



**U.S. NRC**

UNITED STATES NUCLEAR REGULATORY COMMISSION

*Protecting People and the Environment*

# **Current and Future Application of Seismic Research Activities at the NRC in Response to the Accident at the Fukushima Dai-ichi Nuclear Power Plant**

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U.S. Nuclear Regulatory Commission

IAEA-IEM8

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- Background and Regulatory Framework
  - Generic Issue 199
  - Previous Seismic Research
- Fukushima Task Force Recommendations
  - Implementation and Results
- Future Seismic Research Needs
- Summary

# Background

- Significant advancements in our understanding of seismic hazard processes have occurred since the existing fleet of reactors was licensed.
- New data has been acquired and models have been developed in the past 30+ years that suggest significantly different assumptions than those used in licensing of existing fleet.
- This information indicates that previous assumptions regarding seismic hazards were not bounding
- Evaluation of the impact of these changes on plant safety is not straightforward.

# Regulatory Framework Has Evolved Through Time

**Department of Energy  
 And National Codes**

**DOE Std. 1020**

**ASCE 43-05**

*Performance  
 Based Seismic  
 Design*

**Time** →

**1994**

**2005**

**1973**

**1997**

**2007**

**NRC  
 Guidance**

**Reg. Guide 1.60**

**Reg. Guide 1.165**

**Reg. Guide 1.208**

**Pre-1997:**  
 10 CFR 100.10(c)(1)  
 Appendix A, 10 CFR Part 50  
 General Design Criteria 2

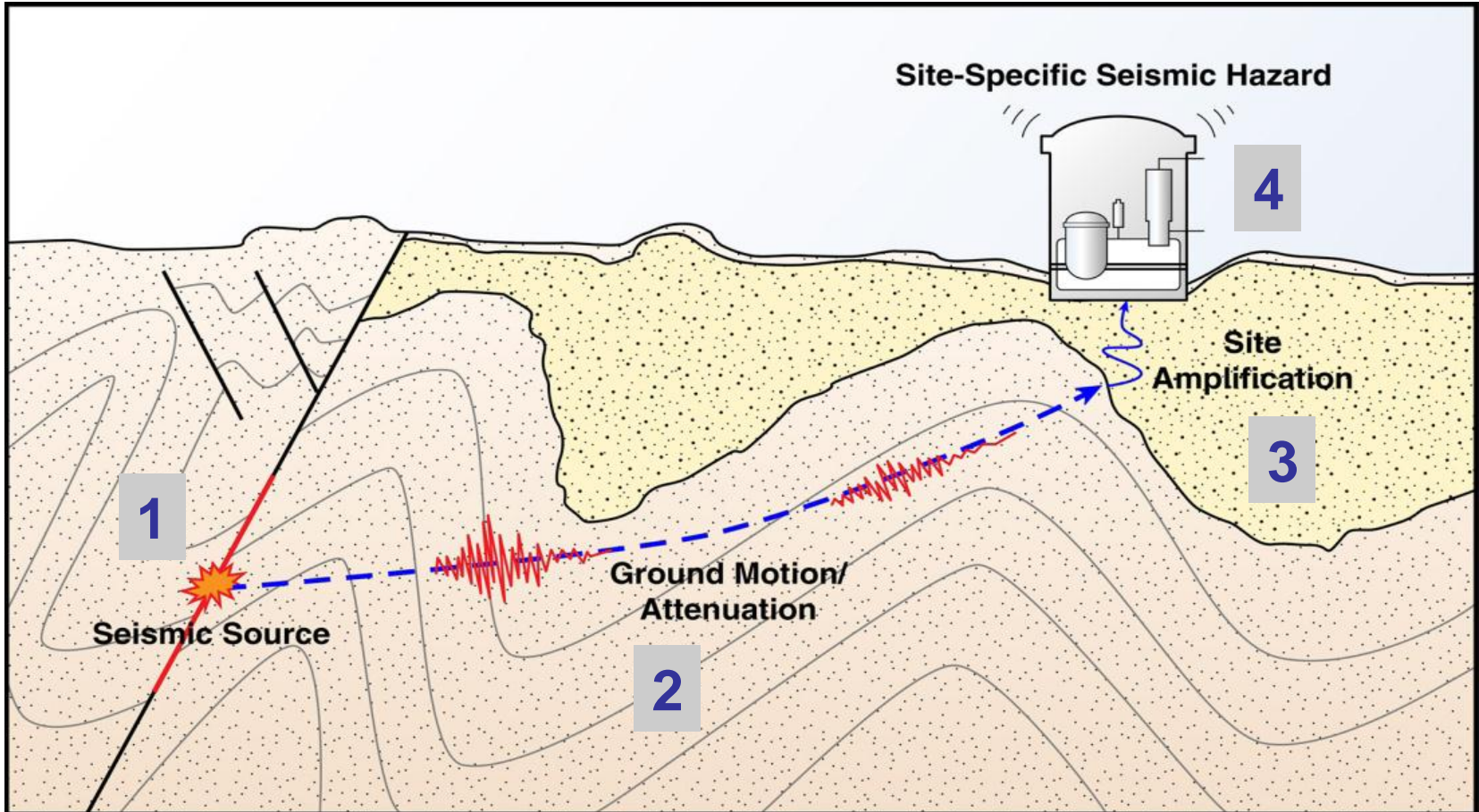
**Post-1997:**  
 10 CFR 100.23  
 Appendix S, 10 CFR Part 50  
 General Design Criteria 2

**Deterministic**

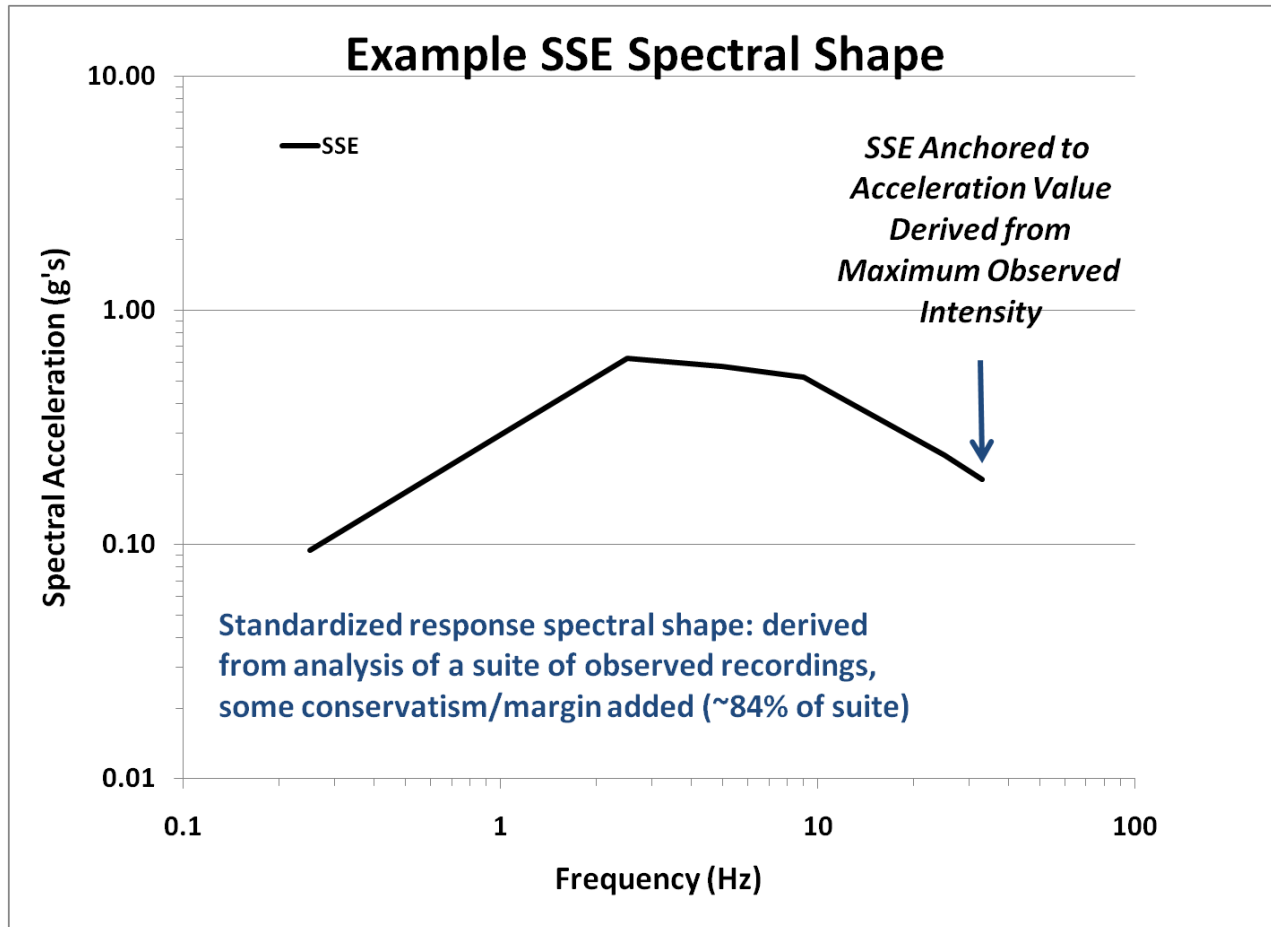


**Probabilistic**

# Seismic Design/Analysis For Nuclear Plants



# Safe Shutdown Earthquake Ground Motion or SSE



No site-specific insights regarding shape

## Beyond Design Basis Seismic Evaluation and Generic Issue 199 (GI-199)

- Recently available seismic data and models show increased seismic hazard estimates for some sites relative to existing design bases
- Formally recognized as an issue for operating reactors in 2005 as Generic Issue 199
- Safety/Risk Assessment completed (2010)
- GI-199 Safety/Risk Assessment identified significant challenges to performing site-specific assessments at all operating reactors
  - Required updated seismic hazards at all sites in a timely fashion
  - Required information on beyond-design basis events that was suitable for use in a risk-informed decision-making process
- Subsumed into Fukushima Near-Term Task Force Recommendation 2.1 (2012)

## **Pre-2011: Relevant NRC Seismic Research**

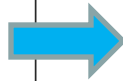
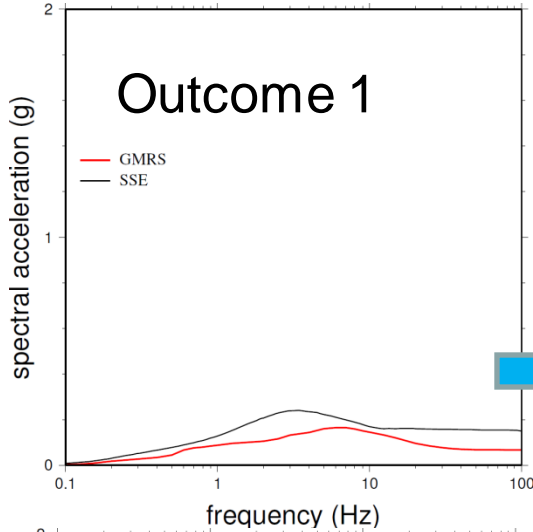
- Development of state-of-the-art seismic source characterization (CEUS-SSC) and ground motion (NGA-East) models for the central and eastern-U.S.
- Updating of the protocols for conducting hazard studies where significant uncertainties exist in the data, models and methods (SSHAC Guidelines)
- Methodology to incorporate uncertainty in site-response into seismic hazard calculations
  - Use of random-vibration theory
  - Development of software tools
  - Two-dimensional effects



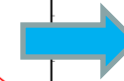
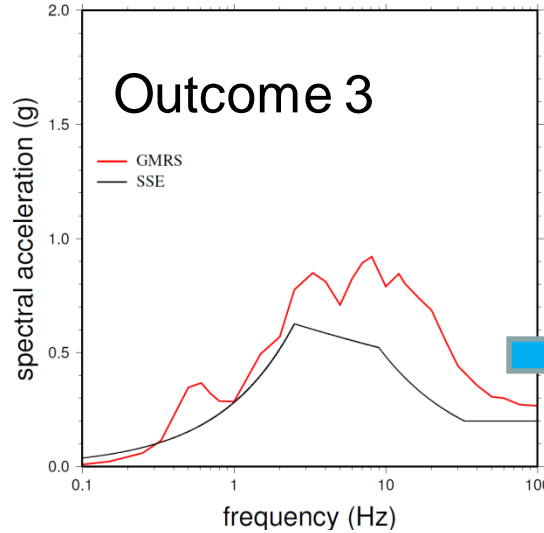
## Fukushima Accident: Background on NRC Response

- NRC established Near Term Task Force (NTTF) in response to the accident at Fukushima Dai-ichi nuclear power plant
- NTTF Recommendation 2.1 (Seismic) implemented through 10 CFR 50.54(f) information request
  - Requests Licensees reevaluate seismic hazard **using present-day regulatory guidance and methodologies** and, if necessary, perform a risk assessment (Phase 1)
    - Current NRC regulations and guidance specify a probabilistic approach for developing design ground motions
      - Results are characterized by a Ground Motion Response Spectrum or GMRS—which is compared to SSE
  - Based on results of Phase 1, NRC will determine if further regulatory actions are necessary to protect against updated hazard (Phase 2)

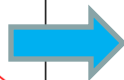
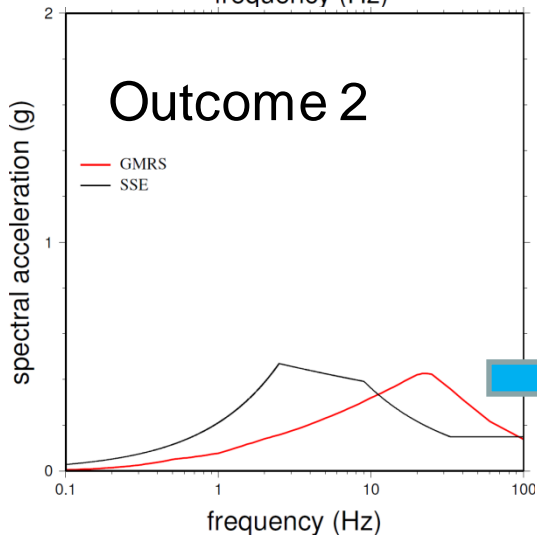
# Potential Outcomes for NTTF R2.1 Evaluations



No  
Further  
Analysis



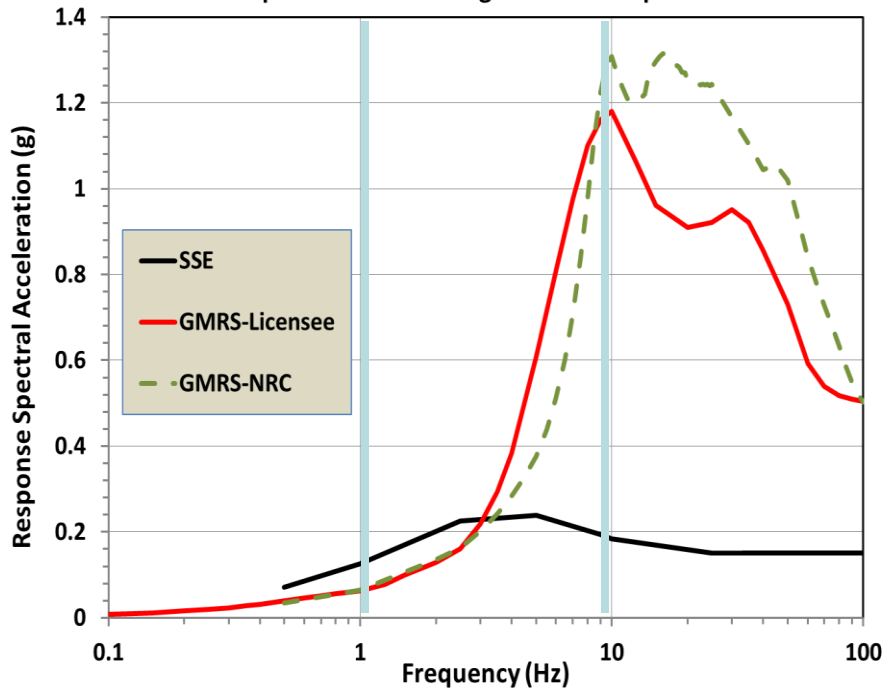
Plant Risk  
Evaluation  
Needed



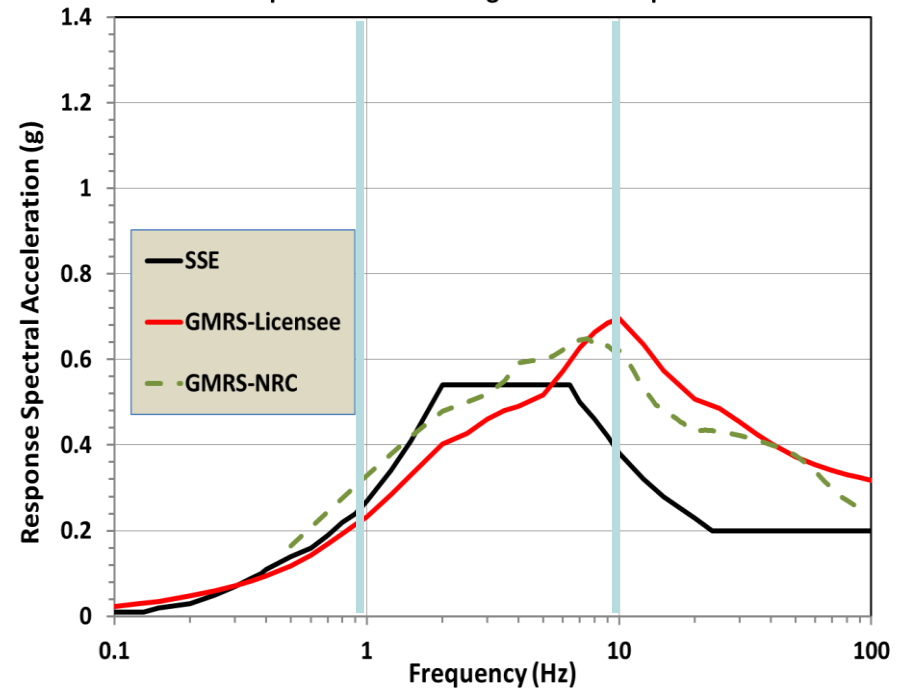
Industry Testing Program for High Frequency  
Sensitive components

# Examples of NTTF R2.1 Evaluation and Screening

Comparison of Screening Results-Group 1



Comparison of Screening Results-Group 2

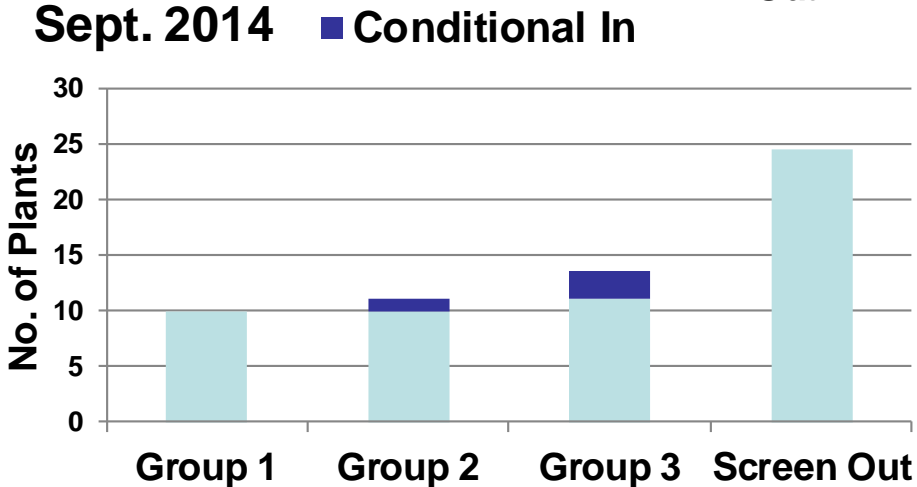
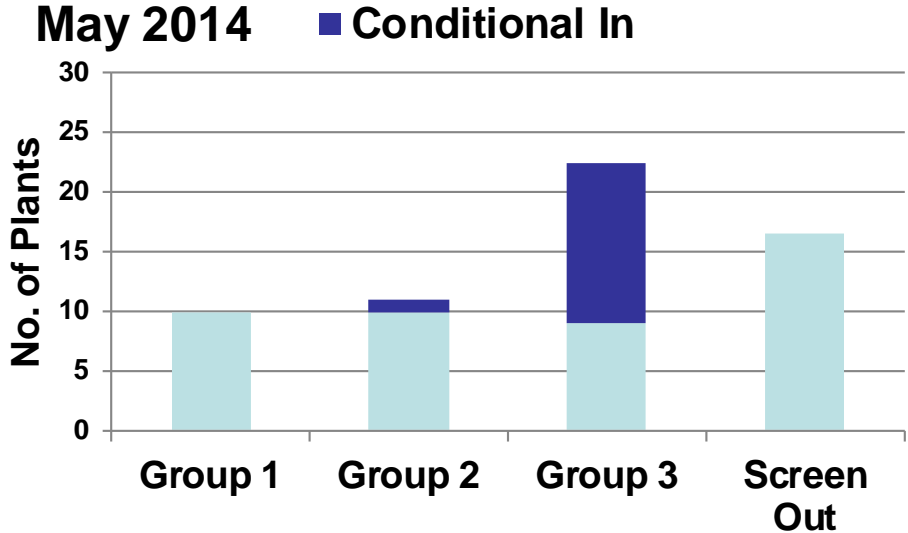


***Plants grouped based on relative amplitude of SSE and updated hazard (GMRS) between 1 and 10 Hz***

# NTTF R2.1: Screening & Prioritization Results

**Final Results for  
 Central and  
 Eastern U.S.  
 Plant Sites:**  
 25 Screen-Out  
 13 Group 3  
 10 Group 2  
 10 Group 1

**Results for  
 Western U.S.  
 Plant Sites:**  
 Ongoing



# Research Insights from Fukushima NTTF R2.1 Process

- NRC staff reviewed licensee submittals and has performed independent confirmatory analyses for more than 50 plant sites (~90 reactors).
- This process identified specific issues requiring further research including:
  - specific guidance on characterizing existing sites where the available data on geological and geotechnical properties is less robust than current practices would require
  - characterization and treatment of the uncertainty in the calculation of site response
  - techniques for recognizing and addressing sites where significant two- or three-dimensional effects may influence site response.

# Research Insights from Fukushima NTTF 2.1 Process (cont'd)

- Focus of NTTF 2.1 changing from seismic hazard assessment to risk evaluation- NRC staff has identified additional research topics of importance
  - Representing uncertainty in site response in an un-biased manner during the process of transferring motions from near-surface soils/rock into the structures
  - Evaluating different methodologies for soil-structure interaction (SSI) calculations recognizing the epistemic uncertainty inherent in those calculations
  - Identifying consistent, efficient, robust methods for developing fragility estimates utilizing available design data to support probabilistic risk analyses
  - Incorporation of earthquake experience data into assessment

# Summary

- Significant advancements in our understanding of seismic hazard processes have occurred since the existing fleet of reactors was licensed
  - These advancements pose regulatory challenges
- Focused seismic-related research has been instrumental in responding to Fukushima NNTF Recommendation 2.1
  - Has provided a risk-informed method to evaluate the potential safety significance of evolving state-of-the art scientific knowledge
  - Response to Fukushima accident lead to development of protocol for assessment of operating reactors
- A number of important future research objectives have been defined as a result of Fukushima response
  - Hazard issues- uncertainty in ground motion models, site response and induced seismicity
  - Structural and risk issues- fragility and in-structure response

# References - Bibliography

- Senior Seismic Hazard Analysis Committee - SSHAC
  - U.S. NRC NUREG/CR-6372 (1997) and NUREG-2117 (2012)
- Seismic Source Models for the CEUS
  - Result of collaborative research involving NRC, DOE, EPRI and USGS
  - <http://www.ceus-ssc.com/>
- Regional Ground Motion Models (CEUS)
  - Ongoing Next Generation Attenuation Models-East (NGA-East) Project. Collaborative research project involving NRC, DOE, EPRI and USGS
    - <http://peer.berkeley.edu/ngaeast/>
  - NRC reviewed and endorsed updated EPRI Ground Motion Prediction Equations (GMPEs) for the NTTF 2.1 reevaluations
    - <http://pbadupws.nrc.gov/docs/ML1315/ML13155A553.html>
    - <http://pbadupws.nrc.gov/docs/ML1323/ML13233A102.pdf>



# References - Bibliography

- NRC Request for Information and Response
- NRC (U.S. Nuclear Regulatory Commission), 2012a, letter from M.R. Johnson, to All Power Reactor Licensees 03122012, ADAMS No. ML12053A340
- Electric Power Research Institute, 2012. EPRI Report 1025287 "Seismic Evaluation Guidance, Screening, Prioritization and Implementation Details [SPID] for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic" 11272012, ADAMS No. ML12333A170
- Site Response
  - U.S. NRC NUREG/CR-6728 and Reg. Guide 1.208
  - Screening Prioritization and Implementation Details (SPID) EPRI Report 1025287 (Appendix B)
- Related Documents:
- Industry Issued Guidance on Expedited Approach for Seismic Re-Evaluations (EPRI Report)
- Generic Issue 199: Results of Safety/Risk Assessment of Generic Issue 199, 'Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States on Existing Plants,'" ADAMS No. ML100270582, "September 2, 2010.

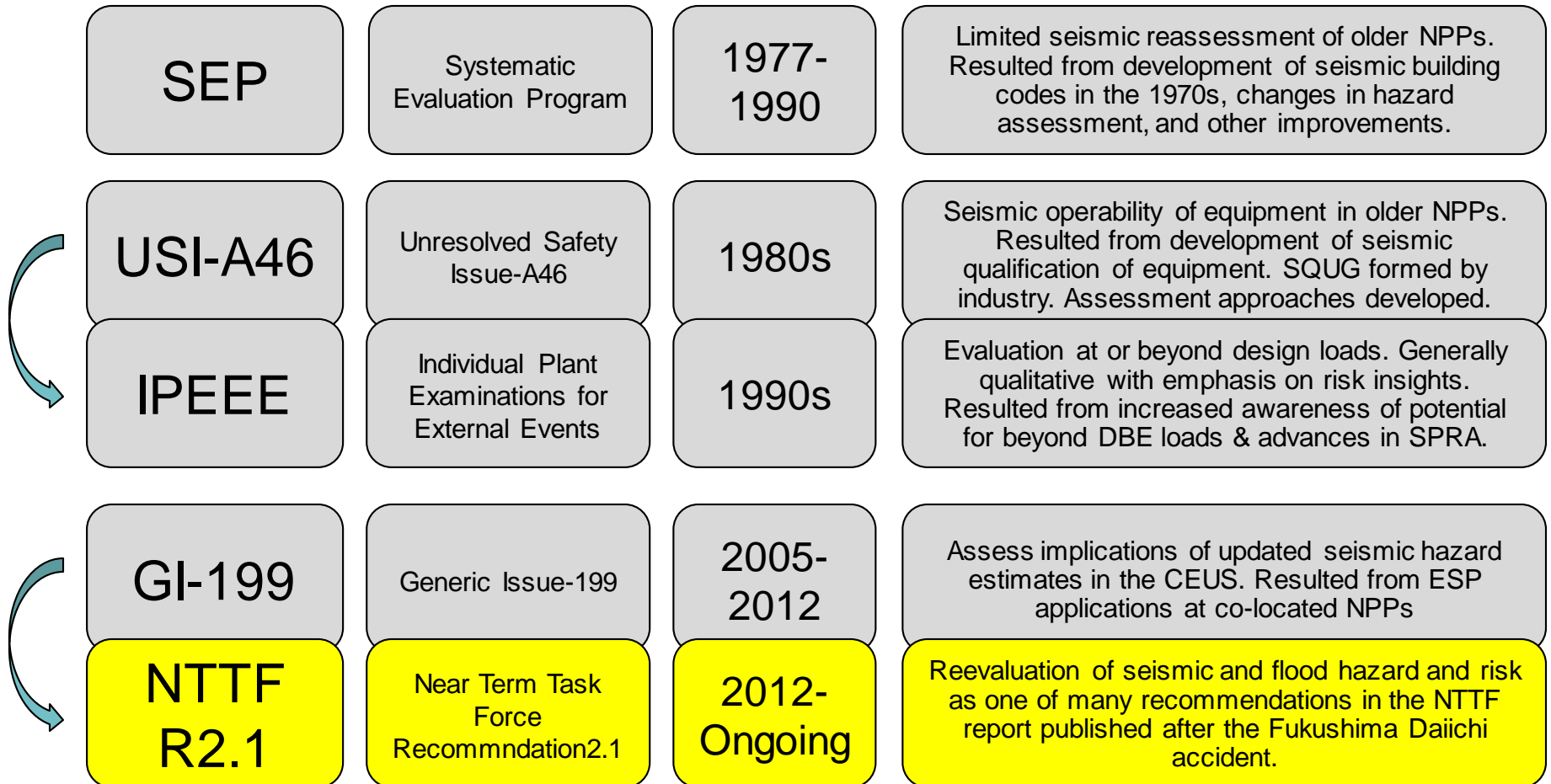
# List of Acronyms

- ASCE – American Society of Civil Engineers
- CDF – Core Damage Frequency
- CEUS – Central and Eastern United States
- GMRS – Ground Motion Response Spectrum
- NRC – U.S. Nuclear Regulatory Commission
- NTTF – Near-Term Task Force
- SCDF – Seismic Core Damage Frequency
- SSE – Safe Shutdown Earthquake
- SSHAC – Senior Seismic Hazard Analysis Committee
- SSI – Soil-Structure Interaction
- SPID – Screening, Prioritization, and Implementation Details
- WUS – Western United States

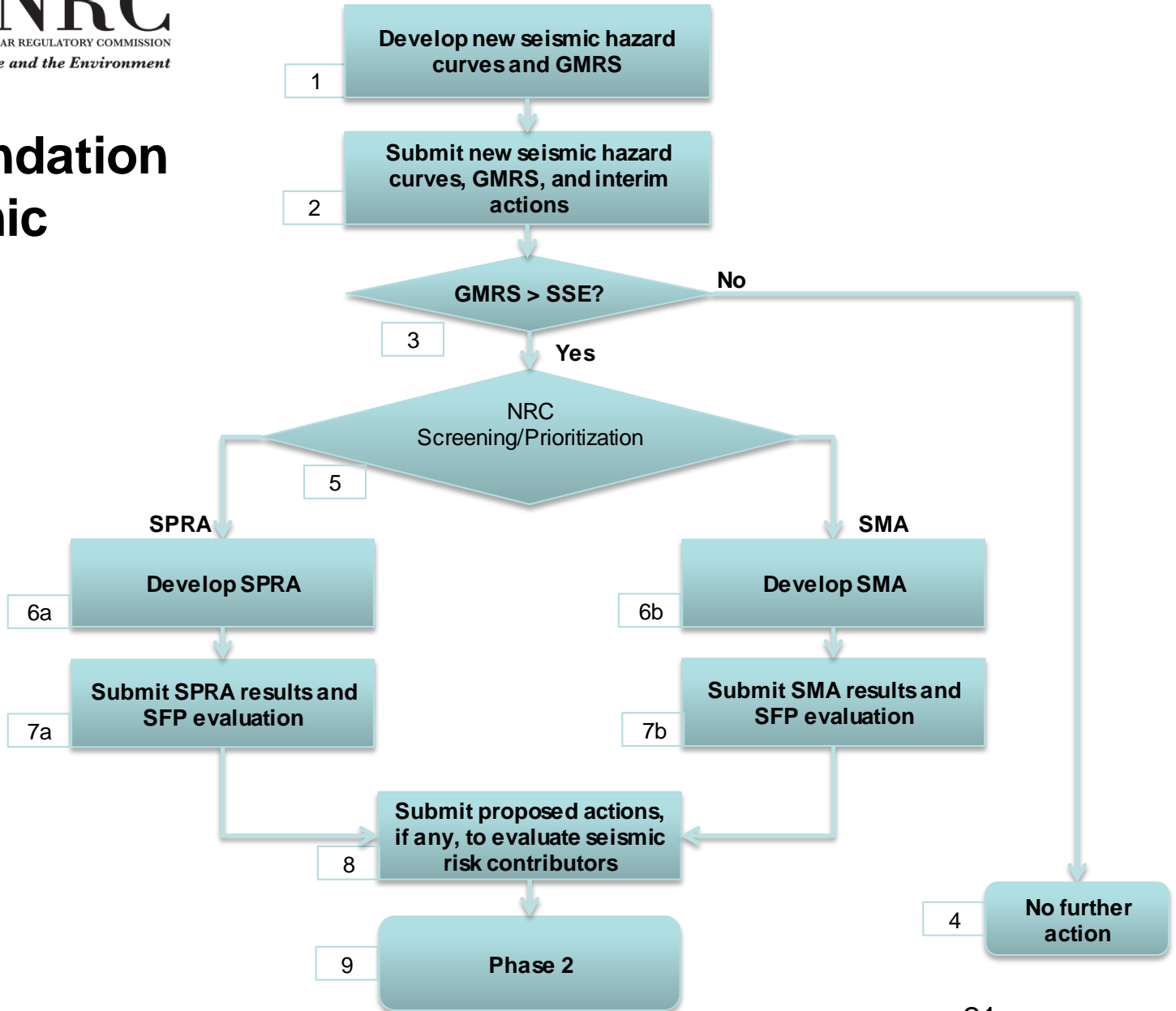


# Background/Discussion Slides




# History of Seismic Reevaluations

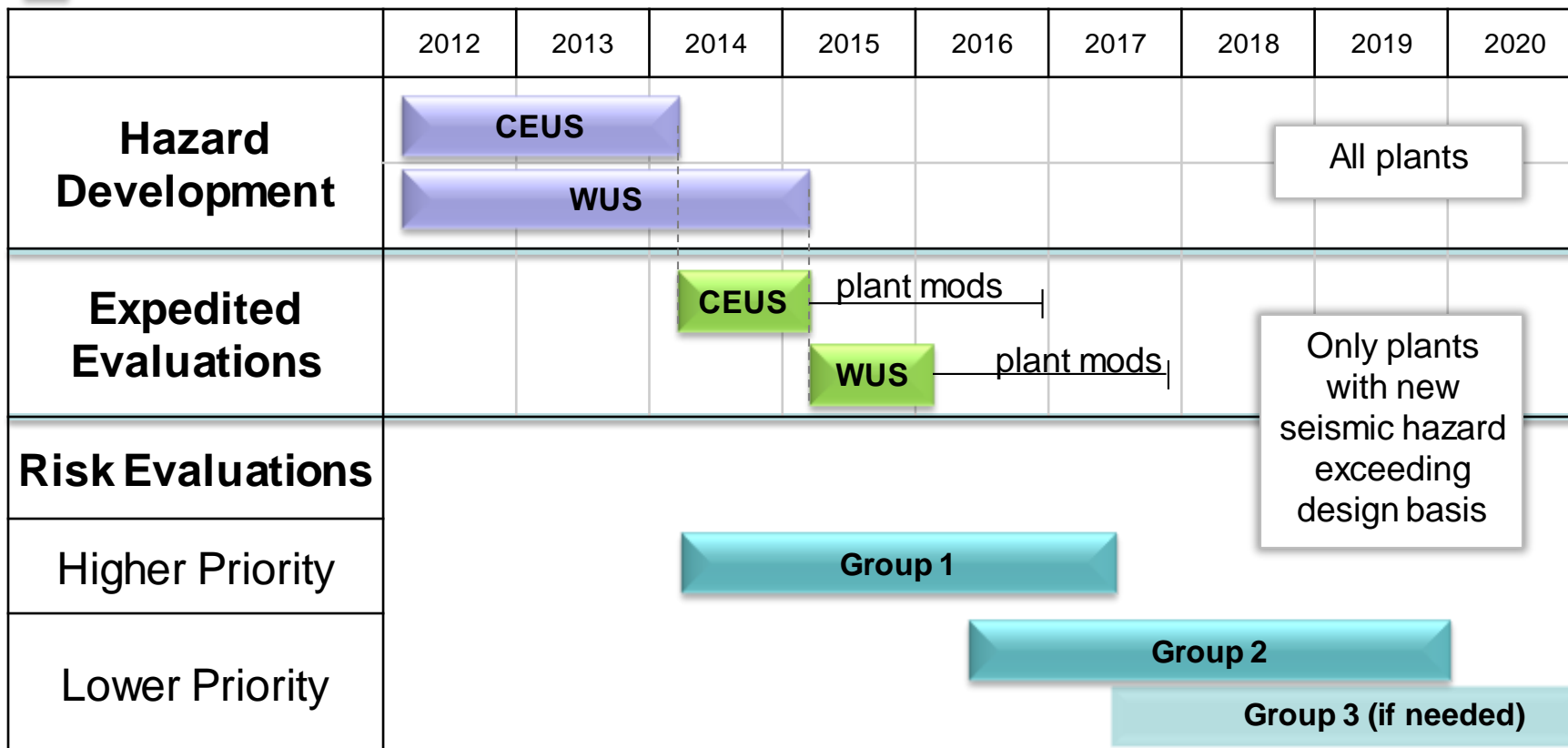


# Recommendation 2.1: Seismic



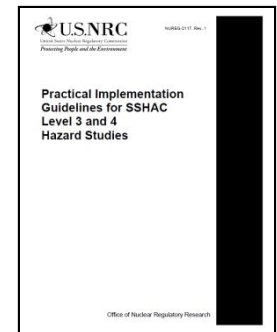
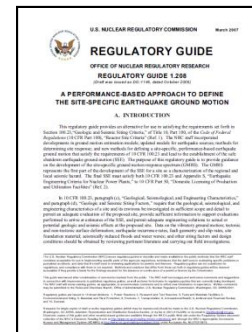
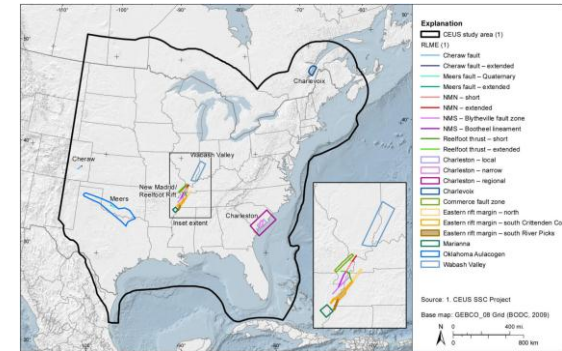
# Schedule for Seismic Hazard and Risk Evaluations

-  Hazard Analyses
-  Enhanced Interim Actions
-  Risk Evaluations

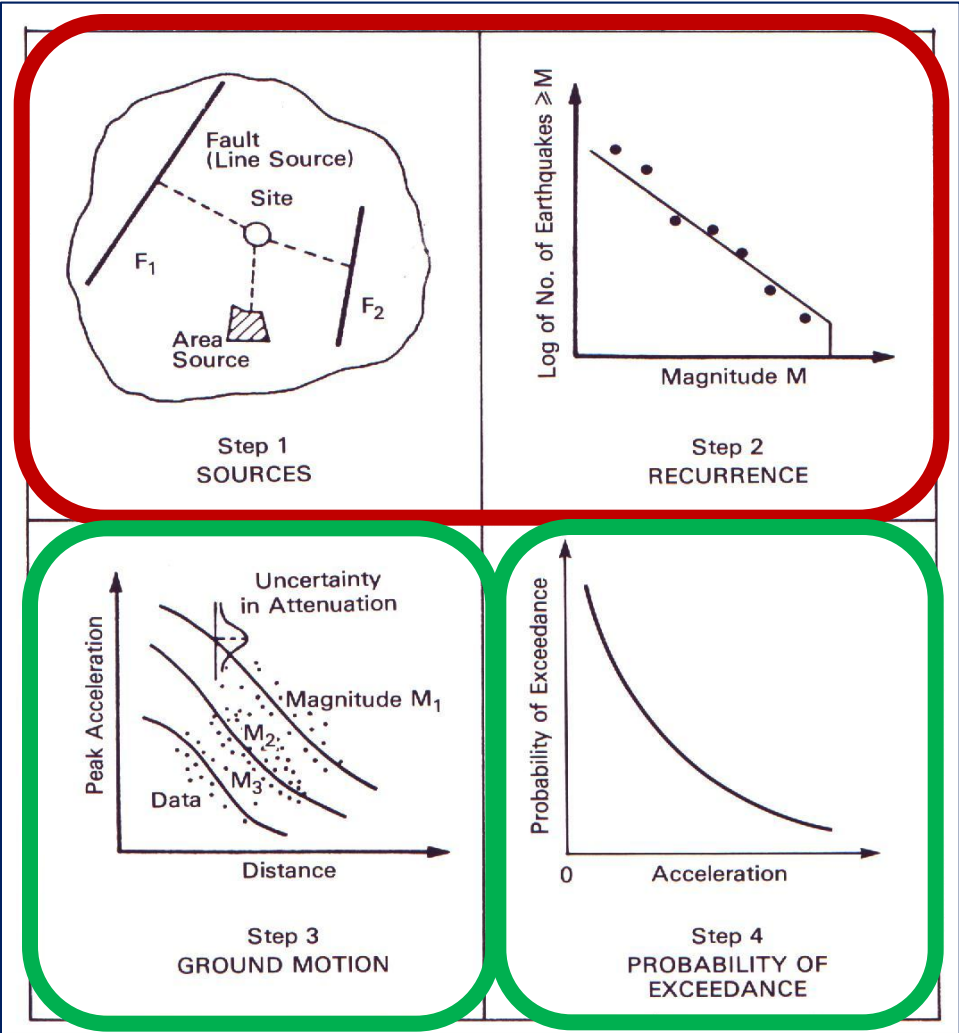


## NTTF R2.1 Seismic Hazard Reevaluations use Current Methods and Information

- PSHA develops plant-specific GMRS (RG1.208)
- CEUS licensees (96 units/59 sites)
  - CEUS SSC Source model (NUREG 2115)
  - EPRI Ground Motion model (2013)
  - Plant-specific site response analysis
- WUS licensees (8 units/4 sites)
  - Site-specific SSHAC level 3 studies for sources and ground motion (NUREG 2117)
  - Plant-specific site response analysis



# Input Models for PSHA



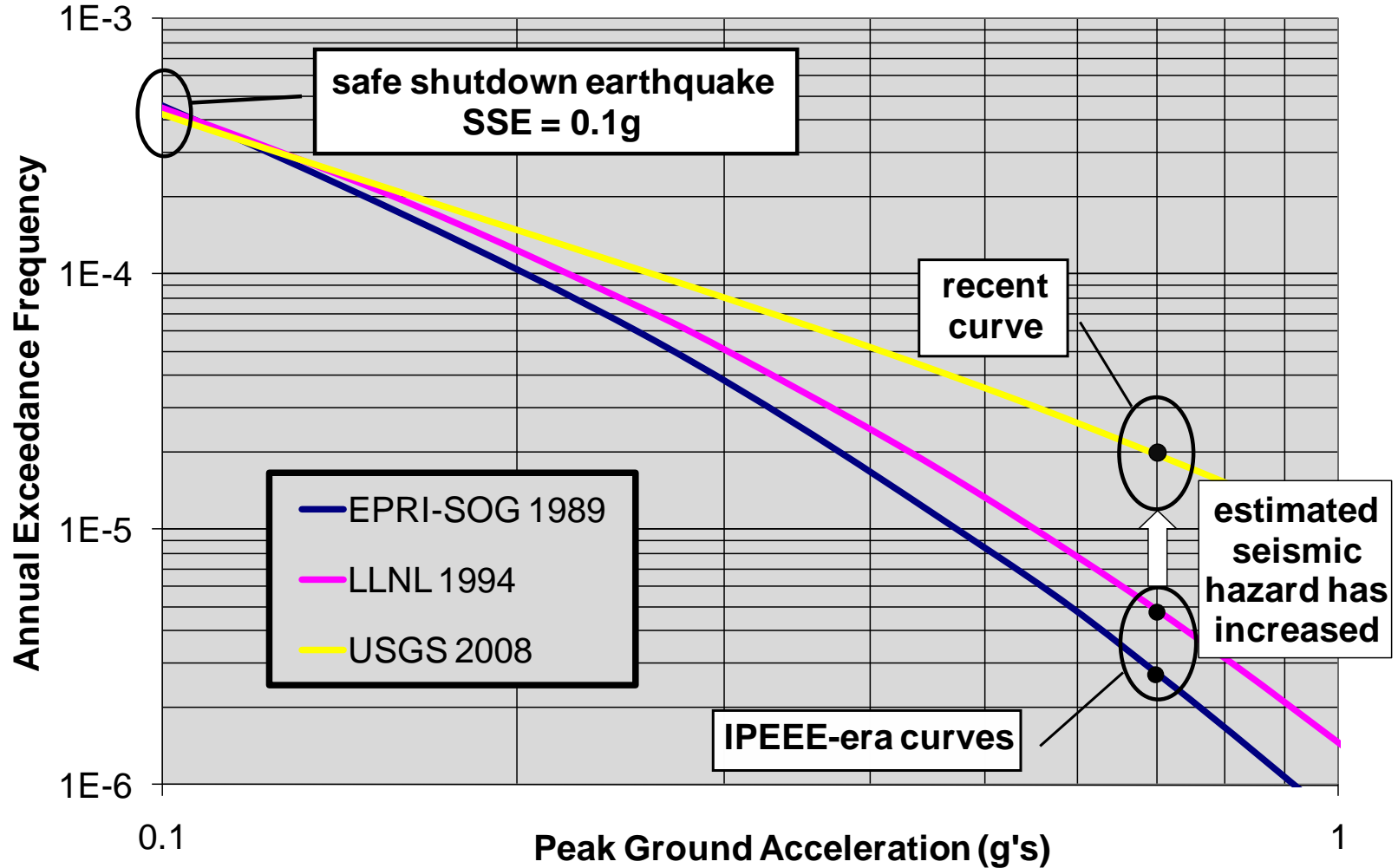
**SSC**  
 Seismic Source  
 Characterization

**GMC**  
 Ground Motion  
 Characterization

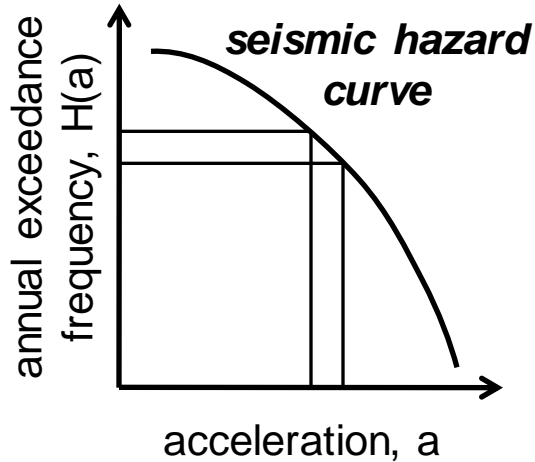
**Hazard**  
 Calculations



# Example Seismic Hazard Curves: PSHA Output



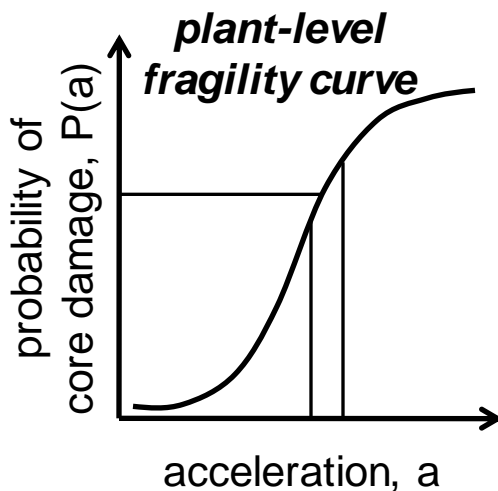
# Risk Metric: Computing Seismic Core Damage Frequency (SCDF)



Over a small range of accelerations, the SCDF contribution is the product of:

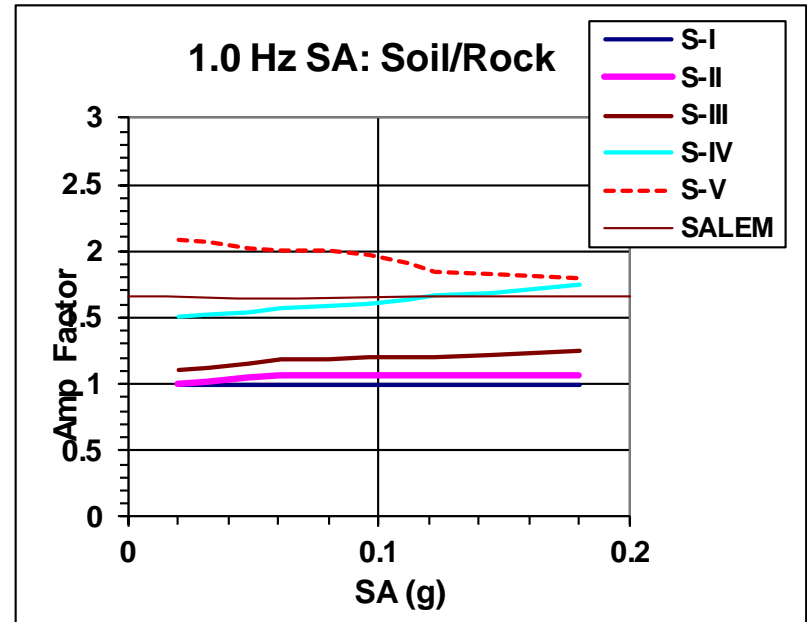
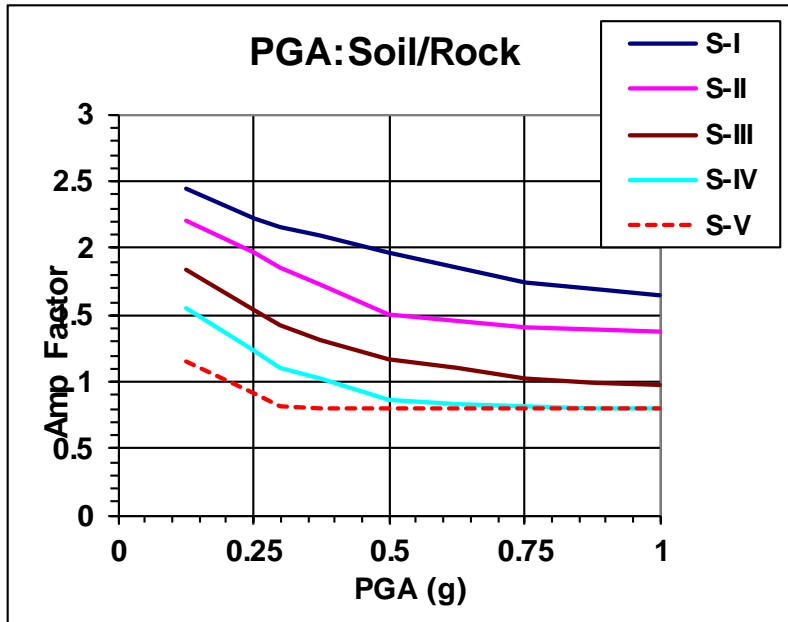
- The frequency of earthquakes with accelerations in the range, and
- The probability of core damage given acceleration within the range

Add up the contributions over all accelerations.



$$\begin{aligned}
 SCDF &= \int_0^{\infty} P(a) \left( -\frac{dH(a)}{da} \right) da \\
 &= \int_0^{\infty} H(a) \frac{dP(a)}{da} da
 \end{aligned}$$

# Example Generic Soil Amplification Functions



MEDIAN CURVES

# Senior Seismic Hazard Analysis Committee (SSHAC)

NUREG/CR-6372  
UCRL-ID-122160  
Vol. 1

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## Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts

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Main Report


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Prepared by  
Senior Seismic Hazard Analysis Committee (SSHAC)  
R. J. Budnitz (Chairman), G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, P. A. Morris

Lawrence Livermore National Laboratory

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Prepared for  
U.S. Nuclear Regulatory Commission  
U.S. Department of Energy  
Electric Power Research Institute



NUREG-2117

## Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies

Manuscript Completed: May 2011  
Date Published: December 2011

Prepared By:  
Annie M. Kammerer  
Jon P. Ake

NRC Project Manager:  
Richard Rivera-Lugo

Office of Nuclear Regulatory Research  
Division of Engineering

# SSHAC Process Objectives

- Create reproducible, stable estimates of probabilistic seismic hazard at a site. This provides greater regulatory assurance.
- Obtain this stability by:
  - Evaluation: Considering the data, models, and methods of the larger technical community
  - Integration: Building models that represent the center, body, and range of technically defensible interpretations.
- Assess uncertainties in the input data and quantify uncertainties in the results.

# Determination of the Safe Shutdown Earthquake (SSE)

