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DEVELOPMENT AND APPLICATION OF THE SEISMIC HAZARD PERIODIC REEVALUATION METHODOLOGY FOR MEETING DOE ORDER O 420.1C AT IDAHO NATIONAL LABORATORY

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ABSTRACT

U.S. Department of Energy Order, DOE O 420.1C, establishes programmatic and facility requirements for nuclear facility design, including natural hazard mitigation. This includes criteria for periodic seismic assessment at sites of existing nuclear facilities with seismic design category-3 (SDC-3) or higher. The Order points the reader to other supporting documents that provide additional supporting criteria and approaches for evaluating the need to update an existing PSHA. While all the supporting documents are consistent at a high level, none of the documents provides step-by-step detailed guidance. Additionally, the conceptual approaches and criteria given in these documents deal only with changes related to the hazard assessment and do not address the capacity of the facility to withstand vibratory ground motions.

To address the limitations of the available guidance, Idaho National Laboratory (INL) undertook activities to develop and apply a risk-informed approach to meeting the Order. These activities included organizing the INL Seismic Risk-Informed Methodology Independent Panel, which developed a new risk-informed methodology referred to as the *seismic hazard periodic re-evaluation methodology* (SHPRM) as detailed in INL Report INL/EXT-15-36510.

The SHPRM was applied at two existing INL SDC-3 facilities: the Fuel Manufacturing Facility (FMF) and Zero Power Physics Reactor (ZPPR). The application of the SHPRM started with a PSHA study conducted using the Senior Seismic Hazard Analysis Committee (SSHAC) guidelines for a Level 1 (SL1), consistent with recommendations by the SHPRM Report. Once the SL1 seismic hazard model and results were developed, the review criteria that form the backbone of the SHPRM were evaluated, as detailed in Appendix A of INL Report INL/EXT-16-37751.

BACKGROUND

U.S. Department of Energy (DOE) Order, DOE O 420.1C (DOE 2012a), establishes programmatic and facility requirements for natural phenomena hazard (NPH) mitigation, including criteria for seismic assessment at sites of existing nuclear facilities with seismic design category-3 (SDC-3) or higher[1]. DOE Order 420.1C requires that all SDC-3 facilities review their NPH assessments no less than every ten years and evaluate the need for an update. The Order points to criteria in Standard DOE-STD-1020-2012. This

[1] SDC categories are described in Standard ASCE/SEI 43-05 (ASCE 2005)

Standard also references other documents such as Standard ANSI/ANS-2.29-2008 (ANSI/ANS, 2008) and NUREG-2117 (NRC, 2012). These documents provide supporting criteria and approaches for evaluating the need to update an existing PSHA. All of the documents are consistent at a high level regarding the general conceptual criteria to be considered. However, none of the documents provides step-by-step detailed guidance on the required or recommended approach to evaluating whether or not an existing PSHA should be updated.

Further, all of the conceptual approaches and criteria given in these documents deal only with hazard-related changes. Given that the DOE Order is aimed at ensuring the safety of nuclear facilities—which is a function not only of seismic hazard but also the seismic capacity of the facility—the inclusion of risk information in the evaluation process is in line with the spirit and objectives of the Order. However, no risk-informed guidance existed that could be directly applied.

DEVELOPMENT OF THE SEISMIC HAZARD PERIODIC RE-EVALUATION METHODOLOGY

To address the limitations of the available guidance for meeting the DOE Order, Idaho National Laboratory (INL) undertook activities to develop and apply a risk-informed approach to meeting the Order. These activities included organizing the INL Seismic Risk-Informed Methodology Independent Panel, which developed a methodology referred to as the *seismic hazard periodic re-evaluation methodology* (SHPRM) as detailed in INL Report INL/EXT-15-36510, Revision 1 (Kammerer et al., 2015). The SHPRM is a risk-informed methodology that provides a graded approach appropriate for SDC-3, SDC-4, and SDC-5 facilities. Figure 1 shows the SHPRM flowchart for a SDC-3 nuclear facility.

Seven criteria (summarized below) are used in the meethodology. The first four criteria are from DOE-STD-1020-2012 and are supported and amplified in ANSI/ANS-2.29-2008 and NUREG-2117. These address the inputs to the hazard analysis and the hazard results themselves. Criteria #5 through #7 are proposed to provide additional risk-focused considerations. These seven criteria are applied slightly differently for SDC-3, SDC-4, and SDC-5 facilities due to the differing radiological risk of the categories. Because a confident basis is needed for applying the criteria, a site-specific SSHAC Level 1 (SL1) or 2 (SL2) study is conducted as a starting point. The study should include (an assessment of associated uncertainties and in-process peer review).

Criterion #1 requires that all relevant new and updated data, models, and methods be identified, compiled and evaluated to determine if relevant new information is available beyond that used for the original PSHA.

Criterion #2 requires that appropriate changes to the PSHA model be determined and implemented based on the activities associated with Criterion #1. Important inputs to the hazard model include those required for the seismic source characterization, ground motion characterization, and near-surface site response analysis.

Criterion #3 evaluates whether the technical bases for the PSHA model have changed, even if the calculated hazard has not changed. The technical bases include the technical arguments and justifications for the hazard inputs and the associated treatment of uncertainties.

Criterion #4 compares the original hazard results with estimated results from an updated model, accounting for the precision with which mean seismic hazard is typically calculated.

Criterion #5 compares the mean hazard at the hazard exceedance probability specified for the SDC category (Table 1) to the facility's design basis ground motion (DBGM).

Table 1: Target performance goals, probability ratios, and hazard exceedance probabilities recommended for design of nuclear facilities (summarized from Table 2-2 of ASCE/SEI-43-05).

Earthquake Design Parameters			
	Seismic Design Category (SDC)		
	3	**4**	**5**
Target Performance Goal (P_F)	1×10^{-4}	4×10^{-5}	1×10^{-5}
Probability Ratio (R_P)	4	10	10
Hazard Exceedance Probability (H_D)	4×10^{-4}	4×10^{-4}	1×10^{-4}
Note: $H_D=R_P \times P_F$			

Criterion #6 is similar to #5, but the basis for comparison is a Ground Motion Response Spectrum (GMRS), as defined for SDC-5 NPPs in NRC Regulatory Guide (RG) 1.208 (NRC, 2007). The GMRS is developed based on a uniform hazard spectrum (UHS) at an annual frequency of exceedance (AFE) of risk significance coupled with "Design Factors" (DF) that account for the slope of the hazard curve at the AFE. The GMRS was used by the NRC as a risk-informed screening measure for the post-Fukushima evaluation of all US NPPs (NRC, 2012c).

The GMRS in RG 1.208 defines a level of ground motion for design that will confidently ensure that risk levels of NPPs are within acceptable limits. The definition of GMRS for SDC-3 and SDC-4 categories must also achieve the appropriate target performance goals. Unfortunately, at the time of this writing, modification factors for SDC-3 and SDC-4 facilities have not been published. However, the upcoming revision of ASCE 43 is expected to provide "Scale Factors" (SF) similar to the DF in ASCE 43-05. Until these SF are published, there are three options: (1) do not calculate the GMRS and follow the "no" path from Criterion #6 to Criterion #7, (2) develop and justify a site-specific GMRS following the concepts in ASCE 43-05, or (3) use GMRS processes for SDC-5 facilities. Facilities outside the US could make use of this approach for determining GMRS, provided that their facilities have similar seismic capacities (and can meet similar performance criteria). Alternately, country-specific factors could be developed.

Criterion #7 is a comparison of the facility-specific risk information against risk-informed criteria. Risk-informed criteria are both quantitative (e.g., performance goals in ASCE/SEI-43-05) and qualitative (e.g., diversity of risk-significant equipment and accident sequences). The criteria discussed in (INL, 2015b) are specific to US regulatory frameworks. However, other countries can make use of this approach by defining the specific basis for risk-informed decision-making consistent with their own risk-informed regulatory frameworks.

APPLICATION AT INL'S FUEL MANUFACTURING FACILITY AND ZERO POWER PHYSICS REACTOR

The SHPRM was applied at two existing INL SDC-3 facilities: the Fuel Manufacturing Facility (FMF) and Zero Power Physics Reactor (ZPPR). The application of the SHPRM started with a PSHA study conducted using the Senior Seismic Hazard Analysis Committee (SSHAC) guidelines for a Level 1 (SL1), consistent with recommendations by the SHPRM Report (Kammerer et al., 2015). Once the SL1 seismic hazard model and results were developed, the review criteria that form the backbone of the SHPRM were evaluated, as detailed in Appendix A of INL Report INL/EXT-16-37751 (Kammerer, Payne and Coleman, 2016).

Because a confident basis is needed for applying the criteria, the SHPRM Report recommends starting with a site-specific probabilistic seismic hazard analysis (PSHA) study conducted using the Senior Seismic Hazard Analysis Committee (SSHAC) guidelines for a Level 1 or 2 study (hereafter noted as "SL1" or

"SL2" study). The application of the SHPRM at the FMF and ZPPR started with a SL1 study that is documented in INL (2016b). Once the SL1 seismic hazard model and results were developed, the review criteria that form the backbone of the SHPRM were evaluated. The evaluation requires that both the baseline PSHA study and the Design Basis Ground Motions (DBGM) of the facility be determined and documented. This information is provided in detail in Appendix A (Kammerer, Payne and Coleman, 2016) of INL report INL/EXT-16-37751 (INL 2016a).

FMF AND ZPPR STUDY RESULTS

As described by Kammerer, Payne and Coleman (2006), the application of SHPRM stepped through analysis of each of the criterion. Criteria #1 to #4, are focused on earth science-related evaluations that come directly from DOE-STD-1020 (DOE 2012b) and its supporting documents. The evaluation of Criterion #1 determined that a significant level of new data, models and methods are available as compared to those used in the baseline PSHA for the facilities, leading to a "yes" outcome. The evaluation of Criterion #2 determined that the new information would lead to development of a new PSHA model. The evaluation of Criteria #3 determined that the technical bases that underpin the baseline PSHA were no longer viable. The evaluation of Criterion #4 determined that the resulting hazard estimates have decreased in some cases of interest, and increased in others, as compared to the baseline (original) PSHA model. As a result, consistent with the methodology in Figure 1, additional decision making criteria were evaluated.

Criteria #5 through #7 are focused on understanding the safety and risk implications of new hazard information. The evaluation of Criterion #5 determined that the DBGM for the FMF and ZPPR meet or slightly exceed both the Uniform Hazard Spectrum (UHS) at the annual frequency of exceedance (AFE) provided in Structural Engineering Institute of the American Society of Civil Engineers (Standard) ASCE/SEI 43-05 (ASCE 2005) for SDC-3 facilities. This outcome included evaluation two small exceedances using the narrow-band exceedance process as described in Appendix A to INL/EXT-16-37751. The evaluation of Criterion#6 determined that each DBGM for the FMF and ZPPR meet or slightly exceed the Ground Motion Response Spectra (GMRS) calculated for the facilities following Nuclear Regulatory Commission guidance (NRC, 2007). The GMRS is the ground motion that would be used for design of a new facility following ASCE/SEI 43-05.

Given these evaluations, according to the SHPRM, an update to the PSHA is not required to meet the DOE Order and further risk evaluations are not required for the SHPRM. However, completion of the SHPRM methodology requires that the evaluation process is completely documented.

While the SL1 study provides a reliable basis for evaluating the need for an update of a PSHA, the SL1 study is not, in itself, an update and should not be used for purposes of design or safety assessments. Consistent with the SHPRM, the existing PSHA remains in place and should be used as the baseline for the next 10-year reevaluation. The SL1 PSHA can be thought of as a useful starting point for any new PSHA study at INL. The documentation of the evaluation process (including this report and its appendix and the complete set of documentation for the SL1 PSHA) is intended to be sufficient to meet the requirements of the DOE Order for the current 10-year reevaluation.

INSIGHTS GAINED ROM APPLICATION OF THE SHPRM AT FMF AND ZPPR

A set of insights gained during the application of the SHPRM to the FMF and ZPPR facilities was presented in December of 2016 (Kammerer et al. 2016).

These insights included the following:

- A new approach to assessing inputs to the PSHA was needed in order to transparently perform and document the evaluation of Criteria 1 to 4. Tables 1 and 2, below, show the approach to

documentation and an example application, respectively. The complete evaluation is available in Kammerer, Payne and Coleman (2016).

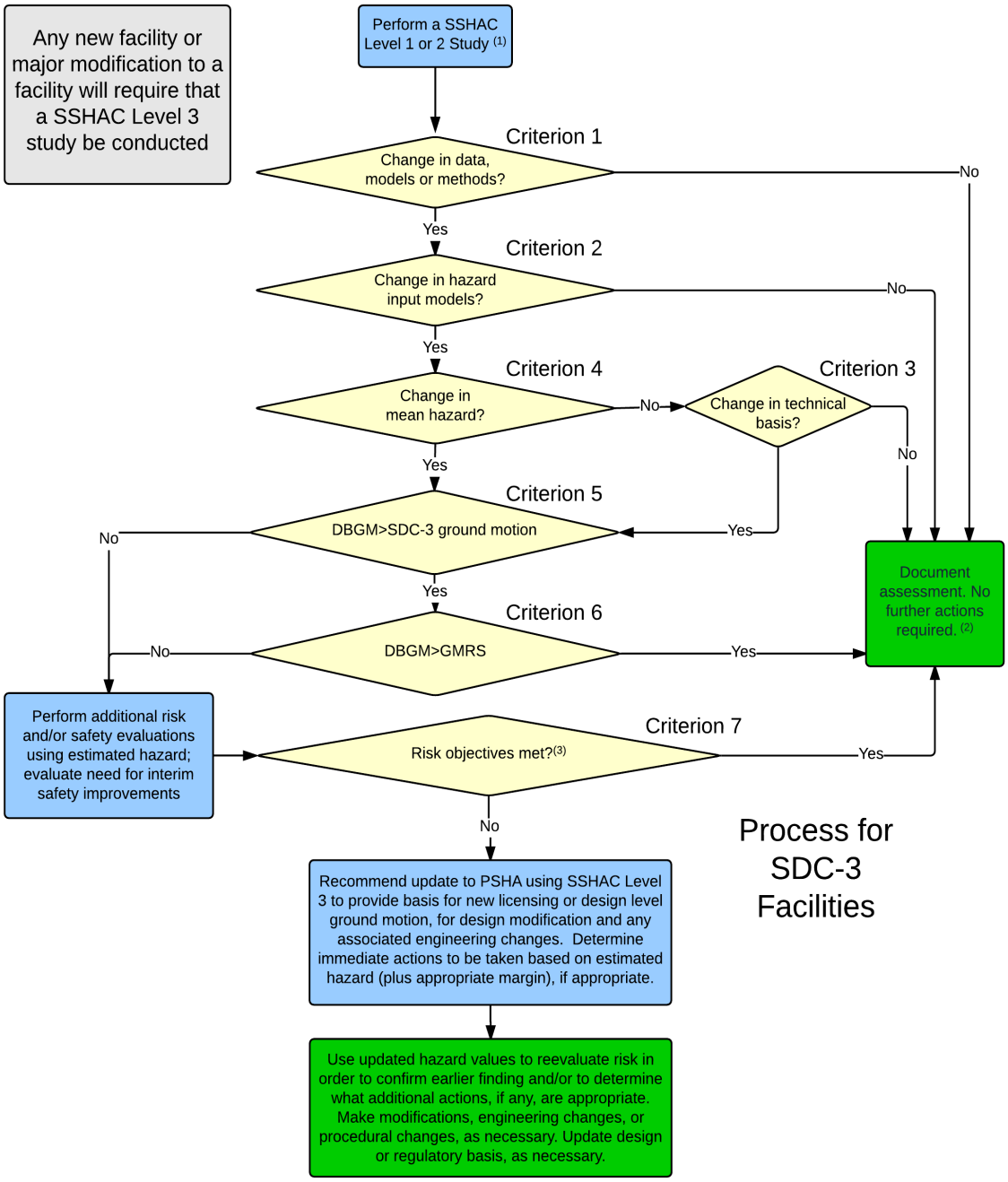
- The comparisons for Criteria 1 to 4 are most appropriately performed by the SSHAC Technical Integration team (perhaps reviewed by the Participatory Peer Review Panel (PPRP)). Therefore, the scope of work of the SSHAC project should include both the SSHAC project itself and the evaluation and documentation of criteria 1 to 4.

- SSHAC has strong documentation requirements that should make future comparisons "straight forward". However, future re-evaluation activities may be something for the PPRP to keep in mind when reviewing the sufficiency of documentation.

- The differing ground motion terminology found in the documentation for the FMF and ZPPR facilities created a challenge. Terminology has changed along the way and the "design" basis ground motions defined for the facilities changed in various resource reports as the hazard was revised and the plant was reevaluated. Not only did this cause issues, but it is not correct from a technical perspective as the facility as constructed didn't change (and so the actual design ground motions never changed. Improved terminology would make it clear which ground motions are actual design motions, which are the current licensing ground motions, and which were used for re-evaluations.

- Current DOE guidance provides deterministic performance requirements in terms of dose during an event, but not risk criteria. DOE-STD-3009 sets deterministic targets at 25 rem at site boundary and 100 rem for co-located workers. This limitation did not significantly impact the INL case studies because (1) FMF and ZPPR are simple facilities for which the only safety-significant SSCs are the structures and (2) the structures at FMF and ZPPR are sufficiently robust that their high-confidence of a low probability of failure (HCLPF) values from fragility curves exceeded the performance criteria (thereby allowing for a type of hybrid evaluation). Any facilities wanting to apply the SHPRM much agree upon the risk criteria with their managing and regulatory organizations a priori on a case by case basis. The process would benefit from the development of DOE complex-wide risk objectives.

- A challenge in documenting the INL study was that a number of documents that were relied up on are not public. These were removed from the public report, which diminished its effectiveness in terms of communications with the regulator. It may be appropriate to create a public and non-public version so that the complete chain of information is available and reviewable in-house.



Notes:
1. The SSHAC level 1 or 2 study must include a documented in-process peer review. The resulting estimated hazard should be compared with the existing studies used to develop design or regulatory bases for the facility.
2. The estimated hazard and any risk-informed findings apply to this facility only and cannot be used for other facilities
3. See the report for discussion of the appropriate risk-related information to be considered

Figure 1. Chart of proposed methodology for a SDC-3 facility (reproduced from Kammerer et al., 2015).

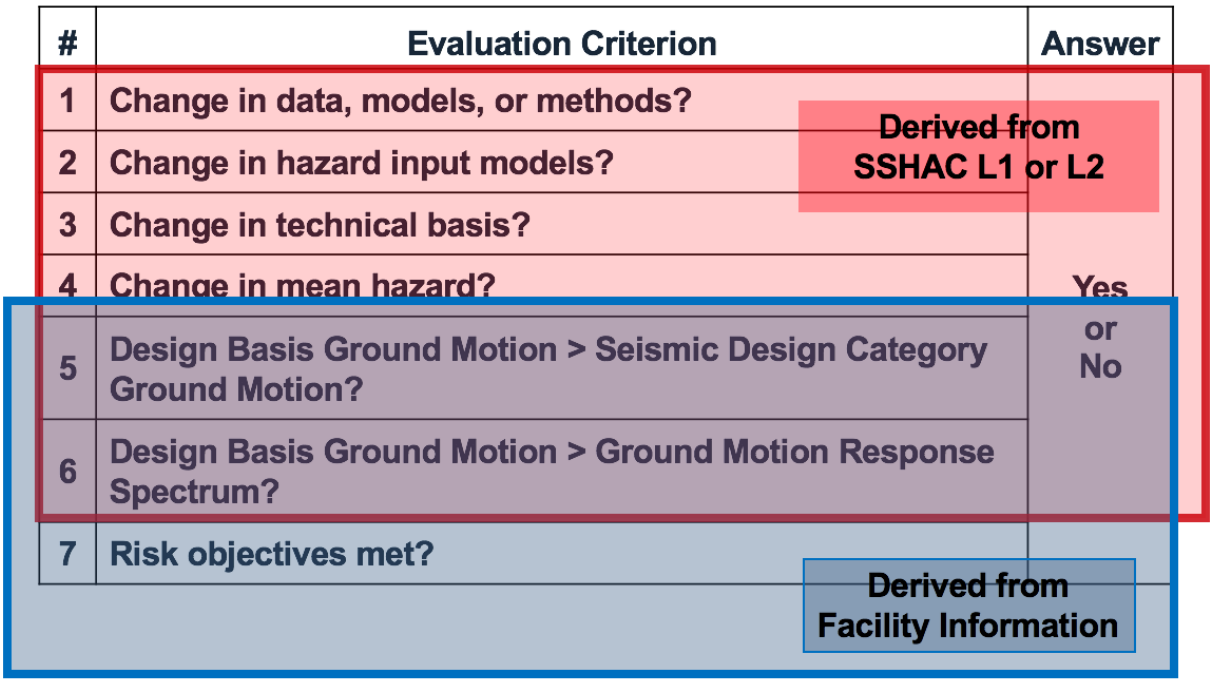


Figure 2. Overlap of Criteria Evaluation Processes (From Kammerer et al., 2016)

Table 1. Overview of approach for documenting evaluation of Criteria #1 through #4 (From Kammerer, Payne and Coleman, 2016)

Change Relative to the Baseline PSHA Supporting Design Basis			
Evaluation Criterion 1	Evaluation Criterion 2	Evaluation Criterion 3	Evaluation Criterion 4
Changes to data, models, and methods?	Changes to input SSC or GMC models?	Changes to the technical bases?	Change in mean hazard?
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

Table 2. Example documentation for evaluation Criteria #1 through #4 (From Kammerer, Payne and Coleman, 2016)

Change Relative to the 1996 and 2000 INL PSHAs			Evaluation Criterion 4 Significance (or Meaning) to INL SSHAC L1 Hazard
Evaluation Criterion 1	Evaluation Criterion 2	Evaluation Criterion 3	
Changes to data, models, and methods?	Changes to input SSC or GMC models?	Changes to the technical bases?	Implications or why changes occur to the current hazard
Applied the GMM developed by the SWUS Ground Motion Characterization project	Implemented the SWUS median GMM for shallow crustal earthquakes for the tectonic source zones, volcanic zones, regional fault sources and local fault sources	Change to the technical basis to include only empirical GMPEs for the GMM at INL	Incorporates a SSHAC Level 3 GMM that is applicable to extensional environments and has complete characterization of median ground motions and their aleatory variability

GMM – Ground Motion Model
GMPEs – Ground Motion Prediction Equations
SWUS – Southwestern United States

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