Seismic Hazards and Risk at U.S. Nuclear Power Plants: An NRC Perspective

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• Background and Regulatory Framework
• NRC Activities and Codes/Standards
• Post-Fukushima Activities
• Seismic/Structural Research Plan
• Summary
• Significant advancements in our understanding of seismic hazard processes have occurred since the existing fleet of reactors was licensed
  – Review of new reactor applications and Post-Fukushima seismic re-evaluations
• Evaluation of the impact of these changes on plant safety is not straightforward
### History of Seismic Reevaluations

| USI-A46 | Unresolved Safety Issue-A46 | 1980s | Seismic operability of equipment in older NPPs. Resulted from development of seismic qualification of equipment. SQUG formed by industry. Assessment approaches developed. |
| IPEEE | Individual Plant Examinations for External Events | 1990s | Evaluation at or beyond design loads. Generally qualitative with emphasis on risk insights. Resulted from increased awareness of potential for beyond DBE loads & advances in SPRA. |
| GI-199 | Generic Issue-199 | 2005-2012 | Assess implications of updated seismic hazard estimates in the CEUS. Resulted from ESP applications at co-located NPPs |
| NTTF R2.1 | Near Term Task Force Recommendation2.1 | 2012-Ongoing | Reevaluation of seismic and flood hazard and risk as one of many recommendations in the NTTF report published after the Fukushima Daiichi accident. |
These re-evaluations were in response to:

- Increased scientific knowledge regarding seismic sources and associated ground motions
- The Commission’s 1985 *Severe Accident Policy Statement* (SECY-86-162)
- These re-evaluations and generic issues have been accompanied by industry, DOE, and NRC research programs

To address lessons-learned from recent licensing reviews and safety assessments (new reactors, licensing amendments, and post-Fukushima safety re-assessments of operating reactors)

Informing periodic seismic hazard re-evaluations and, as needed, review of ongoing seismic re-evaluations (SECY-15-137).

Assessing the safety implications of new knowledge
Important Drivers and Outcomes:

- Continue to advance the potential for risk-informed and performance-based (RIPB) approaches to regulation of seismic and structural safety for nuclear facilities.
  - Update NRC guidance (regulatory guides (RG) and Standard Review Plan) for seismic design and analysis.
  - Incorporate RIPB philosophy to align with developments by the design community, industry (Standards Development Organizations) and other external stakeholders.
- Facilitate extending or updating the regulatory framework to designs other than large LWRs (NLWRs) in a manner that minimizes technology-specific aspects.
- Supporting subsequent license renewal (SLR) (SECY-14-016) and long-term operations (LTO)
Evolution of Performance-Based and Risk-Informed Seismic Design

**DOE and consensus standards**

- **DOE 1020-2002**
  - Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities (updated in 2012)

- **ASCE 43-05**
  - Establishes criteria for risk-informed performance-based seismic design (Reviewed in NUREG/CR-6926)

- **ASCE 43 Update (2018)**
  - ASCE 4 Update (2016)
  - Seismic and structural analysis (consistent with ASCE 43)

- **ASCE 1 (Update) (2018)**
  - Geotechnical analysis and design

**GDCs**

- **RG 1.60**
  - Standardized seismic design response spectra

- **10CFR100.23**
  - Requires addressing uncertainties in SSE estimates and permits use of PSHA

- **10CFR50 App. S**
  - Relocated seismic engineering design criteria in Part 50

- **RG 1.165**
  - PSHA guidance

**1971-1973**

- **1973**
  - RG 1.208 Update
  - New RGs
  - Performance-based seismic design criteria and analysis

- **SRP Revisions**
  - Advanced Reactors
  - Performance-based guidance

**2005**

- **2007**
  - Performance-based approach for site-specific earthquake ground motion

**2016-2021**

- **> 2021**
  - Other hazards
Seismic Codes and Standards: Relationship to NRC Activities

• NRC staff involved in relevant codes and standards development
  – Risk-informed Performance-based Seismic Design Criteria (ASCE 43---impact on RG 1.208 update)
  – Seismic Analysis for Risk-informed Performance-based Design (ASCE- 4, 43, and 1--- impact on seismic analysis RGs and SRP)
    • Includes geotechnical analysis/design and SSI
  – ASME/ANS PRA Standard
  – Performance-based Approach for Seismic Design of Non-LWRs
  – Seismic Hazard Evaluation (ANS-2.26, 2.27, and 2.29---impact on RG 1.208 update and SRP)
 Insights from Fukushima
NTTF R2.1 Process

• NRC staff reviewed licensee submittals and performed detailed independent confirmatory analyses for more than 50 plant sites (~90 reactors)
  – Plants located in the Central and Eastern U.S. relied on consensus regional models (CEUS-SSC and EPRI GMM)
  – Western U.S. plants performed site-specific hazard analyses
  – All developed following Senior Seismic Hazard Analysis Committee (SSHAC) guidelines

• For CEUS plants: completely independent analyses performed

• For WUS plants: selective evaluation of hazard significant elements of models
WUS Example: PSHA Confirmatory- YFTB Host Source Zone

- Developed 0.25° Grid
- Place 204 virtual faults in source zone
- Randomly orient between N60°E and N120°E ($F_{\text{rev}}$)
- $M_{\text{max}}=6.8$ & uniform rate
- Truncated exponential MFD
- Run hazard for each virtual fault
Example: NRC Staff’s Site Response Sensitivity Analyses

- Epistemic uncertainty for upper base-case $V_s$ profile-
  - Evaluate-
    - Single vs. multiple profiles
- Sedimentary interbeds within Saddle Mtn. Basalts
  - Evaluate-
    - Interbed dynamic properties
    - Potential absence of interbeds
• New reactor reviews and post-Fukushima NTTF R2.1 re-evaluation process have identified issues:
  – Systematic incorporation of uncertainty into site response analysis
  – Use of multiple approaches to characterize site kappa
  – Use of Method 3 to develop final hazard curves
  – Use of partially non-ergodic sigma for WUS sites
  – Use of new approaches to capture range of median GMPEs
  – Use of site (Vs-kappa), source, and path adjustments for median GMPEs
• These issues have been incorporated into the updated version of the NRC Seismic Research Plan.
Seismic, Geotechnical and Structural Engineering Research Plan (SGSERP)

• A comprehensive, integrated plan across disciplines
  – Recognizes inter-relationships and dependencies between projects, subject areas, and standards development organizations

• Significant interaction with technical staff in NRC user offices and external stakeholders/entities in development of plan

• Plan continues development of tools and processes to support application of performance-based and risk-informed approaches to design and safety assessment

• Also addresses other current or anticipatory issues
  – (Subsequent License Renewal, Long-term Operations, Repair)
Seismic Analysis - Overview

Chapter 2.1
Chapter 2.2
Chapter 2.3
Chapter 3.1
Chapter 4
• Significant advancements in our understanding of seismic hazard processes have occurred since the existing fleet of reactors was licensed
  – These advancements pose regulatory challenges
  – Implementation of PBRI processes help to address these challenges
• Process implemented for NTTF R2.1 utilizing current regulatory framework provides a risk-informed method to evaluate the potential safety significance of these changes.
  – Provides transparent “linkage” to NTTF R2.2 which requires periodic re-assessment of natural hazards
• A number of important future research objectives have been identified as a result of Fukushima response
• The SGSERP contains research projects to address many of these issues
Please Note: Upcoming session on Seismic Safety: RIPB Approaches at NRC RIC 3/16/2017 AM
Integration of SGSERP Topics