Interim Staff Guidance on
Implementation of a Probabilistic Risk Assessment-Based
Seismic Margin Analysis for New Reactors
DC/COL-ISG-020

1.0 Purpose

This interim staff guidance (ISG) supplements the guidance provided to the U.S. Nuclear Regulatory Commission (NRC) staff in Section 19.0 of NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants,” issued March 2007 (hereafter referred to as the Standard Review Plan (SRP) (Ref. 1), and DC/COL-ISG-03, “Probabilistic Risk Assessment Information to Support Design Certification and Combined License Applications,” dated June 11, 2008 (Ref. 2), concerning the review of probabilistic risk assessment (PRA) information and severe accident assessments submitted to support design certification (DC) and combined license (COL) applications. This ISG provides guidance on (1) a PRA-based seismic margin analysis method and its implementation for DC, (2) site- and plant-specific updates of the DC PRA-based seismic margin evaluation for COL applications, (3) post-COL verification of as-designed and as-built plant seismic margin capacity preceding initial fuel load, and (4) documentation of findings. This ISG applies to the review of seismic margin information submitted in support of DC and COL applications. Guidance for seismic PRA and its implementation by COL holders in accordance with Title 10 of the *Code of Federal Regulations,* Section 50.71(h), Ref. 3 (10 CFR 50.71(h)) is provided in DC/COL-ISG-03 and; therefore, is not within the scope of this ISG.

2.0 Basic Terms and Concepts

This section presents acronyms and defines key terms and concepts used in this ISG.

Accident Sequence – A representation in terms of an initiating event followed by a sequence of failures or successes of events (such as system, function, or operator performance) that can lead to undesired consequences, with a specified end state (e.g., core damage or large release).

Accident Sequence Analysis – The process to determine the combinations of initiating events, safety functions, and system failures and successes that may lead to core damage or large release.

Certified Seismic Design Response Spectra (CSDRS) – Site-independent seismic design response spectra that have been approved under Subpart B, “Standard Design Certifications,” of 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants” (Ref. 4), as the seismic design response spectra for a nuclear power plant using an approved certified standard design.

Fragility – The conditional probability of the failure of a structure, system, or component (SSC) at a given hazard input level. For seismic fragility, the input parameter could be peak ground acceleration (PGA), peak spectral acceleration, floor spectral acceleration, or others. The fragility calculation typically uses a double lognormal model with three parameters, which are the median acceleration capacity (A_m), the logarithmic standard deviation of the aleatory (randomness) uncertainty in capacity (β_R), and the logarithmic standard deviation of the

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epistemic (modeling and data) uncertainty in the median capacity ($\square_U$). The aleatory and epistemic uncertainty can be combined into a composite variability. The fragility using a composite variability is referred to as the mean fragility.

Ground Motion Response Spectra (GMRS) – Site-specific spectra characterized by horizontal and vertical response spectra determined as free-field motions on the ground surface or as free-field outcrop motions on the uppermost in situ competent material using performance-based procedures in accordance with Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion" (Ref. 5).

High Confidence of Low Probability of Failure (HCLPF) Capacity – A measure of seismic ruggedness. HCLPF is defined as the earthquake motion level at which there is a high (95 percent) confidence of a low (at most 5 percent) probability of failure. Using the lognormal fragility model, the HCLPF capacity is expressed as A_m exp $[-1.65\ (\square_R + \square_U)]$. When the logarithmic standard deviation of composite variability $\square_C$ is used, the HCLPF capacity could be approximated as the ground motion level at which the probability of failure is at most 1 percent. In this case, HCLPF capacity is expressed as A_m exp $[-2.33\square_C]$.

HRHF – Hard rock high frequency.

ITAAC – Inspections, tests, analyses, and acceptance criteria.

MIN-MAX Method – Method used in the determination of functional and accident sequence level of fragility. The overall fragility of a group of inputs combined using OR logic (i.e., seismic event tree nodal fault tree) is determined by the lowest (minimum) input. Conversely, the overall fragility of a group of inputs combined using AND logic (i.e., seismic event tree sequence) is determined by the highest (maximum) input.

RRS – Required response spectra.

Seismic Equipment List (SEL) – The list of all SSCs that require evaluation in the seismic fragilities task of a PRA-based seismic margin analysis.

Soil Liquefaction – A fluid-induced loss of soil strength with two typical failure modes: (1) flow failure where the shear strength of the soil drops below the level needed to maintain stability and (2) cyclic mobility failure (lateral spread). Either failure mode can lead to excessive strains and displacements that could result in unacceptable performance of supported SSCs.

SSE – Safe-shutdown earthquake.

TRS – Test response spectra.

3.0 Background and Discussion of Issues

10 CFR 52.47(a)(27) states that a DC application must describe in its final safety analysis report (FSAR) the design-specific PRA and its results. According to Section C.I.19.3 of Regulatory Position Part I, “Standard Format and Content of Combined License Applications,” of RG 1.206, “Combined License Applications for Nuclear Power Plants (LWR Edition)” (Ref. 6), the scope of the assessment should be a level 1 and level 2 PRA that includes internal and external hazards and addresses all plant operating modes.
The key elements of a seismic PRA include (1) the seismic hazard analysis used to estimate the frequencies of occurrence of different levels of ground motion at a particular site, (2) the seismic fragility evaluation used to estimate the conditional probability of failure of important SSCs whose failure may lead to core damage and/or a large release, and (3) the plant response analysis. The latter involves modeling and quantification of the various combinations of structural and equipment failures, including consideration of random errors, operator actions, correlated seismic responses of equipment and common failure under seismic vibration that can lead to a seismically induced core damage event, and the integration of these results to quantify the risk.

The NRC staff recognizes that it is not practical for a DC to perform a seismic PRA because a DC application would not contain site-specific seismic hazard information. As an alternative approach to seismic PRA, the NRC staff proposed in SECY-93-087, “Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs,” dated April 2, 1993 (Ref. 7), and the Commission approved in the corresponding NRC staff requirements memorandum, dated July 21, 1993 (Ref. 8), a PRA-based seismic margin analysis. The approved analysis preserves the latter two key elements of a seismic PRA to the maximum extent possible and estimates the design-specific plant seismic capacity in terms of sequence-level HCLPF capacities and fragility for all sequences leading to core damage or containment failures up to approximately 1.67 times the ground motion acceleration of the design-basis SSE. Using this approach, the analysis can demonstrate acceptably low seismic risk for a DC.

This ISG provides guidance for performing PRA-based seismic margin analysis in support of a DC application and post-DC updating activities, including COL updates to incorporate site- and plant-specific features and post-COL verifications. The NRC staff used the industry standard (Ref. 9), as endorsed by the NRC, to the maximum extent applicable in developing this guidance.

Section 5.1 of the ISG provides guidance on the performance of a PRA-based seismic margin analysis based on design-specific information for a DC application, including the design-based (passive and other advanced reactor and system design) logic model development, seismic fragility analysis of SSC, HCLPF quantification, and acceptable plant-level HCLPF seismic margin. It also provides guidance on DC application assumptions, post-DC updating activities in COL action items, and the as-designed and as-built plant verification process for COL holders.

Section 5.2 of the ISG provides guidance on acceptable methods for updating the DC PRA-based seismic fragility analysis by a COL applicant incorporating the DC by reference to reflect site-specific effects and plant-specific features of the COL site, pursuant to 10 CFR 52.79(a)(46) and 10 CFR 52.79(d)(1). It also provides guidance on COL holder action items for as-designed and as-built plant HCLPF capacity verification.

Section 5.3 of the ISG provides guidance on post-COL activities associated with verifications of the as-designed and as-constructed plant seismic HCLPF capacity by COL holders.

Section 5.4 describes the submitted information and results necessary for the NRC staff to conduct a review and prepare pertinent safety evaluation reports.

4.0 Applicability

This ISG will be implemented on the day following its issuance. It will remain in effect until it has been superseded, withdrawn, or incorporated into a revision of the SRP and RG 1.206.

5.0 Technical Positions

5.1 Position on Performance of a PRA-Based Seismic Margin Analysis

A PRA-based seismic margin analysis should provide a clear understanding of significant seismic vulnerabilities and other seismic insights to demonstrate the seismic robustness of a standard design. Accordingly, the level of detail of a PRA-based seismic margin analysis needs to be sufficient to gain risk insights, in conjunction with the assumptions made in the PRA-based seismic margin analysis, and to identify and support requirements important to the design and plant operation. To this end, Part 5, "Requirements for Seismic Events at-Power PRA," of the American Society of Mechanical Engineers/American Nuclear Society (ASME/ANS) PRA standard, RA-Sa-2009 (Ref. 9), is used to the extent practical and as endorsed by RG 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," Revision 2 (Ref. 10), in guiding the performance of the PRA-based seismic margin analysis in support of a DC application. The seismic margin methods for as-built and as-operated plants as described in Part 10, "Seismic Margin Assessment Requirements at-Power," of the ASME/ANS PRA standard RA-Sa-2009 (Ref. 9) are not acceptable for performing a design-specific PRA-based seismic margin analysis.

The process for a design-specific PRA-based seismic margin analysis includes (1) design-specific system and accident sequence analysis, (2) seismic fragility evaluation, and (3) plant-level HCLPF determination. Considering the generic nature of a standard design, a DC application would not contain site-specific and plant-specific information. Therefore, exceptions to Part 5 of the ASME/ANS PRA standard will be taken relating to requirements for information about the site-specific, plant-specific, and as-built and as-operated plant.

Also discussed are post-DC activities to update the PRA-based seismic margin analysis throughout the licensing process of new reactors, including COL action items and COL holder items to ensure a coherent and consistent process for the quality of PRA-based seismic margin assessment to adequately meet 10 CFR 52.47(a)(27) and 10 CFR 52.79(a)(46).

5.1.1 Design-Specific Plant System and Accident Sequence Analysis

The design-specific plant system and sequence analysis for a PRA-based seismic margin analysis is performed in accordance with Capability Category I requirements of Section 5-2.3 of Part 5 of the ASME/ANS PRA standard, with the exceptions that the analysis should not be based on site-specific and plant-specific information and should not rely on an as-built and as-operated plant. Screening of rugged SSCs can be performed on the basis of the DC's

CSDRS with its PGA scaled by a factor of 1.67. The basis for the screening should be adequately documented and ensure that the so-called “super element,” as described in Note 3 of Section 5-2.3 of Part 5 of the ASME/ANS PRA standard, will not control the plant seismic margin capacity. The analysis should consider random equipment failures, as well as operator actions as applicable.

It is important that the plant systems analysis focus on those sequences leading to core damage or containment failures, including applicable sequences leading to the following containment failures: (1) loss of containment integrity, (2) loss of containment isolation, and (3) loss of functions for prevention of containment bypass. The operating modes to be considered include at power (full power), low power, and shutdown.

An SEL should document the SSCs associated with the accident sequences that will require seismic fragility evaluation for determining sequence-level HCLPF.

5.1.2 Seismic Fragility Evaluation

The NRC staff accepts that the seismic fragility evaluation of SSCs is performed based on Capability Category I requirements of Section 5-2.2 of Part 5 of the ASME/ANS PRA standard to the extent applicable and as endorsed by RG 1.200 with following exceptions. First, the seismic fragility calculations should be based on design-specific information provided within the scope of a DC application; site- and plant-specific information would not be available at the DC stage and; therefore, cannot be relied on for computing seismic fragility. Two methods, separation of variable and conservative deterministic failure margin (Refs. 11 and 12), are acceptable for determining seismic fragility.

Second, the seismic fragility calculation should use the response spectrum shape defined as the DC’s CSDRS.

When generic data (such as test data, generic seismic qualification test data, and test experience data) are used to support the seismic fragility analysis, justification should be provided to demonstrate that the generic data are consistent and applicable to SSCs within the scope of the certified design application. For seismic fragility of equipment on the SEL, which is to be qualified by seismic qualification tests, the procedure as described in E.5 of the Electric Power Research Institute (EPRI) Report 1002988, “Seismic Fragility Application Guide,” issued December 2002 (Ref. 13), is acceptable for developing fragility. In this procedure, consistent with Ref. 13 of the above EPRI guidance document, the TRS should be specified at the 99-percent confidence level to account for uncertainties in tests. The seismic demands to equipment defined in terms of RRS should use CSDRS-based (or HRHF, if applicable) seismic input and account for the structural amplifications caused by the supporting structures, including soil-structure interaction effects and supporting systems, and incorporate an additional seismic margin factor, as appropriate.

5.1.3 Plant-Level Capacity of HCLPF

The HCLPF value for an SSC should be determined corresponding to a 1-percent failure probability on the mean fragility curve. The HCLPF value should be expressed in terms of PGA for consistency in the PRA-based seismic margin analysis process. The plant-level HCLPF capacity should be determined based on the sequence-level HCLPF values for all sequences as identified in the design-specific plant system and accident sequence analysis. The max-min method is acceptable for computing sequence-level HCLPF values. The plant-level HCLPF is therefore the lower bound of the sequence-level HCLPF values. The design-specific plant-level HCLPF value should be demonstrated to be equal to or greater than 1.67 times the CSDRS PGA.

In addition, the design-specific PRA-based seismic margin analysis should be peer-reviewed in accordance with Section 5-3 of Part 5 of the ASME/ANS PRA standard.

5.1.4 Activities after Design Certification

A PRA-based seismic margin analysis for a DC provides results that include all identified seismically initiated accident sequences, the SEL with HCLPF values and associated failure modes, and plant and sequence HCLPFs, as well as risk insights for seismic events. However, the PRA-based seismic margin analysis is performed using the design-specific information within the scope of a DC application. Therefore, post-DC activities should ensure that the PRA-based seismic margin analysis and the results remain valid and adequately reflect the site-specific and plant-specific information for a site for which the COL application incorporates the appropriate DC by reference.

In accordance with 10 CFR 52.79(a)(46) and 10 CFR 52.79(d)(1), the post-DC activities should include COL items requiring the COL applicant to (1) update the design-specific plant system and accident sequence analysis to incorporate site-specific effects (soil liquefaction, slope failure, etc.) and plant-specific features (safety-related site-specific structures), as applicable, (2) update the SEL with HCLPF values and associated failure modes to adequately reflect the site-specific effects and plant-specific features of the COL site (for soil-related failure modes, the site-specific GMRS can be used for HCLPF calculations), and (3) demonstrate that the design-specific plant-level HCLPF capacity is maintained at the COL stage.

The activities after DC should also include COL holder items to verify the plant- and sequence-level HCLPF capacity based on the as-designed, as-built configuration of the plant before the initial loading of fuel.

5.2 Position on Updating DC PRA-Based Seismic Margin Analysis by COL Applicants

In accordance with 10 CFR 52.79(a)(46) and 10 CFR 52.79(d)(1), a COL application must describe the plant-specific PRA and results in its FSAR, and the site-specific PRA must use the PRA information for the referenced DC and must be updated to account for site-specific design information. For a COL incorporating a DC by reference, the NRC staff expects that the COL will implement the COL action items provided by the respective DC and update the DC's PRA-based seismic margin analysis to adequately incorporate site-specific and plant-specific information for the COL site. To this end, Part 5 of the ASME/ANS PRA standard, RA-Sa-2009, is used to the extent applicable and as endorsed by RG 1.200 in guiding the COL updating process.

5.2.1 Updating the Plant System and Accident Sequence Analysis

Capability Category I requirements of Section 5-2.3 of Part 5 of the ASME/ANS PRA standard as endorsed by RG 1.200 can be used to the extent applicable to update the design-specific plant systems and sequence analysis to reflect site-specific and plant-specific information on the COL site; however, the update should not rely on an as-built and as-operated plant since the plant is not being built at the time of the COL application. The update should focus on the fault-space systems analysis model for the plant to account for site-specific effects and plant features. Site-specific plant features may include site-specific effects such as seismically induced liquefaction settlements, slope stability, foundation failure, and relative displacements, as well as site-specific features such as underground piping, intake structure, intake tunnel, and ultimate heat sink, if any.

The analysis incorporates in the system-level model the site-specific effects and plant-specific features that cannot be addressed using stand-alone evaluations. In general, these effects and structures would relate to site-specific structures that affect the probabilities of events in the event sequences. For these cases, the calculation of sequence-level and plant-level HCLPF seismic margin factors for the updated system model accounts for the probabilities of failure for these site-specific effects and plant-specific features.

As the accident sequences are updated, additional SSCs may be identified and should be included in the updated SEL.

5.2.2 Updating the Seismic Fragility Evaluation

The seismic fragility calculations performed for SSCs in the SEL for a DC need not be updated by a COL application that incorporates the DC by reference if (1) site-specific soil effects are deemed not controlling with adequate justification the seismic fragility of the pertinent SSC and the plant-level HCLPF, and (2) the COL application demonstrates the COL site GMRS is enveloped by the DC CSDRS; the comparison should be made at free-field ground surface.

For those SSCs susceptible to the soil failures of the COL site, updating of the seismic fragility of these SSCs are necessary to reflect the actual soil effects of the COL site. In addition, SSCs that are identified and added to the updated SEL as a result of updating the plant system and accident sequence analysis to incorporate site-specific effects are also required of the estimate of the seismic fragility. To this end, the NRC staff finds acceptable the seismic fragility evaluation of these SSCs based on Capability Category I requirements of Section 5-2.2 of Part 5 of the ASME/ANS PRA standard to the extent applicable and as endorsed by RG 1.200. However, the fragility calculations cannot be based on an as-built and as-operated plant, since the plant construction is not expected to commence at the time of a COL application.

When the seismic fragility analysis is performed considering site-specific effects and plant-specific features, the response spectrum shape should be based on the COL site-specific GMRS. Fragility for seismically induced liquefaction can be developed using a fragility method described in Section G of the EPRI report "Seismic Fragility Application Guide" (Ref. 13), together with the limit state defined in terms of the allowable settlements specified in the design control document for the referenced DC.

When generic data (such as test data, generic seismic qualification test data, and earthquake experience data) are used to support the seismic fragility analysis, justifications should be provided to demonstrate that the generic data are consistent and applicable to the site- and plant-specific information concerning SSCs provided within the scope of a COL application.

5.2.3 Updating the Plant-Level Capacity of High Confidence of Low Probability of Failure

The plant-level HCLPF capacity expressed in terms of PGA should be updated in the COL application, based on the sequence-level HCLPF values for all sequences as updated to incorporate site-specific effects and plant-specific features of the COL site. The max-min method is acceptable for computing sequence-level HCLPF values. Therefore, the plant-level HCLPF is the lower bound of the sequence-level HCLPF values. The plant-specific plant-level HCLPF value should be demonstrated to be equal to or greater than 1.67 times the site-specific GMRS PGA.

Should the plant-level HCLPF capacity be estimated as less than 1.67 times the site-specific GMRS, two options are acceptable: (1) the COL application identifies the affected SSCs and upgrades their capacity to ensure that the plant-level HCLPF capacity be maintained at the level of 1.67 times the GMRS PGA, or (2) the COL application performs full convolution of sequence fragility for all sequences with the site mean hazard curve to develop risk metrics to demonstrate that the seismic risk is acceptably low for the licensed plant. The NRC staff will review and accept the analysis associated with the second option on a case-by-case basis.

5.2.4 Activities after the Issuance of the COL

The post-COL activities include verifications of the plant- and sequence-level HCLPF capacity by the COL holder to ensure the as-designed, as-built configuration of the plant before the initial loading of fuel. These verification activities should be designated in the COL application as COL holder items.

5.3 Verifications after the Issuance of the COL

The COL holders verify the plant SSC capacity to demonstrate that the plant- and sequence-level HCLPF capacity is consistent with the FSAR. COL holders perform the verification based on the as-designed, as-built configuration of the plant. The plant walkdown process described in EPRI NP-6041 (Ref. 12) can be used for the capacity verifications.

The COL holders should complete the verification activities before the initial loading of fuel to confirm that the as-designed and as-built plant-level HCLPF capacity is at the level of 1.67 times the site GMRS PGA, or the values reviewed and approved for the licensee. The COL holder should document the verification findings and make the documentation available for inspection. “After completion of the as-built verification of seismic fragility target values for applicable seismic SSCs, the FSAR should be updated to reflect the as-built values.”

5.4 Position on Documentation

The FSAR referenced in SRP Section 19 should conform to the guidance in Appendix A to Section C.I.19 of Part I of RG 1.206 and can use relevant requirements in Part 5 of AMSE/ANS PRA standard for documentation which should include the following for the NRC staff’s review and evaluation.

For a DC application, Chapter 19 of the FSAR should include the following:

(1) seismic accident initiation events

(2) a summary of the operating modes, accident sequences and event/fault trees, and damage levels considered in the analysis

(3) the definition of the response spectrum shape used for the fragility analysis of SSCs, accident sequences, and the plant

(4) identification of the methods used to calculate sequence-level and plant-level HCLPFs for the sequences, operating modes, and damage levels considered

(5) a table with the capacities (e.g., in terms of the median and logarithmic standard deviation of the fragilities) for the SSCs in the SEL

(6) a summary description of the methods used for the derivation of the component fragilities, including a summary of how the component probability of failure is related to the ground motion parameter

(7) for equipment in the SEL which is qualified via tests, a description of procurement specification including the enhanced RRS as described in Section 5.1.2 of this ISG to ensure appropriate HCLPF capacity of the procured equipment

(8) risk-significant SSCs, dominant cut-sets and sequences, and seismic event/fault trees

(9) sequence-level and plant-level HCLPF capacities for the operating modes and damage levels

(10) independent peer reviews

(11) analysis assumptions, COL action items, interface items, and COL holder action items

For a COL application that references a certified design, Chapter 19 of the FSAR should contain the following:

(1) updated seismic initiating events based on available site- and plant-specific information if the COL application references a DC

(2) identification of site-specific effects and plant-specific features, including those that correspond to single event sequences

(3) a summary of the systems model update for incorporating site-specific plant features and site-specific effects if the COL application references a DC

(4) a table with the HCLPF capacities for the effects and features in item (2) of this list expressed in terms of the site GMRS for the COL scope

(5) a list of cases (e.g., sequences) for which there is no significant change from the certified design PRA-based seismic margin analysis

(6) updated sequence-level and plant-level HCLPF capacities for those cases with a significant change from the certified design PRA-based seismic margin analysis, if any

(7) site hazard information if the option 2 in Section 5.2.3 is performed and risk metrics are calculated

(8) COL holder action items and interface requirements to be verified before initial fuel loading

References:

1. NRC, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," NUREG-0800, March 2007, Section 19.

2. NRC, "Interim Staff Guidance on Probabilistic Risk Assessment Information to Support Design Certification and Combined License Applications," DC/COL-ISG-03, June 11, 2008, Agencywide Documents Access and Management System Accession No. ML0814306751.

3. U.S., 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities."

4. U.S., 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

5. NRC, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion," RG 1.208, March 2007.

6. NRC, "Combined License Applications for Nuclear Power Plants (LWR Edition)," RG 1.206, June 2007.

7. NRC, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," Commission Paper SECY-93-087, April 2, 1993.

8. NRC, "Staff Requirements Memorandum to SECY-93-087," July 21, 1993.

9. ASME/ANS, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," ASME/ANS RA-Sa-2009, New York, NY, 2009.

10. NRC, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," RG 1.200, Revision 2, March 2009.

11. EPRI, "Methodology for Developing Seismic Fragilities," EPRI Report TR-103959, Palo Alto, CA, June 1994.

12. EPRI, "Nuclear Plant Seismic Margin R-1," EPRI Report NP-6041, Palo Alto, CA, August 1991.

13. EPRI, "Seismic Fragility Application Guide," EPRI Report 1002988, Palo Alto, CA, December 2002.