Technical Advisory Committee of the Nuclear Risk Research Center
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SUBJECT: PROPOSED NRRC RESEARCH ON SELECTED SEISMIC ISSUES FOR FISCAL YEAR 2021

Dear Dr. Apostolakis:

This is a companion report to our February 16, 2021 letter report on "Proposed NRRC Research Plan for Fiscal Year 2021." It provides more detailed discussions and recommendations for two specific areas of the Nuclear Risk Research Center (NRRC) seismic research program:

(1) Development of a guide for probabilistic seismic hazard analysis (PSHA), including the specific plan for applying the Senior Seismic Hazard Analysis Committee (SSHAC) methodology-based implementation to a region; and

(2) Development of a simplified elasto-plastic assessment method for evaluating piping system fragilities, based on experimental and analytical approaches.

CONCLUSIONS AND RECOMMENDATIONS

1. To establish technical adequacy, meet the applicable standards, and reflect the international state-of-practice, the PSHA guidance and a regional approach for evaluating seismic hazards should include activities to demonstrate how to incorporate local site effects and site response into a site-specific PSHA.

2. As part of its fragility analysis research, NRRC should consider developing selection and screening criteria for piping systems. Those analyses should examine various direct and indirect failure modes to determine which are important, considering plant-specific PRA success criteria, past studies, and experience data. We agree with the NRRC that a simplified approach would be desirable for practical applications.

3. We would like to be briefed on these hazard and fragility assessment research activities as more progress is made and detailed plans are available.

BACKGROUND

Some of the most important issues related to the restart of Japanese nuclear power plants are related to the seismic hazard and seismic response. These seismic issues, particularly those related to the seismic hazard, have played a very important role for safety decisions at the national regulatory level, all levels of prefecture and local governments, and in the courts. The NRRC seismic research program has produced very useful methods and analytical tools to address these issues. The effort related to implementation of the SSHAC methodology for the Ikata site has been a critical step in advancing the state-of-practice for seismic hazard analysis in Japan. The planned work in FY2021 for developing a PSHA guide and the specific plan for applying the SSHAC methodology-based implementation to a region is a very important next step.

Similarly, NRRC's research related to the development of realistic seismic fragilities has addressed and advanced the state-of-practice in several important areas. Examples include ground and slope failure fragilities and realistic seismic responses. One activity in the seismic fragility research plan for FY2021 is an advanced methodology for the evaluation of piping systems.

We have not had opportunities to discuss the planned work with the research teams in any detail, partly because of the ongoing pandemic. Considering the importance of these elements of a seismic PRA, our comments are intended to provide a perspective and some insights into these two subject areas that may help in determining the scope of the planned research and defining specific activities.

DISCUSSION

SSHAC Methodology Applications

The completion of the Ikata SSHAC project is a very significant milestone. The next step of developing PSHA guidance and implementation of a region-based approach is needed for application of the methodology to other sites. The NRRC is also exploring implementation of several seismic hazard methodology topics through a model plant analysis.

There are three major elements in a PSHA methodology: (1) characterization of seismic sources, (2) propagation of seismic energy to the site, and (3) local site response. The Ikata SSHAC project did not have to deal explicitly with the third element, local site response, because the Ikata plant foundation is on hard rock. To address this issue, in our November 27, 2016 letter report, we recommended:

> "Before further adaptation of the SSHAC process, the NRRC should consider a SSHAC project for one more site which has a seismo-tectonic environment with some features that are different from the Ikata site. This will provide more robust insights for developing guidance and pertinent research to facilitate implementation of the SSHAC process in Japan."

One of the reasons for this recommendation was:

> "For example, a soft site that requires consideration of local subsurface features and site response evaluations may provide additional insights into technical issues, uncertainties, and development of data, methods, and models."

This is an important issue. The NRRC research team has noted that some BWR plants are located on soft rock sites and have some unique site-specific issues, compared to PWR plants, most of which are located on hard-rock sites.

The state-of-the-art and practices for evaluating local site response are evolving. It is instructive to look at the Japanese and U.S. seismic PRA standards and guidance with respect to this issue. Examples of relevant elements of the standards and contemporary guidance for evaluating local site response are summarized in Appendix A to provide further context for our recommendation.

The preceding discussion and the references in Appendix A provide a perspective on the importance of local site effects. We understand that for a variety of reasons, the NRRC research team has not been able to implement a full-scope SSHAC procedure at a softer site, as we recommended in November 2016. The activities that are summarized in the FY2021 seismic hazard research plan do not explicitly address the evaluation of local site effects in the planned SSHAC guidance development, implementation of a regional model, or in the hazard studies related to the model plant PRA demonstration. The scope of the seismic hazard research should include a specific task for development and demonstration of a methodology to include local site effects for successful application at all sites, to meet the standards and codes requirements, and to reflect the international state-of-practice.

Piping Fragility Research

The seismic fragility research activities for FY2021 include development of a simplified elasto-plastic assessment method for piping systems, based on experimental and analytical approaches. The research team noted that they intend to adopt fatigue as a piping system failure criterion, instead of the guillotine break (rupture) criterion that has been used conventionally. They explained that the piping fragility is traditionally evaluated using an elastic analysis, with a guillotine break set as the failure mode. The research team indicated that this methodology is conservative, and it does not account for the realistic piping system behavior. They also noted that consideration of the piping system supports remains a key issue for the fragility evaluation. The team plans to investigate fatigue as a failure mode for one key piping system in FY2021. The NRRC is also conducting shaking table tests to support this activity.

It is also instructive to look at the Japanese seismic PRA standards and U.S. guidance with respect to this issue. Examples of relevant elements of the standards and an engineering approach for evaluating piping failures are summarized in Appendix B to provide further context for our recommendation.

The piping system failure modes of concern have been generally related to anchor motions or the existence of some sort of prior degradation. Many tests of piping components and piping systems have been conducted over the years. For example, NUPEC and JNES conducted piping tests with and without any degradation. In the U.S., EPRI and NRC conducted similar tests in the 1990s. These testing programs provide support for the general conclusion that a seismically-caused guillotine break of un-degraded piping has very low probability for most nuclear power plant systems.

Incorporation of specific failure modes for any spatially distributed system, like piping systems, in a seismic PRA tends to be a problematic issue for a variety of reasons. Therefore, it is very important to identify what are the vulnerable systems. Those systems depend on details of the piping designs, configurations, and the plant-specific PRA models and success criteria. For example, in principle, the fragility analyses should quantify the conditional probability that the seismic damage to individual or multiple piping sections has the following effects:

- Very small, small, medium, or large LOCA
- Small or large steam line break
- Functionally disable one or more trains of high pressure or low pressure injection
- Functionally disable one or more trains of open- or closed-loop cooling water
- Flood one or more plant compartments
- Other relevant effects for the specific plant design and risk models

As part of its fragility analysis research, NRRC should consider developing selection and screening criteria for piping systems. Those analyses should examine various direct and indirect failure modes to determine which are important, considering plant-specific PRA success criteria, past studies, and experience data. We agree with the NRRC that a simplified approach would be desirable for practical applications.

We would like to be briefed on these hazard and fragility assessment research activities as more progress is made and detailed plans are available.

Sincerely,

John W. Stetkar

John W. Stetkar
Chairman

REFERENCES

1. "NRRC Overview: Research Program for FY2021, External Natural Events," Presentation to NRRC Technical Advisory Committee, November 4, 2020, Proprietary

2. Technical Advisory Committee individual members' comments and questions on "NRRC Overview: Research Program for FY2021, External Natural Events," December 4, 2020, Confidential.

3. NRRC Research Team responses to comments and questions on "NRRC Overview: Research Program for FY2021, External Natural Events," January 30, 2021, Confidential.

4. Technical Advisory Committee of the Nuclear Risk Research Center, "Proposed NRRC Research Plan for Fiscal Year 2021," February 16, 2021.

5. Technical Advisory Committee of the Nuclear Risk Research Center, "Interim Report on Probabilistic Seismic Hazard Analysis Enhancements in Japan and Fault Displacement Evaluation," November 27, 2016.

6. Atomic Energy Society of Japan, "A Standard for Procedure of Seismic Probabilistic Risk Assessment for Nuclear Power Plants: 2015," AESJ-SC-P006E:2015, December 2015, English translation.

7. American Nuclear Society, "American National Standard, Probabilistic Seismic Hazard Analysis," ANSI/ANS-2.29-2020, April 2020.

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9. U.S. Nuclear Regulatory Commission, "Central and Eastern United States Seismic Source Characterization for Nuclear Facilities," NUREG-2115, Vols. 1-6, January 2012 (ML12048A776).

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11. U.S. Nuclear Regulatory Commission, "Probability of Pipe Failure in the Reactor Coolant Loops of Westinghouse PWR Plants," NUREG/CR-3660, UCID-19988, Vols. 1-4, 1985.

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13. U.S. Nuclear Regulatory Commission, "Probability of Pipe Failure in the Reactor Coolant Loops of Babcock and Wilcox PWR Plants," NUREG/CR-4290, UCRL-53644, Vols. 1-3, 1985.

14. U.S. Nuclear Regulatory Commission, "Probability of Failure in BWR Reactor Coolant Piping," NUREG/CR-4792, UCID-20914, Vols. 1-4, 1988.

APPENDIX A
REFERENCE STANDARDS AND TECHNICAL GUIDANCE FOR EVALUATION OF LOCAL SITE RESPONSE

Japanese Seismic PRA Standard AESJ-SC-P006E:2015

Section 6.4.2 of the Standard addresses the seismic ground motion propagation characteristics in the site vicinity and around the unit of interest. It states, in part:

> "In characterizing the seismic ground-motion propagation, first analyze the seismic-motion propagation characteristics in the site vicinity and around the unit of interest at the site in order to understand whether local uniqueness of those propagation characteristics exists".

The Standard contains guidance for various aspects of this issue. For example, Annex AP, "Difference in Ground-Motion Propagation Characteristics within a Same Site," apparently expands on this discussion. However, we did not have an English translation of that annex available for this review.

U.S. Probabilistic Seismic Hazard Analysis Standard ANSI/ANS-2.29-2020

Section 4.4 of the Standard addresses site effects. It states:

> "This section identifies acceptable procedures to incorporate local site effects into the calculation of ground motions at different elevations in a site profile overlying a reference horizon, typically the shallowest rock stratum that satisfies the assumptions associated with an elastic half-space. The purpose of a site response analysis is to quantify the influence of the geologic profile above a reference horizon on the amplitude and frequency of seismic waves propagating to the profile surface. In cases where major above- or below-grade topographic effects are minimal and where the geologic layers are generally flat, one-dimensional ground response analysis is adequate to represent the wave propagation conditions in which the response is assumed to be dominated by vertically propagating and horizontally polarized shear waves."
>
> "The guidance provided in this section covers the development of site-spectral amplification factors that can either be (1) used to scale 5% damped uniform hazard response spectra (UHRS) at the reference horizon or (2) used with the PSHA results for the reference conditions in order to develop surface or control point elevation hazard curves. Consistent with this, the site response analysis shall properly account for the uncertainties as well as the variability in the site effects on the ground motions computed at the surface of the geologic profile of interest."

Subsequent subsections of the ANSI/ANS Standard expand on available approaches for the site effects analyses.

NUREG-2213, "Updated Implementation Guidelines for SSHAC Hazard Studies"

A more succinct discussion of regional and site-specific studies and relationships to local site effects is provided in NUREG-2213. Section 3.2.2, Regional and Site-Specific Studies, states:

> "Another decision factor at the outset of a SSHAC study is determining whether a regional or site-specific study is needed. A site-specific study is one that is done for a single site or facility at a particular location, while a regional study is one that is conducted over a geographically extended region that includes multiple sites. An example of a regional SSHAC Level 3 study was the central and eastern United States (CEUS) SSC study (NRC, 2012b), which included the entire CEUS east of the Rocky Mountains. This regional study was intended to provide an SSC model that could be used at multiple nuclear facility sites across the eastern half of the U.S."
>
> "Experience has shown that there are essentially two alternative methods for which the concept of a regional study has been implemented (with subtle variations within these two general approaches). In the first method, referred to herein as a phased regional study, a general SSC and/or GMC model is developed that is applicable for the entire study region. At a future date, site-specific refinements are made to this model to make it appropriate for site-specific use. An illustration of this process is given in Figure 3-6(a). The second method, herein referred to as an integrated regional study, incorporates a series of site-specific assessments that are conducted simultaneously within the regional study. In this integrated regional method, the SSC and GMC models share some common elements, such as the seismic source geometries and recurrence, but the details of the SSC and GMC models are constructed to include site-specific aspects [e.g., behavior of nearby faults, shear wave velocity and kappa corrections to ground-motion prediction equations (GMPEs)]. An illustration of this process is given in Figure 3-6(b). The key difference between these two types of regional assessments is that the phased regional study uses general SSC and/or GMC models assuming that site-specific applications will be conducted at a later time. Presumably, these could be conducted under a lower level SSHAC process such as Level 2. The integrated regional model is developed for multiple sites in the region incorporating both regional and site-specific data, such that the model is immediately adaptable to all of the sites considered in the study region. An important additional feature of the integrated regional model is the incorporation of site-specific information that has traditionally been used for site response. In the integrated regional model approach, many aspects of the site response can therefore be included in the ground motion model. It may be possible for other sites to utilize much of the information developed by the integrated regional study at a future time, but that is not the primary purpose. Although both approaches provide an adequate way of incorporating available information and satisfying SSHAC goals, the choice of an integrated regional study or a phased regional study will depend on the needs of the Sponsor and status of existing SSHAC studies."

Figure 3-6 from NUREG-2213 is reproduced below to facilitate this discussion.

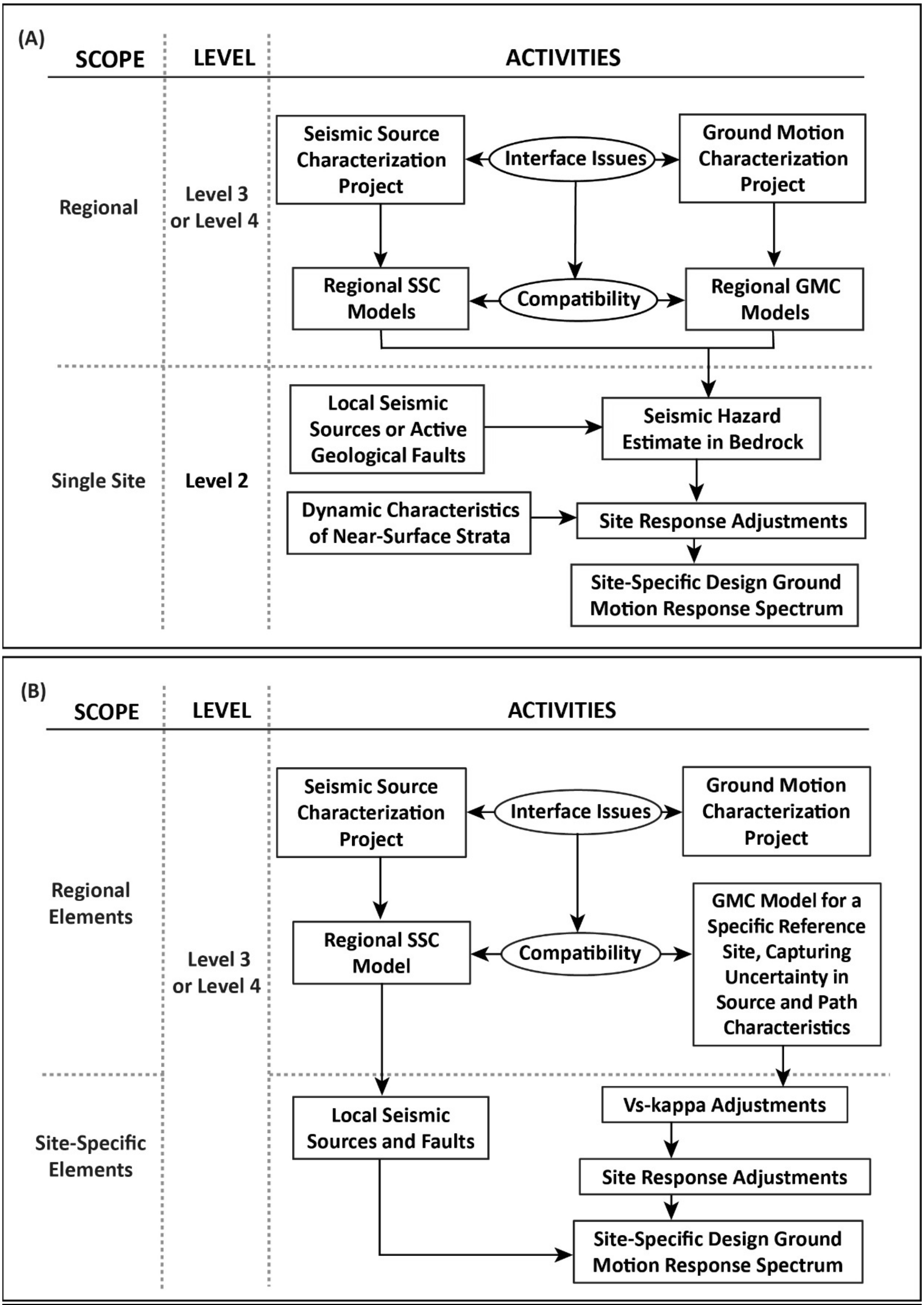

Figure 3-6. Illustration of two types of regional SSHAC Level 3 or 4 studies. A phased regional study is illustrated in the first panel (A), and an integrated regional study is shown in the second panel (B). (from NUREG-2213)

APPENDIX B
REFERENCE STANDARDS AND EXAMPLE OF AN ENGINEERING APPROACH FOR EVALUATION OF PIPING FRAGILITIES

Japanese Seismic PRA Standard AESJ-SC-P006E:2015

Annex CB of the Standard includes evaluation methods for realistic response of components and piping systems. Annex DE, "Example of a Method of Calculating the Probability of the Occurrence of an Initiating Event as a Result of an Earthquake," includes examples of analyses for seismic-induced small, medium, and large LOCAs. Those analyses should require careful consideration of the pipe rupture failure criteria. However, we did not have an English translation of Annex DE available for this review.

NUREG-1903, "Seismic Considerations for the Transition Break Size"

One study, which was conducted by the U.S. NRC in connection with a proposed risk-informed revision of Emergency Core Cooling System (ECCS) requirements in 10 CFR 50.46, provides an example of evaluating piping fragilities considering various failure mechanisms. It is documented in NUREG-1903, and it provides some insights into this issue. The question was what break size can be postulated considering seismic effects. Although the focus of this study was for a primary loop, the findings can be extended to other piping systems. The study used the seismic hazard estimates for the central and eastern U.S. sites, and it looked at PWR primary loops in detail. The Japanese seismo-tectonic environment would need further examination.

The study evaluated the following four failure mechanisms and conditions:

1. Fatigue
2. Unflawed piping
3. Flawed piping
4. Indirect failure because of support movement

The analyses in NUREG-1903, in part, utilized an extensive study conducted by the Lawrence Livermore National Laboratory (LLNL) in 1980s. The LLNL results were updated considering newer data. The unflawed piping failure probabilities were evaluated using the capacity information based on evaluation of the EPRI/NRC piping system and component data. However, treatment of the flawed or degraded piping issue is quite difficult. Instead of directly estimating probabilities of through-wall failures, the NRC staff examined what would be the size of a critical flaw (depth and circumferential) that would lead to a break at the earthquake levels associated with annual exceedance frequencies of $1x10^{-5}$ and $1x10^{-6}$ event per year. Evaluation of the indirect failures included an update of key support fragilities and use of the available seismic hazard information.