Seismic Hazard Definition through a SSHAC Level 1 Study at the Idaho National Laboratory for the Seismic Hazard Periodic Reevaluation Methodology

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Presentation Overview

• Seismic Risk Assessment Project at INL
• Risk-Informed Seismic Hazard Periodic Review Methodology
• Implementation of SSHAC Level 1 PSHA study at INL
• Inputs to the Risk-Informed Methodology
  – Approach to identify changes
  – Hazard results
• Lessons Learned

** Annie Kammerer will present application of the Risk-Informed Methodology at 10:15 am after the break

PSHA – Probabilistic Seismic Hazard Analysis
SSHAC – Senior Seismic Hazard Analysis Committee
**INL Seismic Risk Assessment (SRA) Project**

- Goal was to develop a “Risk-Informed Methodology” to assess the need for an update of the PSHA when considering existing facilities.

- Selected a SSHAC Level 1 PSHA to produce:
  - Mean-centered definition of the seismic hazard with appropriate treatment of uncertainties and technical justification.
  - Defensible, well-documented basis to make comparisons with the existing technical underpinnings of the current seismic design basis for the facility of interest.

- Candidate nuclear facility was chosen as the Fuels Manufacturing Facility (FMF) at the Materials and Fuels Complex (MFC) at INL.

- FMF is classified as SDC-3 with a Target Performance Goal at $1 \times 10^{-4}$ and Hazard Exceedance Probability of $4 \times 10^{-4}$ (as defined by ASCE/SEI 43-05).

SDC – Seismic Design Category.
## Risk-Informed Seismic Hazard Periodic Review Methodology

<table>
<thead>
<tr>
<th>#</th>
<th>Evaluation Criterion</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Change in data, models, or methods?</td>
<td>Yes or No</td>
</tr>
<tr>
<td>2</td>
<td>Change in hazard input models?</td>
<td>Derived from SSHAC L1 or L2</td>
</tr>
<tr>
<td>3</td>
<td>Change in technical basis?</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Change in mean hazard?</td>
<td>Yes or No</td>
</tr>
<tr>
<td>5</td>
<td>Design Basis Ground Motion &gt; Seismic Design CategoryGround Motion?</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Design Basis Ground Motion &gt; Ground Motion Response Spectrum?</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Risk objectives met?</td>
<td></td>
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</tbody>
</table>
INL SSHAC Level 1 Study Had 5 Components

1. Cleary defined roles and responsibilities for the participants

2. Objective evaluation of available data, models, and methods

3. The outcome of the evaluation process was integrated into SSC and GMC models that reflected both the best estimate and the associated uncertainty

4. Thoroughly documented the study to allow reproduction of the hazard analyses (including Hazard Input Documents and Summary Data Table)

5. Technical and procedural reviews throughout the entire study performed by a Participatory Peer Review Panel (PPRP)

GMC - Ground Motion Characterization
SSC - Seismic Source Characterization
Features of INL SSHAC L1 Study

• Work Plan defined and scheduled key tasks and activities
  – Developed at 3-day kick-off meeting held at INL
  – Involved the Technical Integration (TI) Team and PPRP
  – All attended a 1-day field trip at INL
  – Work Plan issued within 3 weeks of the meeting

• Project SharePoint site setup to exchange files and work on documents

• TI Team and PPRP held conference calls every 3-4 weeks (7 calls)

• On-site review and presentation to the SRA project

• INL SSHAC L1 study was completed in 10 months
Participatory Peer Review Panel

- Provided technical and procedural reviews from start to finish

- Technical reviews ensured:
  - Full range of data, models, and methods were considered
  - Captured the center, body, and range of technically defensible interpretations
  - Technical decisions were adequately justified
  - HID was complete and adequate for the PSHA calculations

- Procedural reviews ensured:
  - Work Plan was implemented
  - TI Team addressed issues and implemented recommendations that were identified during conference calls
  - INL SSHAC Level 1 PSHA conformed to the SSHAC process

- Concurrence provided through a PPRP Closure Letter
Compilation of Existing Data and Models

Project Databases

Evaluation by TI Teams

Integration by TI Teams

SSC and GMC Logic Trees

PSHA Calculations

Project Documentation (PPRP Closure Letter)

Process and Technical Review (PPRP)

Work Flow
INL SSHAC
Level 1 PSHA
INL SSHAC Level 1 PSHA – SSC Model

• Compiled data and information from literature and existing studies including:
  – Expansion of the regional earthquake catalog 1850-2014
  – New data such as geodetic data and interpretations
  – Source geometries, recurrence rates, maximum magnitudes, and associated uncertainties

• Considered methods and models from other SSHAC studies and previous INL PSHAs
  – Hanford SSHAC Level 3 PSHA (PNNL, 2014)
  – INL fault sensitivity analysis (AMEC, 2013)

• INL SSHAC Level 1 SSC model included
  – Updates of earthquakes sources used in 1996 and 2000 INL PSHAs
  – New earthquakes sources
  – Cascadia plate interface source as a sensitivity analysis
SSHAC L1 SSC Sensitivity Analyses

Cascadia Plate Interface Source

~900 km from INL

$\geq M 9$ earthquakes

High recurrence rates

Included the SSHAC Level 3 BC Hydro (2012) model with the PNNL (2014) modifications
SSHAC L1 SSC Model

**Regional source zones**
- Eastern Snake River Plain (ESRP) host zone
- 10 tectonic source zones

**Volcanic source zones**
- INL Volcanic Regional Zone (IVRZ)
- Great Rift (GRF)

**Local faults**
- Lost River (LRF), Lemhi (LF), and Beaverhead (BF)

**New Source Models**
- Centennial Shear Zone (CSZ#)
- Big Lost fault (BLF)
- 12 Regional faults
INL SSHAC Level 1 PSHA – GMC Model

- Compiled subsurface data and information from literature and existing studies for MFC, INL site-wide, and ESRP
- Considered models and methods for GMC from other SSHAC studies
- Implemented the Southwestern U.S. (SWUS) GMC model:
  - Specifically developed for normal faulting
  - Has SSHAC Level 3 pedigree and Hazard Input Document
  - Adjusted the model to site-specific conditions at MFC
  - Used the SWUS partially non-ergodic variability model
- Estimated kappa and its uncertainty using 27 new regional earthquake recordings (M 3-5) for seismic station at MFC
- Updated the site-specific Vs profile for MFC using measured Vs in the nearby 600-m-deep borehole and shallow boreholes
INL SSHAC Level 1 PSHA Products

• Preliminary and final seismic hazard products
  – Rock outcrop conditions for MFC
  – Site-specific soil surface for FMF
• Dissection of hazard uncertainty contributions
• Sensitivities to the hazard for SSC and GMC models and specific sensitivity analysis
• Mean seismic hazard curves at AEFs $10^{-2}$ – $10^{-8}$
• At 10 Hz and PGA, mean seismic hazard curves at the 5th, 15th, 50th, 85th, and 95th percentiles
• Horizontal mean UHRS at return periods 2,500, 10,000, 25,000, and 100,000 yrs

AEF – Annual Exceedance Frequency
PGA – Peak Ground Acceleration
UHRS – Uniform Hazard Response Spectrum
## Evaluation Criteria for the Risk-Informed Methodology

<table>
<thead>
<tr>
<th>Evaluation Criterion 1</th>
<th>Evaluation Criterion 2</th>
<th>Evaluation Criterion 3</th>
<th>Evaluation Criterion 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes to data, models, and methods?</td>
<td>Changes to input SSC or GMC models?</td>
<td>Changes to the technical bases?</td>
<td>Change in mean hazard?</td>
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| Requires that all relevant new and updated data, models, and methods used in the current hazard be identified to assess how they differ from what was used in the baseline PSHA supporting design basis | Requires that changes to the SSC and GMC inputs (including associated aleatory and epistemic uncertainties) in the current PSHA model be identified based on the changes identified under Evaluation Criterion 1 | Requires an evaluation of whether or not the technical bases for the SSHAC Level 1 or 2 hazard have changed, even if the calculated hazard does not indicate a significant change | Requires a comparison of the baseline PSHA hazard results with the SSHAC Level 1 or 2 to determine if there are significant changes |
Approach to Identify Changes (Qualitative)

- Evaluation Criterion 1
  - **New** means was not previously available or the technical justification was insufficient to be included in baseline hazard
  - **Updated data** means combining new data with existing data

- Evaluation Criterion 2
  - **New** means model inputs were not used in the baseline hazard
  - **Updated** means model inputs are similar to models used baseline hazard and can include different aleatory and epistemic uncertainties

- Evaluation Criterion 3
  - **Updated Technical Basis**: Updated data or new methods led to input of the same or similar models with associated uncertainties
  - **Change to Technical Basis**: New data, models or methods led to new and different input models or uncertainties
  - **New Technical Basis**: New data, models, and methods led to new SSC or GMC models supported by new justifications that are distinctly and largely different than baseline hazard
Approach to Identify Changes For Evaluation Criterion 4

- Defined **Significance** in two ways

1. Qualitative measure as *meaning*
   - Specifies the implications to the current hazard for the identified changes under Evaluation Criteria 1, 2, and 3
   - Defines why quantitative changes occur in the current hazard
   - Can be used to identify future data collection needs

2. Quantitative measure as *impact*
   - Comparison of seismic hazard curves for the baseline hazard and SSHAC Level 1 or 2 hazard
   - Identifies the AEFs or spectral frequencies where changes occur
   - Is used to determine the yes or no response
## Updated Data & New Methods --> Updated SSC Model

<table>
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<tr>
<th>Change Relative to the 1996 and 2000 INL PSHAs</th>
<th>Evaluation Criterion 1</th>
<th>Evaluation Criterion 2</th>
<th>Evaluation Criterion 3</th>
<th>Evaluation Criterion 4 Significance (or Meaning) to INL SSHAC L1 Hazard</th>
</tr>
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<td>Changes to data, models, and methods?</td>
<td>Changes to input SSC or GMC models?</td>
<td>Changes to the technical bases?</td>
<td>Implications or why changes occur to the current hazard</td>
<td></td>
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<tr>
<td>Updated 1850-2014 earthquakes</td>
<td>Updated recurrence models and uncertainties for tectonic source zones</td>
<td>Updated technical basis for earthquake recurrence within tectonic source zones</td>
<td>More appropriate treatment of uncertainties for earthquake magnitude and recurrence estimates</td>
<td></td>
</tr>
<tr>
<td>New methods (e.g., Updated conversion relations for expected moment magnitude $E[M]$ and $N^*$ for magnitude uncertainties)</td>
<td></td>
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New Model -- New Model for Aleatory and Epistemic Uncertainties

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<td>New model incorporated the effective total sigma (combined aleatory and epistemic) for the GMM</td>
<td>Implemented the SWUS partially non-ergodic variability model that separately evaluates the two components, event-to-event variability and single station within-event variability</td>
<td>Change to the technical basis to incorporate the combined aleatory and epistemic sigmas for GMM</td>
<td>Use of a partially non-ergodic variability rather than a fully ergodic variability as used in baseline PSHA</td>
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Evaluation Criterion 4

MFC (Rock)
1996 PSHA vs 2015 SSHAC L1 PSHA

- Lower median motions from the adjusted SWUS GMPEs compared to 1996
- Lower effective total sigma (combined aleatory and epistemic) in 2015 than the 1996 PSHA ergodic sigmas

Changes in use of $E[M]$ and $N^*$ approach for recurrence models for source zones produced lower hazard
**Evaluation Criterion 5**

Requires a comparison between the estimated mean hazard, expressed as the UHRS at the Hazard Exceedance Probability specified for the SDC category for the facility of interest and the DBGM that exists for the facility (ASCE/SEI 43-05)

![Graph showing horizontal spectral acceleration vs frequency comparing 2015 UHRS, AEF 4E-4 and 2006 DBGM for FMF (5-15 ft Soil) and indicating DBGM > UHRS (AEF 4x10^-4) at SDC-3]
Evaluation Criterion 6

Requires a comparison between the GMRS (or DRS) at the SDC category for the facility of interest and the DBGM that exists for the facility (ASCE/SEI 43-05)


Lessons Learned

• SSHAC Level 1 Study at INL demonstrates:
  – Implementation of SSHAC processes and short-duration study
  – Use of a small team of participants with multiple roles and responsibilities
  – Viability of a two-person PPRP

• Developing input to the Risk-Informed Methodology
  – Identify the SDC levels and spectral frequencies of interest to the existing facilities selected and compute hazard at these values
  – Consider the hazard products needed for potential analyses of fragilities and PRAs (e.g., Evaluation Criterion 7)
  – Use a systematic approach to identifying qualitative changes

• INL SSHAC Level 1 provides a starting point for a future SSHAC Level 3 update and potential areas for future data collection