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Challenges in Seismic Hazard Analyses in the U.S. in the 21st Century: Are We Addressing the Extreme Events?

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Introduction

- It has been a year since the 2011 **M** 9.0 Tohoku-Oki, Japan earthquake and the debate rages on:
  1) Why was this earthquake not anticipated?
  2) Why did not Tokyo Electric Power Company, the owner of the Fukushima Dai-ichi nuclear power plant, adequately design the plant for the earthquake and its resulting tsunami?
  3) Why was the existing design approved by Japan's Nuclear and Industrial Safety Agency?

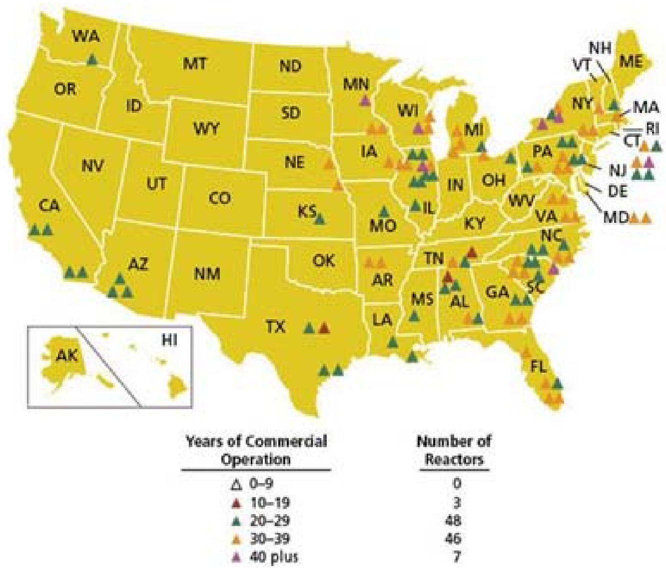
Introduction (cont.)

- The obvious question to be asked in the U.S. in regards to the nuclear power plant safety is:
    1) Are the tools we use today adequate and the knowledge sufficient to evaluate earthquake threats to insure new nuclear plants will be properly designed?
    2) Can “extreme” events such as Tohoku-Oki occur in the U.S.?
    3) If so, can we accurately predict the resulting hazards, i.e., ground shaking, tsunamis, and other effects?

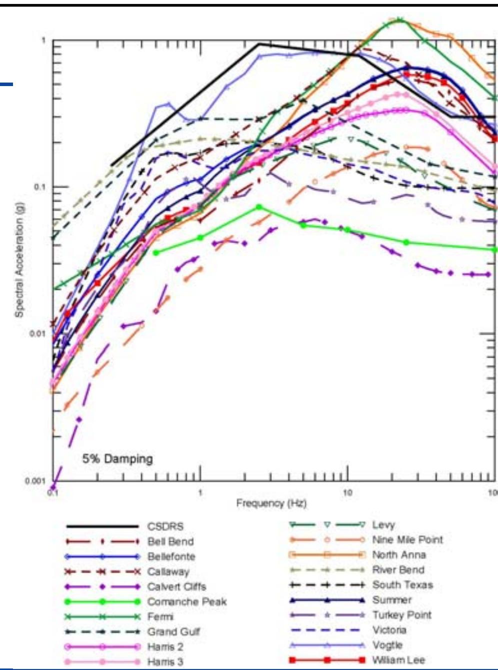
Extreme Earthquakes

- Three key questions can be raised on whether extreme earthquakes and their associated hazard can be predicted using a PSHA methodology:
    1) How good is the PSHA methodology?
    2) How good are the scientific inputs, i.e., seismic source characterization and ground motion prediction models?
    3) How stable are the results?

U.S. Commercial Nuclear Power Reactors



Comparison of GMRS From 18 New Reactor COL Applications

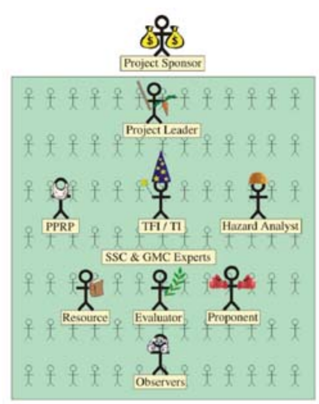


Advancements in PSHA Methodology

- Probabilistic seismic hazard analysis (PSHA) is the approach that is used in the U.S. to estimate the hazard for important and critical facilities such as nuclear power plants.
- The PSHA methodology is well accepted and is well suited to predict extreme events or very low probability consequences assuming adequate inputs and proper implementation.
- Important advancements in the PSHA methodology include a set of guidelines developed by the Senior Seismic Hazard Analysis Committee (SSHAC) in 1997 and a supplemental set of guidelines by Hanks and others (2009) on implementation for Level 3 and 4 PSHAs. Both sets of guidelines focused on the use of expert judgment and the treatment of uncertainty.

Senior Seismic Hazard Analysis Committee Guidelines

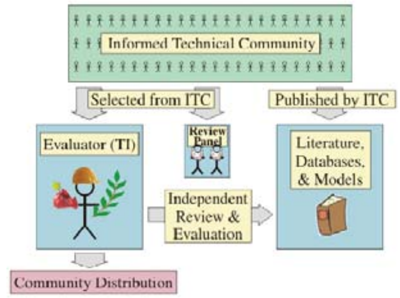
- The guidelines stress the importance of (1) proper and full incorporation of uncertainties and (2) inclusion of the range of diverse technical interpretations that are supported by data.
- I would suggest that the Tohoku-Oki earthquake would have been considered in PSHAs in Japan if the philosophy behind these guidelines had been followed.



Hanks et al., 2009

SSHAC (cont.)

- The most important and fundamental fact that must be understood about a PSHA is that its objective can be attained only with significant uncertainty.
- SSHAC believes that the following should be sought in a properly executed PSHA project for a given difficult technical issue:
  1) A representation of the legitimate range of technically supportable interpretations among the entire informed technical community, and
  2) The relative importance or credibility that should be given to the differing hypotheses across that range.



Hanks et al., 2009

SSHAC (cont.)

- SSHAC identifies there are different types of consensus, and then concludes that one key source of difficulty is failure to recognize that
  1) There is not likely to be "consensus" (as the word is commonly understood) among the various experts; and
  2) No single interpretation concerning a complex earth-sciences issue is the "correct" one.

Criterion for a Successful PSHA

- When independently applied by different groups, would yield "comparable" results, defined as results whose overlap is within the broad uncertainty bands that inevitably characterize PSHA results.
- For this to be true, the uncertainties in the methodology must be confronted and dealt with head-on. No PSHA analyst should attempt less, and no PSHA sponsor should accept less.

Criterion for a Successful PSHA (cont.)

- Regardless of the scale of the PSHA study, the goal remains the same: to represent the center, the body, and the range of technical interpretations that the larger informed technical community would have if they were to conduct the study.

Advancements in Seismic Source Characterization

- Several significant advancements in PSHA inputs have been made in the U.S.
- Extensive research efforts continue in the U.S. in the characterization of seismic sources.
- The characterization is considerably more advanced in the western U.S. (WUS) than the central and eastern U.S. (CEUS), and that is reflected in the differences in approaches: site-specific versus the use of prescribed models (EPRI/DOE/NRC CEUS model).
- Technological advancements such as GPS, LiDAR, broadband seismic monitoring, and seismic waveform analyses are helping to improve seismic source characterization in the U.S. but particularly the CEUS.
- The SSHAC Level 3 EPRI/DOE/NRC seismic source model for the CEUS is a recent outcome of those efforts.

Advancements in Ground Motion Prediction

- Very significant advancements in ground motion prediction have also been made.
- The Pacific Earthquake Engineering Research Center's Next Generation of Attenuation (NGA) ground motion models for tectonically active regions including the WUS is a major milestone.
- Efforts continue to refine these models and a parallel effort is being made for the CEUS as part of NGA-East.
- The significant issue that has always faced ground motion prediction in the CEUS is the absence of strong motion records of large earthquakes ($M > 6$) at short distances (<20 km.)

Advancements in Ground Motion Prediction

- NGA-East is a SSHAC Level 3 project.
- The goal is to produce a new ground motion prediction model for the CEUS.
- Magnitude range will be M 4 to 8 and distances out to 1000 km. Both horizontal and vertical ground motions will be estimated.
- Site response model will also be produced.
- All of these improvements in PSHA inputs will reduce the uncertainties in hazard estimation in the U.S.

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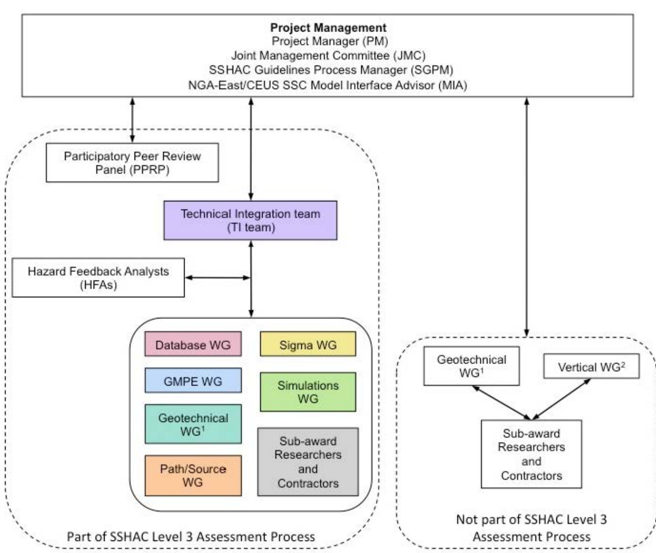
NGA-East Organization



Note: NGA-East has two sets of objectives: one for the SSHAC Level 3 objectives and a set of additional objectives outside of the SSHAC Level 3 assessment process.
[1] The Geotechnical WG has tasks associated with both sets of objectives.
[2] All the tasks associated with the Vertical WG are associated with non-SSHAC objectives.

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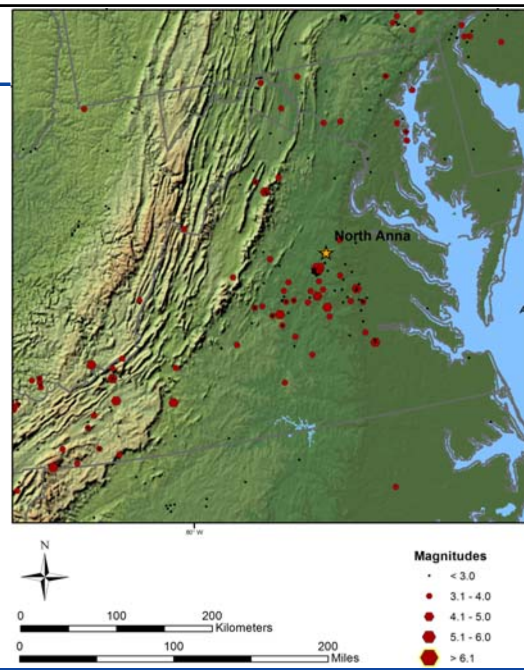
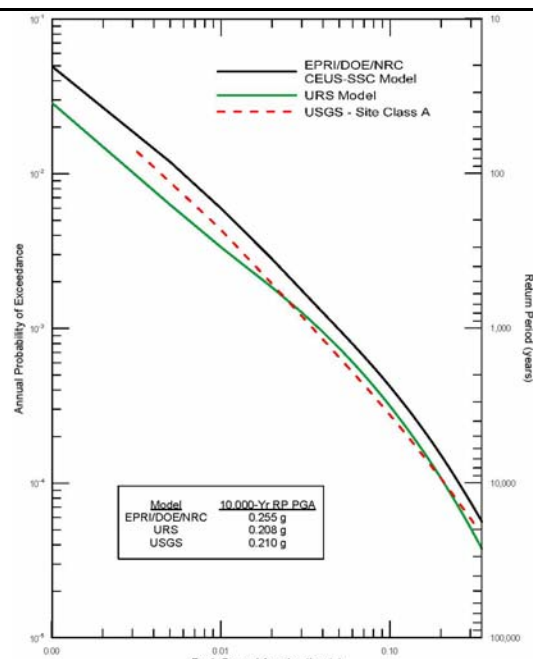
Central Virginia Seismic Zone (1534 to 2011)



PGA Rock Hazard Comparison of Seismic Source Models – North Anna Plant



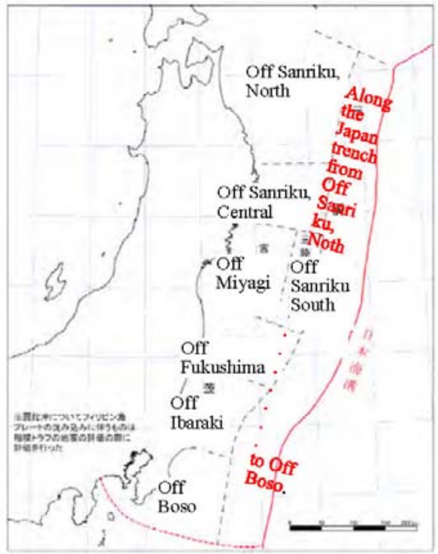
2011 M 5.8 Mineral VA Earthquake

- To some, last year's Mineral, VA earthquake was a surprise although it occurred within the Central Virginia Seismic Zone.
- The magnitude of the earthquake was greater by more than one magnitude unit than the largest historical event.
- Although the historical recurrence of the CVSZ predicts a M 6 every 1000 years, the return period of the ground motions recorded at the North Anna plant may be several orders of magnitude longer.

PSHA Stability

- How long are PSHA results stable? A typical response to this question is that if the uncertainties in inputs have been properly incorporated into a PSHA, the resulting hazard should accommodate changes in input parameters and hence be stable over time.
- That observation is indeed true but because the design of facilities is based on the mean hazard, there can be significant changes.
- A good example is the impact of the NGA-West models, which resulted in decreases up to 30% or more in the National Seismic Hazard Maps.
- Looking back at the stability of mean hazard results in the U.S. suggests that they are stable for only one to at most two decades.
- The practice of monitoring advancements in earth sciences and their impacts on hazard by a project even after a PSHA has been completed and a strong regulatory review process are essential to the PSHA process.

Assumed Segments of Earthquake Occurrence Along the Pacific Coast of the Tohoku Region



869 Sanriku Earthquake

- There was growing body of evidence that the subduction zone beneath northern Japan could produce a megathrust earthquake M > 8.4
- Y. Ikeda was the first to suggest that possibility in 2005
- There were 7 reviewed papers and a number of talks on this topic prior to 2008 (Chris Goldfinger, personal comm.)
- An examination of other subduction zones worldwide indicates that segments of subduction zones can rupture both in large earthquakes (M 8.8 to 9.2) and smaller events (M 8.0 to 8.6).
- So why was this information not evaluated and addressed in an updated PSHA for the Fukishima nuclear power plant?

Predicting Extreme Events

- As to the question of whether extreme hazards can be predicted, as long as the limitations and uncertainties in the *available* earth science are fully and continuously evaluated and incorporated into PSHAs, Fukishima-type incidents in theory should be avoided.
- "*Available*" is a key word and surprises can happen unless the necessary geologic and seismologic investigations are performed.
- That said, the uncertainty about the mean hazard should be more fully appreciated. Extreme events may be better reflected in the fractile hazard curves e.g., 84th percentile.
- This view has been proposed before (e.g., Abrahamson and Bommer) and in light of Fukishima, it should be revisited.

Summary

- The obvious question to be asked in the U.S. in regards to the nuclear power plant safety is:

  1) Are the tools we use today adequate and the knowledge sufficient to evaluate earthquake threats to insure new nuclear plants will be properly designed? Yes as long as there is proper implementation of the tools and the uncertainties in the inputs are recognized.
  2) Can "extreme" events such as Tohoku-Oki occur in the U.S.? Yes but the proper research needs to be performed and any new information needs to be continually reviewed and incorporated into PSHA updates.
  3) If so, can we accurately predict the resulting hazards, i.e., ground shaking, tsunamis, and other effects? Yes recognizing the significant uncertainties that are associated with any prediction of the earthquake process.