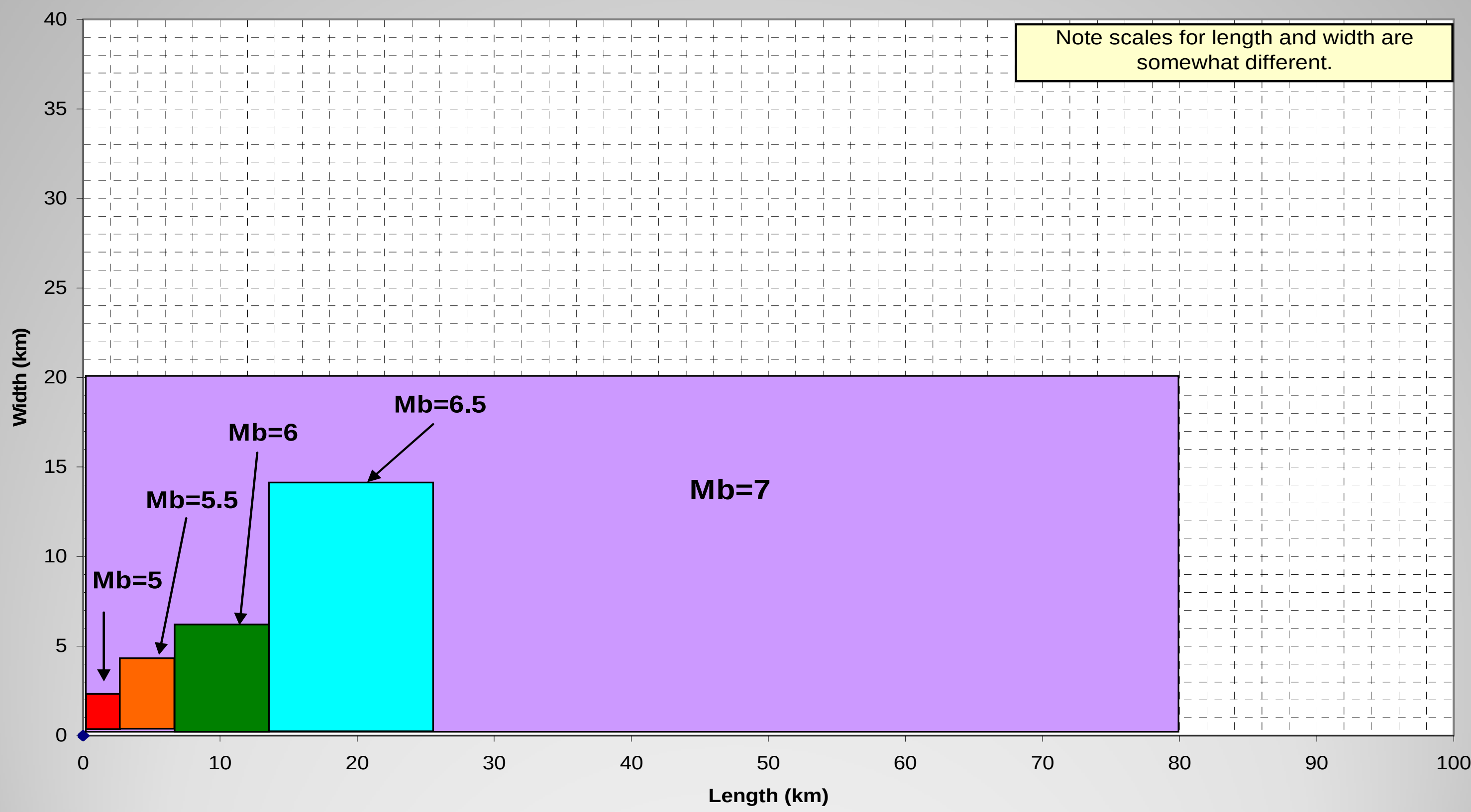
One example illustrating the difficultly of assessing the current understanding of the informed technical community is maximum magnitude to be assumed in any PSHA



PSHA Issues Relevant to Current Application of Performance Based Design

This figure illustrates another basic problem in constraining maximum magnitude;
smaller earthquakes are associated with small fault ruptures,
which in the context of the crust can be hidden anywhere

Figure 2: Earthquake Magnitude and Rupture Area



PSHA Issues Relevant to Current Application of Performance Based Design

A second example of the difficultly of assessing the current understanding of the informed technical community is related to the scale of seismic sources.

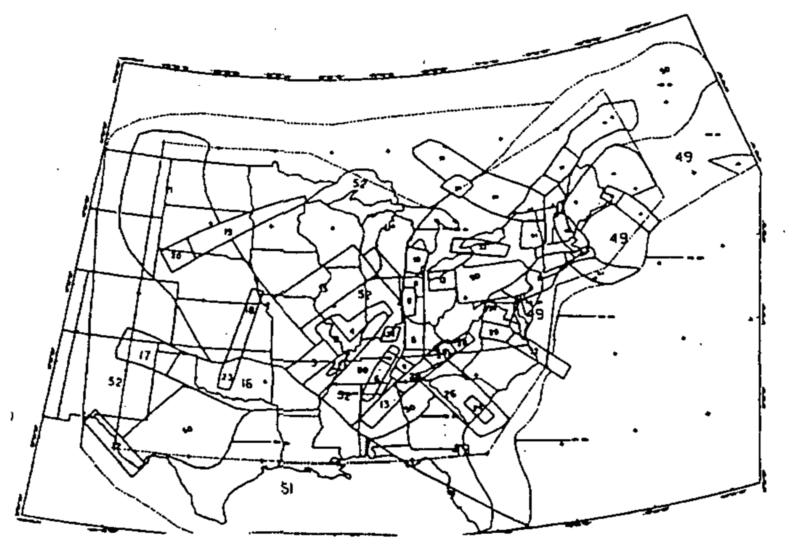


Figure 7-15 Example of an expert seismic source map.

Past PSHAs such as EPRI/SOG(1989) and LLNL (1988, 1993) include numerous seismic sources, many targeted at small features. There is a general trend to move away from such small features towards larger seismic source zones, or allowing for smoothed seismicity to substitute for seismic zones.

PSHA Issues Relevant to Current Application of Performance Based Design
Thoughts related to addressing current PSHA issues

- The intent of RG 1.208 is laudable but implementation is complex – "*any new information related to a seismic source that impacts the hazard calculations must be evaluated and incorporated into the PSHA as appropriate based on the technical information provided*" - in the context of a PSHA, new information inherently requires understanding the current views of the informed technical community.

- The inference that one could start with LLNL (1993) is not practical, and does not reduce the implementation complexity – the mean PSHA must be appropriate today. Applicants and NRC must ensure that starting with EPRI/SOG(1989) results in a PSHA that captures the legitimate range of technically supportable interpretations among the informed technical community.

PSHA Issues Relevant to Current Application of Performance Based Design
Thoughts related to addressing current PSHA issues

- While there are a number of PHSA issues being updated (Charleston, New Madrid, Wabash Valley are examples), additional PSHA sensitivity studies should be used to assess the impact of potential PSHA issues of regional significance, taking the burden away from individual applicants. Issues such as maximum magnitude and seismic source scaling may require additional sensitivity studies.
- Completing the CEUS Seismic Source Characterization for Nuclear Facilities project will ultimately advance the stability of PSHA

PSHA Issues Relevant to Current Application of Performance Based Design
High Priority Research Needs

1. Compatibility of rock and ground surface PSHA, and the associated issue of determining the Uniform Hazard Spectra at foundation levels. Advance the understanding of site response assessment and integration into site-specific PSHAs. This includes methods for taking site data and generating acceptable site profiles, criteria for reviewing adequacy of site profiles, development of advanced site response models that are fully integrated into a site-specific PSHAs, and studies to integrate site response modeling and soil-structure interaction analysis.

2. Advance the understanding of paleoliquefaction evidence and how it should be considered in PSHAs. There are many CUES regions that show some evidence of paleoliquefaction. Evaluation of these paleoliquefaction sites requires established procedures integrating geologic, seismologic, and geotechnical data and analyses. Such procedures are lacking. There are considerable uncertainties in age dating, the influence of site response, the assessment of magnitudes for paleoearthquakes, and associated recurrence rates.

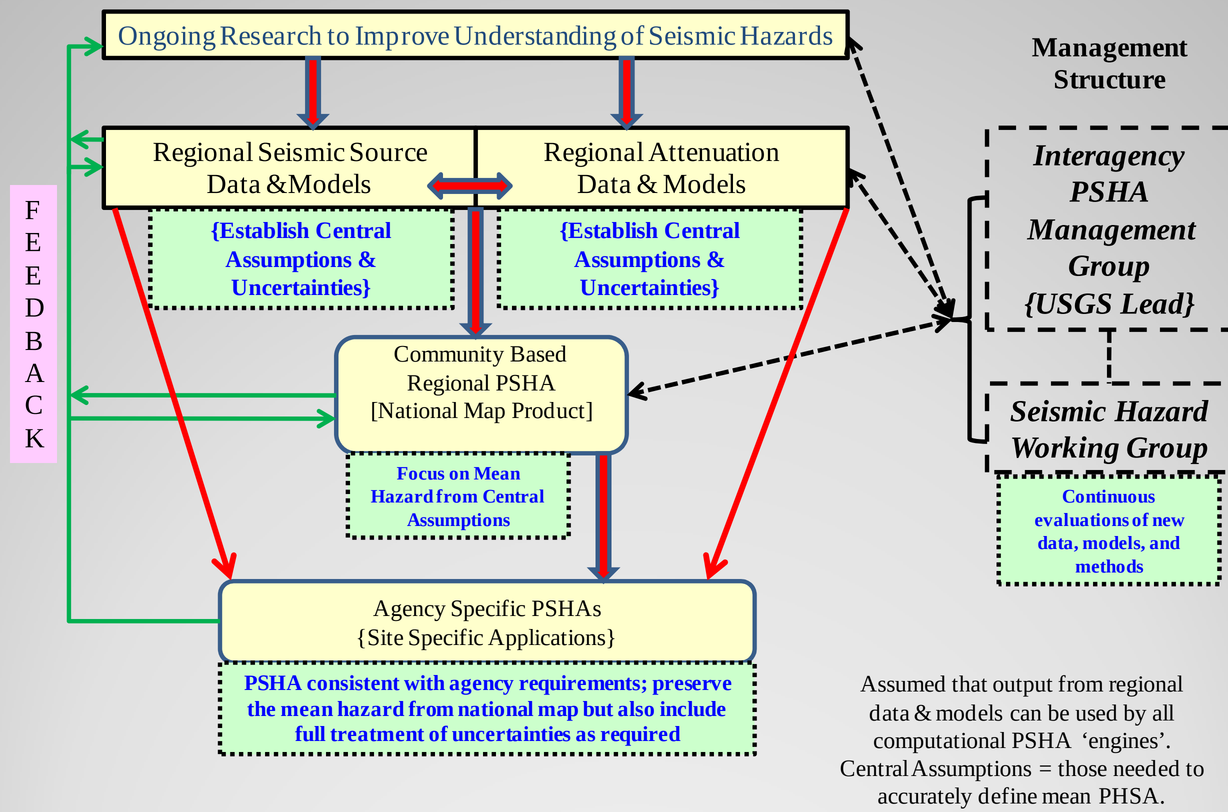
PSHA Issues Relevant to Current Application of Performance Based Design
High Priority Research Needs

3. Advance the understanding of ground motion attenuation in the CEUS. The Next Generation Attenuation Project for the CEUS is critically needed.

4. Advance the concept of developing a community based PSHA for the CEUS. While not strictly research, this would build on NRC work to develop Practical Procedure for Implementing the SSHAC Guidelines. The general framework is provided on the next slide. This concept will take some time (>10 years) to put in place. The intent is for the entire PSHA community (Government, Industry, Academia) to work together, avoiding the considerable resources that are required to discuss and debate differences between PSHA results for a given site.

PSHA Issues Relevant to Current Application of Performance Based Design

FIGURE 1: COMMUNITY BASED CEUS PSHA OVERALL APPROACH



Conceptual Approach for Developing a Community Based

Central and Eastern United States Probabilistic Seismic Hazard Analysis

White Paper

Jeff Kimball, Defense Nuclear Facilities Safety Board

June 2, 2008

The United States Nuclear Regulatory Commission (NRC) is sponsoring a project on developing practical procedures for implementation of the Senior Seismic Hazard Analysis Committee (SSHAC) guidelines for updating existing probabilistic seismic hazard analysis (PSHA). The purpose of this paper is to outline steps that can be taken to improve the approach to developing a community based PSHA, with specific focus on the Central and Eastern United States (CEUS). As part of developing this approach the following current PSHA conditions are recognized.

- The LLNL (1993) and EPRI-SOG (1989) PSHA studies are now 15 to 20 years old. Differences (both numerical and procedural) between these two landmark studies led, in part, to development of additional PSHA guidance published as the SSHAC report (*Recommendation for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, NUREG/CR-6372, April 1997*).
- The United States Geological Survey has published the national seismic hazard map in 1996, 2002, and most recently in 2007. The approach used to develop the national seismic hazard map utilizes interactive workshops with the intent of discussing and documenting the views of the informed scientific community. The national seismic hazard map is used to inform seismic design decisions for building codes. The use of PSHA results from the national hazard map for nuclear applications is subject to debate and controversy.
- The re-emergence of the commercial nuclear power industry has resulted in modifications to the EPRI-SOG (1989) seismic source characterization material. The nuclear industry has also sponsored the development of an updated ground motion attenuation model published as EPRI (2004). Given that this work started with the EPRI-SOG(1989) seismic source material, questions have been raised regarding the need to update all seismic source characterization given the vintage (1980’s) of the originating work.

Past experience has demonstrated that considerable resources are required to discuss and debate differences between PSHA results for a given site. While the intent of the SSHAC guidelines is to establish PSHA procedural actions that would minimize these differences, we are still in the situation where multiple PSHAs result in significant differences in ground motion estimates for a given annual frequency. The bottom line is that current applications of the SSHAC PSHA process can be improved. This would be avoided if the community were to agree that CEUS PSHA, at least at a broad regional level, will be a community product. Everyone would agree to use that product, and that product would be the foundation of the national seismic hazard map.

Currently the USGS plans on revising the national seismic hazard map in 6 years. There are people in the scientific community who view the USGS maps as intentionally conservative, or who may view the EPRI/SOG PSHA modifications as incomplete. The concept proposed in this paper is not intended to debate or resolves these differences of view. The scientific community needs to develop the view that seismic hazard is hazard and all PSHA developers and users need to buy into the PSHA product. Given that the USGS is a critical part of the technical community it is important that a community based CEUS PSHA involve the USGS in an active lead role.

In addition to the USGS PSHA work, the NRC, DOE, and EPRI have also initiated efforts to update PSHA related products. The NRC is organizing an effort to advance the state of practice in CEUS ground motion modeling through a project titled Next Generation Attenuation Models for the Eastern United States. NRC, DOE and EPRI have initiated a project related to updating seismic source characterization input to PSHAs. These efforts should be finished in the next several years, but it remains to be seen if and how this work gets integrated into the national seismic hazard mapping program.

Stability and defensibility are two of the major attributes typically expressed by sponsors of PSHA studies. This holds true for government sponsors such as the USGS, NRC or DOE, or industry related sponsors such as individual nuclear utilities or EPRI. The intent of SSHAC is to provide procedural guidelines that if followed will result in a PSHA product that achieves stability and defensibility. Given this common intent, mutually beneficial synergism will be realized if government and industry come together to promote and develop a community based PSHA following the SSHAC guidelines.

Given the CEUS PSHA situation today, planning for and achieving a community based PSHA will take time. This requires developing a long term view, a vision for the next 10 to 15 years. The first step to advancing this concept is to broadly define roles and responsibilities for all of the stakeholders that would be involved with this effort. The stakeholders fall within three broad categories: Government, Industry, and Academia. Fundamentally, the government is responsible for ensuring that its citizens are appropriately protected from seismic hazards. All agency specific work derives from this fundamental role, with each agency developing their own regulations and requirements depending on mission. In a similar way industry is responsible for their particular facility or activity, ensuring that appropriate seismic safety actions have been taken to protect the public or workers. Industry is clearly interested in ensuring that seismic hazards are properly characterized and PSHA results represent the best product given cost and schedule implications of complying with any applicable seismic requirements. Finally academia supplies the pipeline of talent and focuses on research, attempting to advance the understanding of seismic hazard related issues. These general roles provide the overall framework for developing more specific roles and responsibilities.

- Government: Would own and manage the community based PSHA product. To support an enduring community based CEUS PSHA, this role requires a commitment to fiscally support this effort from year to year. The USGS could be the lead agency for executing this role. While all government agencies have a stake in this effort, there is likely to be a small sub-set of agencies that would supply the funding support for this work.

- Industry: Would be a forcing function, taking the lead in addressing specific PSHA issues of significance. Given the considerable epistemic uncertainties that are commonly associated with CEUS PSHAs, reducing those uncertainties may have a significant cost impact on future industry decisions. Funding for this work could come from both the government and industry.
- Academia: Expertise and research capability addressing specific technical issues.

The development of a community based PSHA would also improve the link between how ongoing research impacts the assessment and reduction of epistemic uncertainties.

<u>CEUS Community Based PSHA – Framework</u>

The overall framework for developing a Community Based CEUS PSHA is shown on Figure 1. The framework has 4 major components: (1) Ongoing research to improve understanding of seismic hazards; (2) The development of regional seismic source characterization and regional attenuation models and data; (3) The computational PSHA engine that creates the community based regional PSHA {the national seismic hazard map}; and (4) the recognition that Agencies will need to execute site specific PSHAs. The red arrows on Figure 1 show the flow of information. The green arrows show the flow of feedback. The envisioned management structure is based on 2 managing groups; (1) an Interagency PSHA Management Group, led by the USGS; and (2) a Seismic Hazard Working Group that would supply the technical oversight of the approach. Fundamental to this concept is the following:

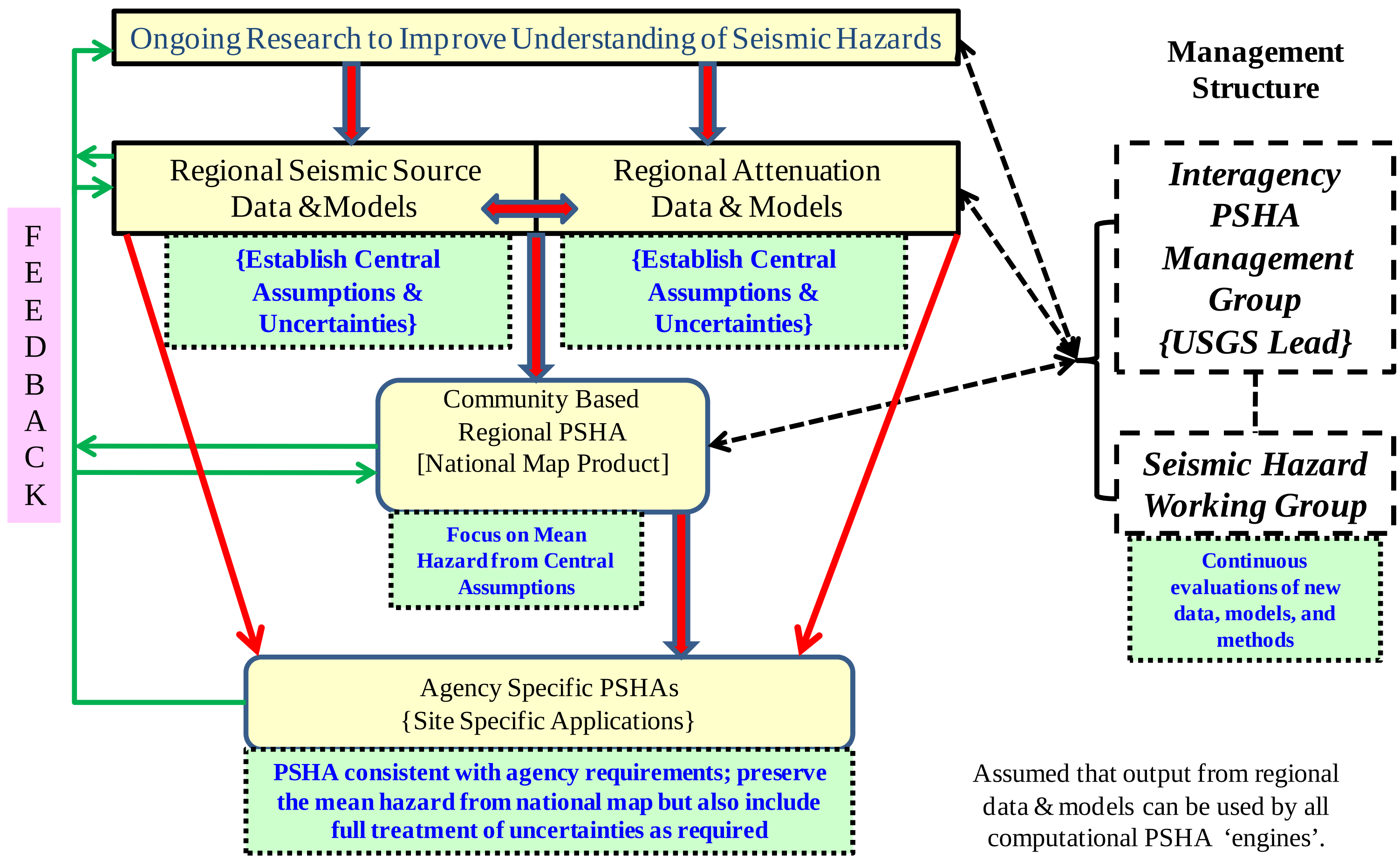
- Agree that the CEUS community based PSHA product would be that used to develop the national map product. Revise the national map revision duration from 6 to 9 years.
- Establish long term PSHA update target: given the current USGS map revision and NRC/DOE/industry PSHA efforts the suggested community based PSHA target date is ~2022. The ongoing PSHA efforts of NRC, DOE, and EPRI, and the next version of the USGS national map (2013) would serve as a "PSHA bridge" to the development of a CEUS community based PSHA.
- Establish an Interagency PSHA Management Group to be led by the USGS. Those agencies supplying funding to the CEUS Community Based PSHA efforts would be represented on the Working Group. The Working Group is made up of federal employees. This working group could be an adjunct to the current Interagency Committee on Seismic Safety in Construction (ICSSC) which is led by NIST. One issue that needs to be discussed is whether industry should be represented on the Management Group.
- Establish a Seismic Hazard Working Group to support the Interagency PSHA Management Group. The Seismic Hazard Working Group is made of up PSHA experts that would advise the Management Group on those actions needed to support the long term plan on developing/updating the CEUS community based PSHA. The Seismic Hazard Working Group is made up of PSHA experts from the government, industry, and academia.

- Under the direction of the Management Group, establish a PSHA community status meeting, to be held at the same time as the Eastern Section of the Seismological Society of America Meeting. This would be a one day meeting with the purpose of reviewing key PSHA research outcomes, with focus on the next 2-3 years of research. Holding the meeting at the Eastern SSA venue would promote involvement of the hosting university and engage new expertise into the effort. This effort is the continuous improvement aspect, eventually the feedback mechanism where PSHA products influence ongoing research, data and model development.
- The Seismic Hazard Working Group would be responsible for developing a community based PSHA Update Plan. This Plan would have long term actions (out to 9 years), and short term actions (out to 3 years). The short term actions would provide an opportunity to explicitly link research activities to PSHA focus areas. This plan would be revised annually. This plan would identify the funding commitments and actions to be taken.

In summary, the overall framework of developing a CEUS community based PSHA has been outlined. The development of a CEUS community based PSHA will ultimately save time and money, by providing a product that has stability, defensibility and longevity. Such an approach breaks down the barrier that SSHAC is only for critical facilities. The USGS national seismic hazard map explicitly becomes SSHAC based. For this vision to become reality it is critical that the USGS as an agency support this idea. This will require identification and resolution of any issues that the USGS identifies with the concept.

The next step would be to take the concept and turn it into a plan of action. To achieve this it is recommended that a Steering Group be formed to advance the concept. The Steering Group would be the people who would interact with the USGS and other organizations such as the ICSSC and industry partners such as EPRI. All parties that utilize PSHA have an interest in making the concept work. A CEUS community based PSHA will improve interagency communication, improve the working relationship between government and industry, improve the link between research and PSHA products, while minimizing PSHA conflicts ultimately saving time and money. This allows for continued progress towards reducing seismic risk in the CEUS.

FIGURE 1: COMMUNITY BASED CEUS PSHA OVERALL APPROACH



Assumed that output from regional data & models can be used by all computational PSHA 'engines'. Central Assumptions = those needed to accurately define mean PHSA.

Senior Seismic Hazard Analysis Committee (SSHAC) Update Project

Jon Ake and Annie Kammerer
Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Presentation to ACRS
April 16, 2009

Outline

- Background of SSHAC
- Motivation for present study
- Observations from previous studies
- Lessons learned and implementation recommendations
- Updates to PSHA's and recommendations
- Status of study and path forward

Senior Seismic Hazard Analysis Committee (SSHAC)

- A group of senior experts assembled to evaluate the differences between the EPRI and LLNL studies and provide guidance on the conduct of PSHA.
- Concluded the differences in the results were primarily procedural rather than technical. The report focused on the appropriate use of experts (NUREG/CR-6372: SSHAC (1997)).
- Problems identified from past studies
  – Overly diffused responsibility
  – Insufficient face-to-face interaction
  – Inflexible aggregation schemes
  – Imprecise or overly narrow objectives
  – Outlier experts
  – Insufficient feedback

Steps in Expert Elicitation/Assessment

- SSHAC Report (1997)
  - Identification and selection of technical issues
  - Identification and selection of experts
  - Discussion and refinement of the technical issues
  - Training for elicitation
  - Group interaction and individual elicitation
    - Information Meetings
    - Issue Interaction and Data Needs Review
    - Post-elicitation Feedback and Interaction
  - Analysis, aggregation, and resolution of disagreements
    - The role of Technical Facilitator Integrator (TFI) as a facilitator
    - The role of TFI as an integrator
  - Documentation and communication

Epistemic Uncertainty in PSHA: SSHAC Recommendations

SSHAC (1997): PSHA studies should characterize both epistemic and aleatory uncertainties

- Not enough to do aleatory alone
- Not enough to do total uncertainty alone

Recognize our partitioning represents a snap-shot in time of the state-of-knowledge of the community

Variability and Uncertainty

- ***Aleatory Variability***
  - Natural randomness in a process
  - Accommodated in the hazard integral
  - Affects the shape of the hazard curve
- ***Epistemic Uncertainty***
  - Scientific uncertainty in our models of the process
  - Incorporated through logic trees
  - Leads to alternative hazard curves (fractiles)
- Avoid double counting
  - Need well defined procedure to track aleatory and epistemic components

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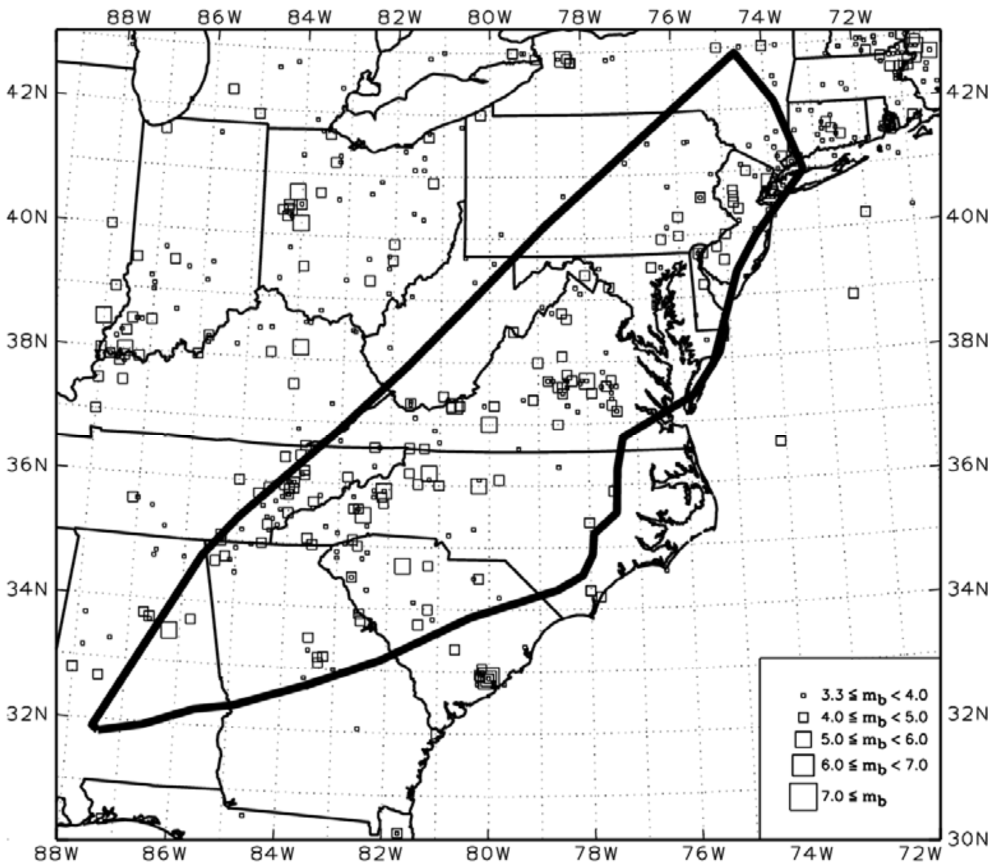
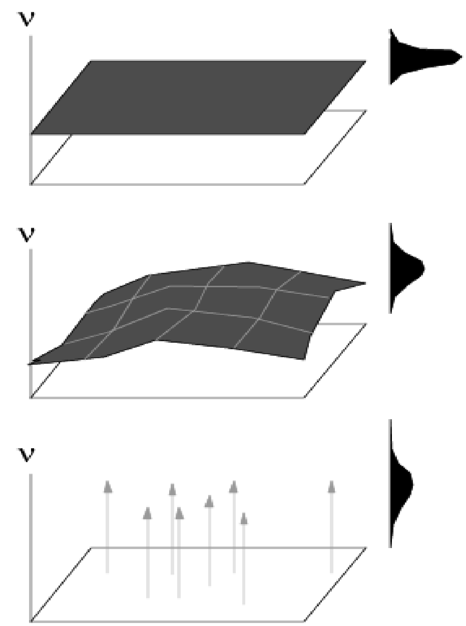
Illustration of model dependence: alternative models for area source





Courtesy of G. Toro, Risk Eng.

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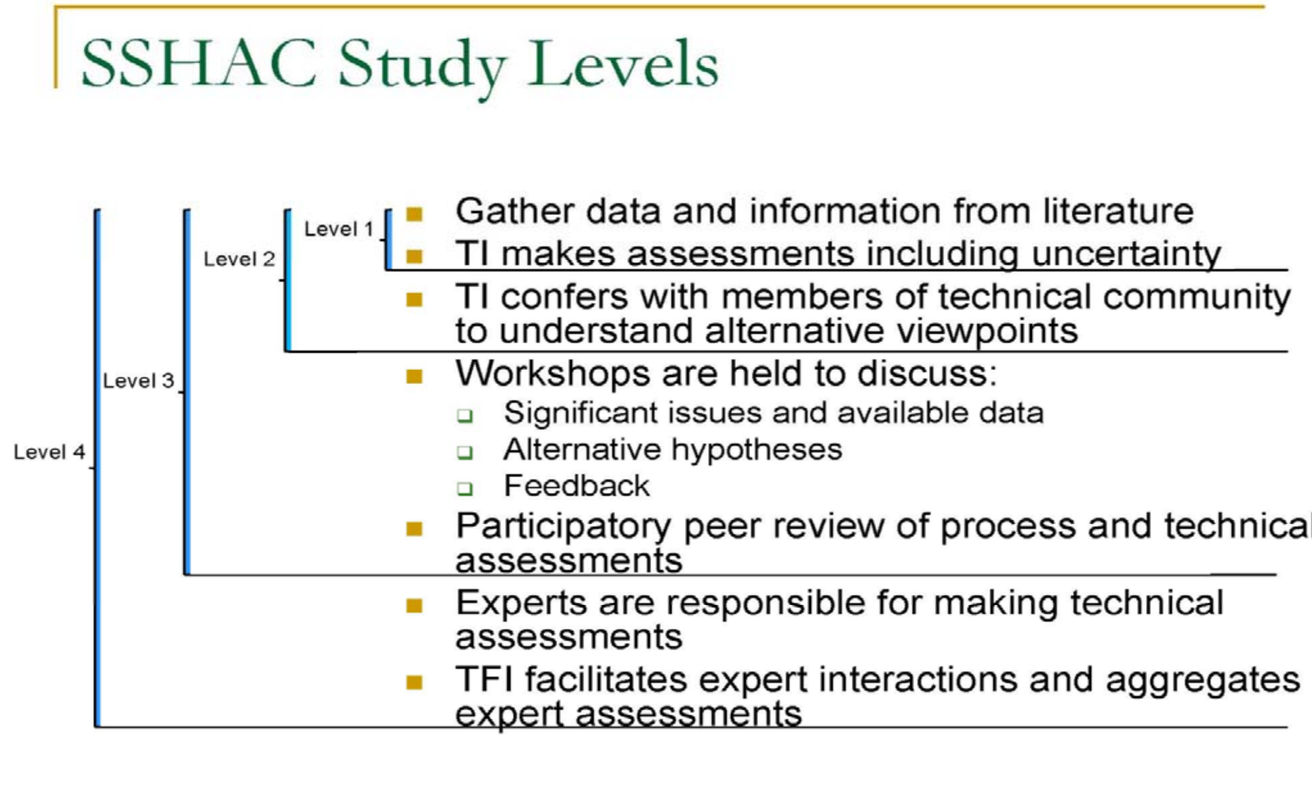
SSHAC Framework



Courtesy of K. Coppersmith

TI: Technical Integrator
TFI: Technical Facilitator Integrator

Goal of SSHAC

- "Regardless of the scale [level] of the PSHA study, the goal remains the same: to represent the center, body and range of technical interpretations the larger informed technical community (ITC) would have if it were to conduct the study." [**The Community Distribution**]
- "Center" is the median of a set of models that purport to do the same thing, "range" reflects the upper and lower bounds about this median, and "body" is the shape of the uncertainties (alternative models) about the median.
- ***Satisfying these expectations is difficult in practice.***

SSHAC Guidelines Update Project

- Satisfying the goal of capturing the Community Distribution is challenging. *The SSHAC process and framework outlined in NUREG-CR/6732 is still appropriate.*
- The SSHAC report dealt with the problem from a conceptual standpoint. The process has now been applied in several major studies. The goal of this project is to capture that experience to augment the original SSHAC report. The project will focus on practical implementation issues.
- Project being led by USGS-Menlo Park.

Previous Studies

- *EPRI-SOG (pre-SSHAC Guidelines)*
- *LLNL (pre-SSHAC Guidelines)*
- *DCNPP Studies (pre-SSHAC Guidelines)*
- *SATSOP (pre-SSHAC Guidelines)*
- **Yucca Mountain PSHA (Level 4)**
- **Yucca Mountain PVHA (Level 4)**
- **EPRI Ground Motion Study (Level 3)**
- **PEGASOS Study (Level 4)**

Ongoing Studies

- BC-Hydro: Level 3 study for source characterization and ground motion estimation. Regional study.
- CEUS-SSC: Level 3 study for source characterization of central and eastern U.S. Regional study.
- South Africa: Level 3 study for source characterization and ground motion estimation.

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SSHAC Implementation Workshops

- Workshop #1: Lessons learned from SSHAC Level 3 and 4 PSHA's, January 30-31, 2008
- Workshop #2: Updates to existing PSHA's, May 6-7, 2008
- Workshop #3: Draft Recommendations, SSHAC Implementation Guidelines, June 4-5, 2008.
- About 40 participants in each workshop.

Lessons Learned: What Works?

- Expert roles as evaluators
- Data development and dissemination; if feasible, focused new data collection
- Expert interactions in facilitated workshops
- Feedback: group and individual; components and results
- Large, public studies build confidence in the technical community and regulatory community
- Level 4 studies can be conducted in efficient, cost-effective manner

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Lessons Learned: What Doesn't Work?

- Definitions of different study levels, need for each, costs to implement
- Understanding of SSHAC rules and intent
- Definition of need for, and ways to update
- Lack of ownership by Level 3 experts
- Probability of capturing the community views is still a function of study level
- Lack of schedule continuity (starting/stopping)

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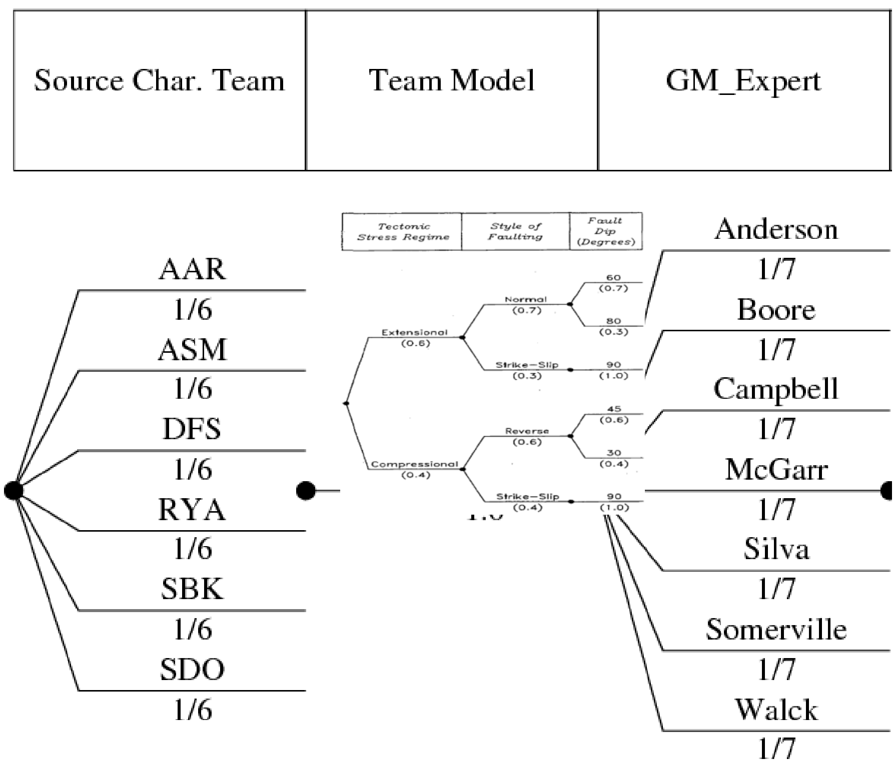
Formal Expert Assessment vs. Expert Elicitation

- ***Formal expert assessment*** is a structured and documented process for identifying and quantifying uncertainties. Subject matter experts participate in an interactive process of data evaluation, learning, model building and quantification of uncertainty. They are explicitly tasked with incorporating the broader views of the technical community.
- In ***formal expert elicitation*** subject matter experts are asked narrowly-defined questions about specific uncertain quantities and they provide judgments in the form of probabilities or distributions. The experts are treated as independent point estimators of uncertain quantities.
- **The SSHAC process is viewed as Formal Expert Assessment rather than Expert Elicitation**

Evaluator Models

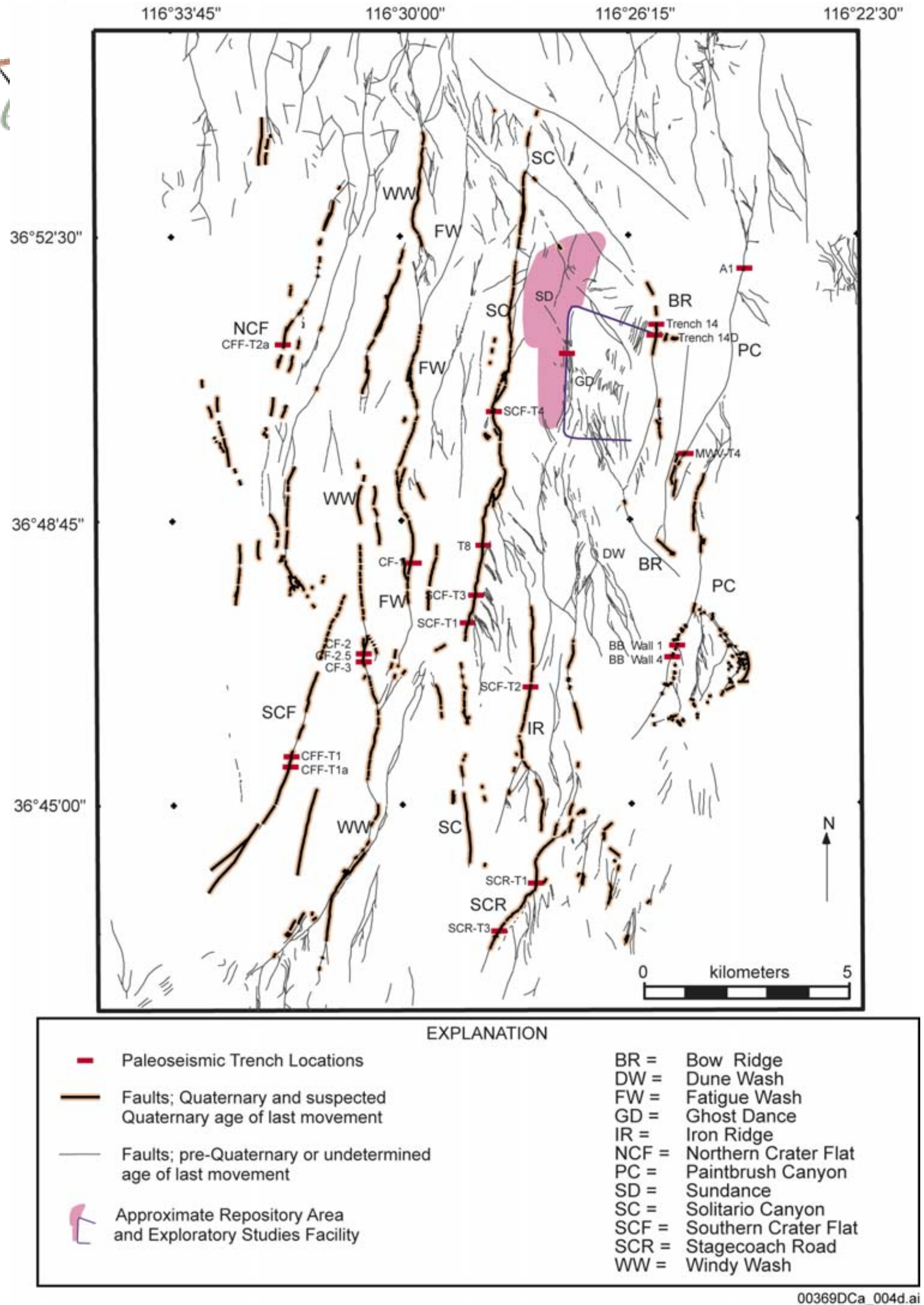
- Evaluator Models are the product of the expert interaction that occurs in SSHAC Level 3 and 4 studies. For Level 3 there is a single evaluator model, for Level 4 there are multiple models.
- Logic trees are the numerical interface between the evaluator models and the hazard calculations. The logic tree captures/structures the epistemic uncertainty in each model.
- The logic trees are much more manageable when they represent the underlying models and not point estimates of ground motion values or earthquake rates.

Epistemic Uncertainty: Yucca Mountain PSHA



$\mu(M,R)$, $\underline{\sigma}$, σ_{μ}, σ_{σ}

Courtesy of G. Toro, Risk Eng.



Complexity: Example of database used by the SSC experts in the Yucca Mountain PSHA

Recommendations: Logic Trees and Final Model

- Hazard insensitive branches should be trimmed from the logic tree with input from experts, TFI/TI-team and hazard analysts.
- The logic tree should be simplified by trimming "dead wood" rather than developing a composite model.
- For major studies a simplified model should be developed to facilitate sensitivity analyses.

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Recommendations: Evaluators and the ITC

How to ensure the goal of capturing the views of the ITC is met?

- Aggressive participatory peer review.
- Training of experts, TI team, and TFI in the role of evaluator.
- Direct participation of the technical community (as proponents in workshops)
- Structured interactions in workshops to draw out alternative models and viewpoints.

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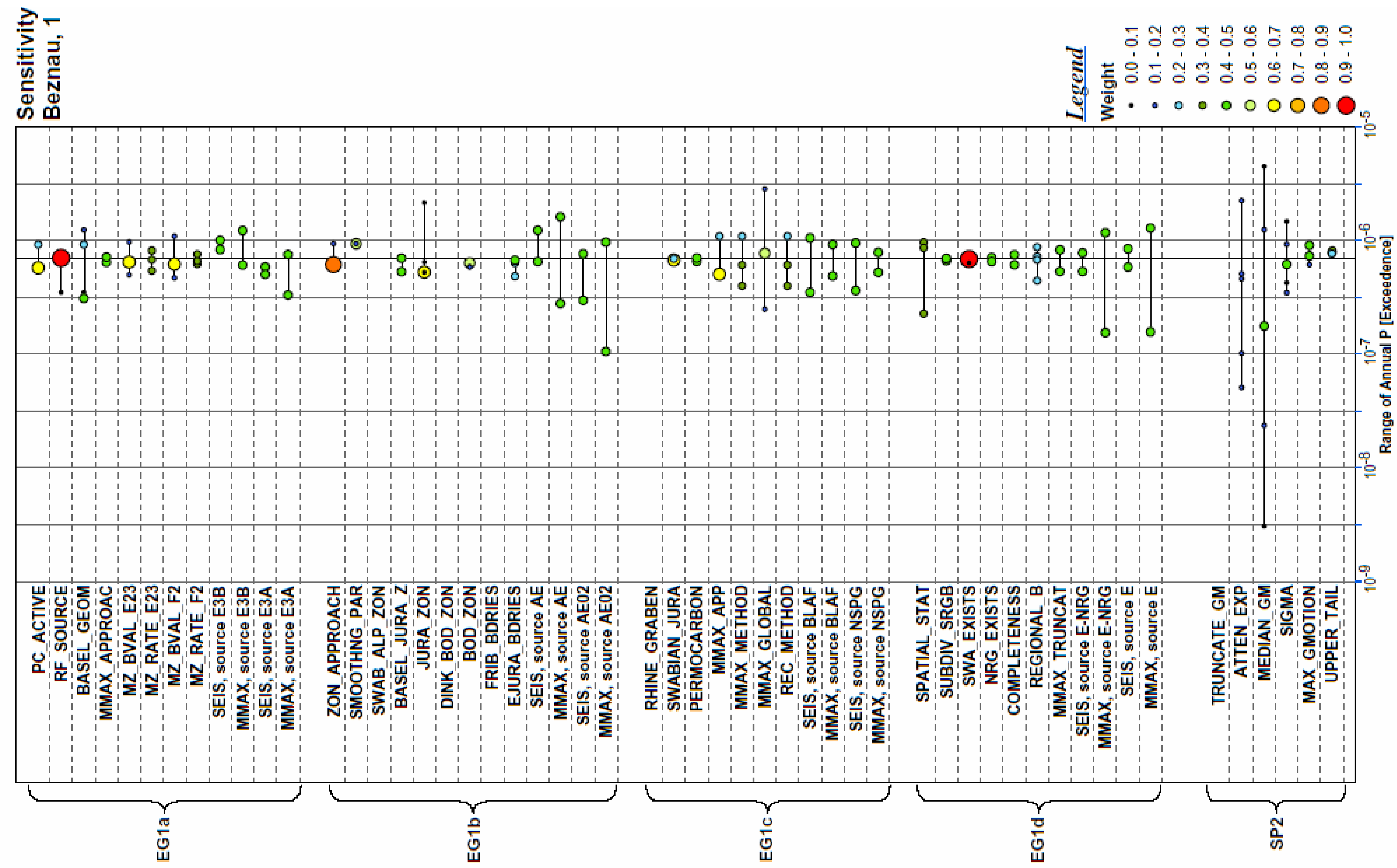
Recommendations: Lessons Learned

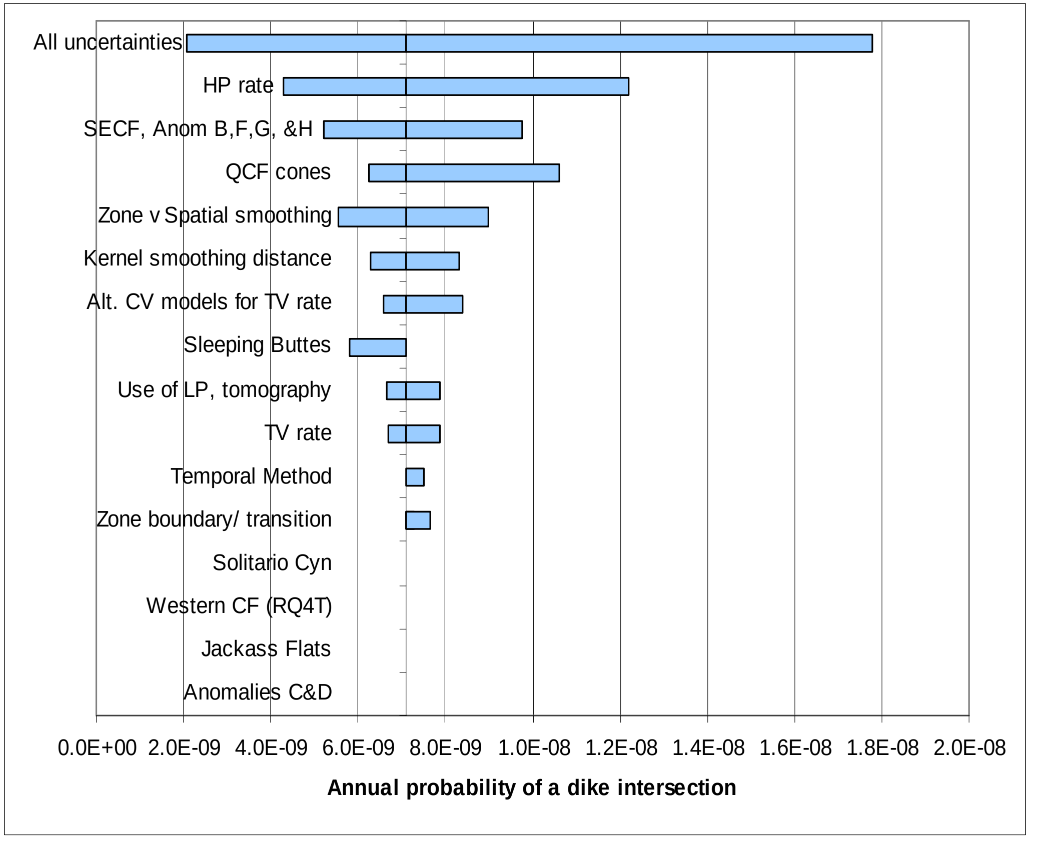
- **Selection of Study Level**: Level 1 studies should not be used for critical facilities. Heavily regulated facilities such as NPP's should be based on regional studies conducted at Level 3 or 4. While the project sponsor will make the decision, communication with regulator is recommended.
- **Feedback Requirements**: Experience has shown that feedback can provide important insights early, during, and late in the evaluation process. Pilot studies, expert-specific feedback and sensitivity analyses can be carried out to provide insight to experts, TFI or TI team.

Sensitivity Histogram: Swiss site (1 Hz, high amplitude)



Courtesy of G. Toro, Risk Eng.

Example of feedback provided to the experts on the PVHA-U for Yucca Mountain



From K. Coppersmith

The Y-axis crosses the X-axis at the "most likely" or nominal value, which represents the annual probability of dike intersection at the repository with all model inputs set at their 50th percentile or most likely value. The length of the top bar represents the 5th to 95th percentiles of the full distribution on the probability of intersection across all model inputs. Subsequent bars illustrate the uncertainty that results from uncertainty in a single specified input. These are calculated by setting all parameters equal to their most likely values, and then varying one from it's lowest to highest value.

Ownership Issues

- For Level 4 studies – intellectual ownership of assessments by experts and shared ownership of results with TFI.
- For Level 3- primary ownership by TI. Expand TI to TI-team.
- For all levels, PPRP reviews both technical and process issues, thus sharing some ownership.
- Sponsors should be capable of specifying scope, understanding and interpreting technical results. [Co-owners, not just underwriters]

Recommendations for PSHA Updates

- Considered three different applications.

  (1) Regional models

  (2) Site-specific updates for new facilities

  (3) Site-specific models for existing facilities

- Terminology:

  "***Revision***"-development of complete regional model (either SSC and/or GM models).

  "***Refinement***"- site-specific modifications to the regional model (site specific issues beyond scope of regional model)

  "***Partial Update***"- update to part of the regional model based on new information

“Significant Change”

- For recommending changes: significance will depend on project.
- For projects focused on design ground motion, significance is in terms of the impact on ground motion at a given probability level.
- For projects that use risk, significance is in terms of hazard at a given ground motion. However, slope of hazard curve is important.

Regional Models (1)

- Major studies-develop SSC and/or GM models applicable to large regions.
- Used for many sites, should be performed at SSHAC Level 3 or 4. Includes comprehensive treatment of epistemic uncertainty. Goal is to provide stability.
- Consists of the logic trees that describe the alternative models and the supporting data bases.
- The regional model does not include the hazard calculations or locale-specific site response models.

Regional Models (2)

- Group concluded that “community-based regional models” could be advantageous.
- Proposed moving to a multi-sponsor framework. Provides stability and enhances funding.
- Sponsors – federal/state agencies and industry.
- Organization: Management Committee and Technical Working Group.
- Issues: long-term commitment by several groups could be problematic, involvement of USGS.

Site-Specific Applications-New License and Existing Facilities

- Two issues: refinement of regional model for site-specific issues and partial updates of the regional model to address new data/models/methods.
- Refinements of regional model- consideration of local faulting/sources
- Partial update based on significance
- Technical review group will interact with USGS and stay informed of new data, interpretations and models.

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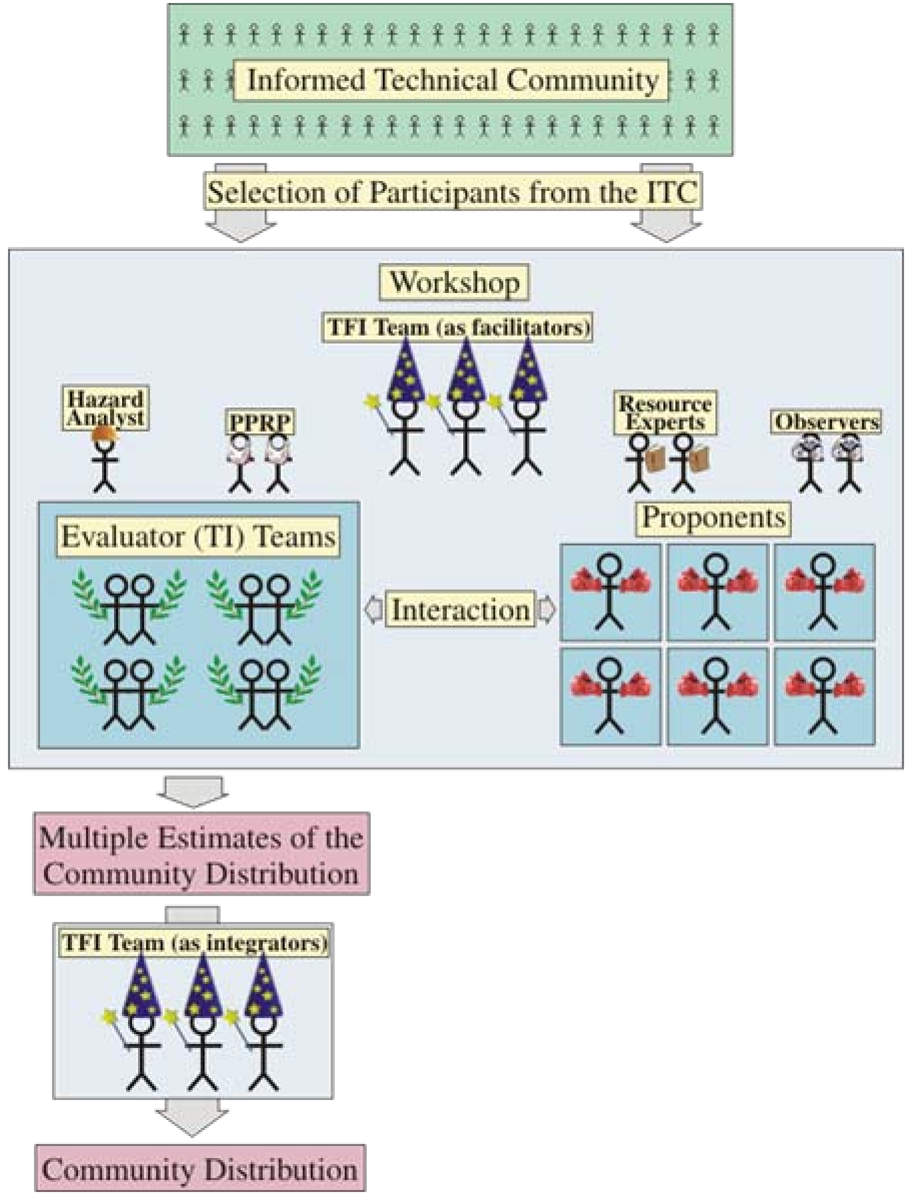
Regional Models: Frequency of Revisions

- Two approaches, likely to be ~2-year duration to updates.
- **Fixed Lifespan:** Clearly defines schedule for updates (enhances budget planning), may require a revision when no significant information available.
- **Indeterminate Lifespan:** Determined by the availability of new/significant data and/or models. Leads to perception of stability-but de-incentives updates.
- ***Recommendation***: Regional models should have a maximum lifespan of nine years. Enhances co-ordination with national hazard maps. May need to be more frequent if significant new information becomes available.

Project Status

- 3 workshops held, ~ 40 participants in each.
- Draft report ("Implementation of SSHAC Guidelines for Level 3 and 4 PSHA's") received by NRC from USGS for review. Report will be produced as USGS Open-File report.
- White paper on recommendations for Updating PSHA's in progress.
- NRC will consolidate documents and produce a NUREG. Estimate draft in early 2010.

Level 4



Courtesy of T. Hanks

Background