Overview and Scope of NRC’s Seismic Hazard Analyses

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Outline

• US NRC’s Seismic Hazard Analyses and Regulatory Perspectives
• Seismic hazard assessments for NPPs
• Seismic hazard assessments for spent fuel dry storage systems
• Seismic hazard assessments for fuel cycle facilities
• Ongoing research activities at the US NRC
Independent Spent Fuel Storage Installations

Fuel Cycle Facilities
Seismic Hazard Analyses for NPPs

- Hazard analyses for NPPs are the most rigorous, requiring in-depth analyses and calculations
- Site-specific
- When available, approved seismic source and ground motion models provide an expedited pathway to acceptable results
- Must conform to established regulations
Satisfying the Regulations

Regulatory Guide, RG 1.208 ‘A Performance-based approach to define the site-specific earthquake ground motion’, provides general guidance on procedures acceptable to the NRC staff to satisfy the Geologic and Seismic Siting Criteria outlined in 10 CFR 100.23.

**Elements of Seismic hazard Analyses:**

- Establish seismic source characterization models
- Establish ground motion prediction models
- Conduct Probabilistic Seismic Hazard Analysis (PSHA)
- Incorporate site response analysis
- Determine Ground Motion Response Spectra (GMRS)
Pathway to GMRS

- Site Selection
  - Geologic Investigations
  - Seismological Assessments

- Development of Earthquake Catalog
  - Identification of Seismic Sources

- Development of Seismic Source Models

- Ground Motion Prediction Models

- Site-specific, Seismic Hazard Curves - Generic Rock Conditions
  - PSHA Analysis
  - Site Response Analysis

- Site-specific Uniform Hazard Response Spectra at Surface

- Performance-based Site-specific GMRS

- Local Site Structure, Rock/Soil Physical Parameters
Seismic Source Models

- For the Central and Eastern United States (CEUS) there is an ‘NRC approved’ seismic source model that can be used as a starting model for any site in this region.

- For sites in the western United States, there are no approved starting seismic source models. Each applicant/licensee needs to develop its own seismic source model using acceptable methodologies (i.e., Senior Seismic Hazard Analysis Committee [SSHAC] processes)
CEUS Seismic Source Model

- Published as NUREG 2115 in January 2012
- Joint effort by NRC, DOE, and EPRI
- A generic, starting model applicable to any CEUS site
- Incorporates scientific information on seismic sources capable of producing earthquakes in the CEUS
- Composite model with varying alternatives
- Used in new reactor applications as well as re-assessment of seismic hazards for operating nuclear power plants.
CEUS Seismic Sources – Type 1/3
Repeated Large Magnitude Sources (RMLEs)
CEUS Seismic Sources – Type 2/3
Maximum Magnitude (Mmax) Sources
CEUS Seismic Sources – Type 3/3
Seismotectonic Sources
(one of four alternatives shown)
Ground Motion Prediction Models

- For the CEUS, there are approved ground motion models that can use used in PSHA calculations.
- As part of the Fukushima seismic re-evaluation, the industry established a working group and updated the EPRI (2004 and 2006) GMPEs in February 2013.
- Office of Nuclear Regulatory Research had a major effort to update the existing EPRI GMPEs under a collaborative project (NGA- East). Almost completed, but not yet formally reviewed and endorsed by the NRC.
Incorporating Local Site Effects into PSHA Calculations

• Local site characteristics are studied using geotechnical, geologic, and geophysical methods
• Dynamic properties of subsurface material are obtained through in-situ and laboratory measurements as well as geophysical methods
• Can be applied to hard-rock PSHA results, or directly incorporated into the PSHA calculations
Developing Performance-based Ground Motion Response Spectra (GMRS)

- Performance is measured in terms of Frequency of Onset of Significant Inelastic Deformation (FOSID), essentially elastic behavior
- Performance Target ($P_{FT}$) is $1 \times 10^{-5}$ per year
  - IPEEE Seismic PRAs conducted for 25 NPPs during mid/late 1990s determined annual seismic Core Damage Frequency values
  - Median SCDF is $1.2 \times 10^{-5}$/yr
Performance-Based Approach to Determine the site-specific GRMS

ASCE 43-05 and RG 1.208 define GMRS as:

\[ PB \ GMRS = DF \times UHRS_{10^{-4}} \]

\[ DF = \text{Max} \ (0.6A_R^{0.8}, 1.0) \]

\[ A_R = \frac{UHRS_{10^{-5}}}{UHRS_{10^{-4}}} \]

DF: Design Factor
AR: Hazard curve slope
UHRS_{10^{-5}} and UHRS_{10^{-4}}: mean Uniform hazard response spectra with annual probability of exceedance of 10^{-5} and 10^{-4}
NPP Site Specific Ground Motion vs. Design

Plant Design

Site-specific Ground Motion Response Spectra (GMRS)

Sa (g)
Spent Fuel Dry Storage Facilities

- Must conform to regulations defined in 10 CFR 72.103
- Can be
  A: Site-specific (similar to NPP analysis)
  B: General license (under an existing NPP)
- NUREG 1567 ‘Standard Review plan for Spent Fuel Dry Storage Facilities’ provides how NRC reviews these seismic hazard studies
Fuel Cycle Facilities

• Must conform to regulations defined in 10 CFR 70.22
• Seismic hazard assessed using established building codes
• NUREG 1520 ‘Standard Review Plan for Fuel Cycle Facilities License Applications’ provides how NRC reviews these seismic hazard studies
Current Activities at US NRC

• Under an Interagency agreement with the USGS, assessing existing seismic source and ground motion models to identify areas needing modification/improvement
• Multi-dimensional site response analyses
• Continuous assessments of seismic hazards at the operating nuclear power plants
• Participation in international activities through the IAEA to develop guidance on physics-based simulations, probabilistic fault displacement hazard analyses and PSHA validation methodologies.
Conclusions

• NRC is a key consumer of new data, information, and knowledge gained by the scientific community at large
• NRC conducts its own confirmatory research activities and works with outside partners in government (e.g., USGS) and academia to address regulatory needs
• NRC seismic hazard analyses follow unique sets of requirements that highlight the importance of constant engagement between scientific community and policy makers
Backup Slides
Probabilistic Seismic Hazard Analysis (PSHA)

Input 1: Seismic Sources

Input 2: Earthquake Recurrence

Input 3: Ground Motion Models

Output: Seismic Hazard Curves

Modified from Reiter (1990)
Pathway to Performance-Based GMRS

Seismic Source Models
- Based on geologic investigations
- Ground Motion Prediction Equations
- Earthquake Catalog

Site-specific Corrections (Geotechnical Observations)

Generic Rock, Uniform Hazard

Seismic Hazard Curves

Comparison with Design

Surface UHRS at site

PSHA
Characterize Seismic Hazard

\[ \lambda(S_a > x) = \sum_{i=1}^{n_{sources}} \lambda(M_i > m_{\text{min}}) \sum_{j=1}^{n_M} \sum_{k=1}^{n_R} P(S_a > x \mid m_j, r_k) P(M_i = m_j) P(R_i = r_k) \]

magnitude recurrence curve such as Gutenberg-Richter (G-R)

use ground motion prediction equation for \( S_a \)

model distribution of distances from earthquakes to site

develop pdf assuming bounded G-R recurrence with \( m_{\text{min}} \) and \( m_{\text{max}} \)
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