Technical Advisory Committee of the Nuclear Risk Research Center
Central Research Institute of Electric Power Industry
1-6-1 Otemachi, Chiyoda-ku, Tokyo, 100-8126 Japan

November 27, 2022

Dr. George Apostolakis
Director, Nuclear Risk Research Center
Central Research Institute of Electric Power Industry
1-6-1 Otemachi, Chiyoda-ku
Tokyo, 100-8126 Japan

SUBJECT: PROPOSED NRRC RESEARCH PLAN FOR FISCAL YEAR 2023

Dear Dr. Apostolakis:

During the 17th meeting of the Technical Advisory Committee (TAC) of the Nuclear Risk Research Center (NRRC), November 14-18, 2022, we met with the NRRC staff to review the proposed research plan for fiscal year 2023. The purpose of our review was to provide comments on the technical merits of the research plan and its relevance for supporting the NRRC's current mission.

CONCLUSIONS AND RECOMMENDATIONS

1. The overall scope of research for fiscal year 2023 and the technical objectives of the individual projects within each major research area remain consistent with the NRRC short-, intermediate-, and long-term goals.

2. During our review, we identified a few individual research activities that merit additional attention in the plans for fiscal year 2023 and subsequent years. Our recommendations for those activities are summarized in the Discussion section of this report.

BACKGROUND

One of the most important objectives of the research plan is to present the technical context of the research needs, including the rationale for prioritization and scope of the research, current state of knowledge, and potential contributions and significance of the research to the goals of the center. Our review of the research plan focused on the objectives of each research project and its supporting tasks, the technical relationships and relative priorities among those activities, and any major needs for additional research. We did not review the technical details of individual research activities or their completion milestones, except as needed to understand how those activities are integrated throughout the plan. We will comment separately on the technical elements of individual research projects in our future detailed reviews of those projects.

DISCUSSION

During this review, we were briefed on all continuing and planned projects in each research area, the major technical tasks in each project, the current status of each task, known or potential problem issues, and the estimated schedule for completion of each task. The overall scope of research for fiscal year 2023 and the technical objectives of the individual projects within each major research area remain consistent with the NRRC short-, intermediate-, and long-term goals.

Based on our review of the research plans and our discussions with the research teams, we offer the following recommendations for further assessments of three individual research activities. We also recommend extensions of the planned research to include two new projects. The new projects should be integrated into the overall research program for fiscal year 2023 and the plans for subsequent years.

Research Assessments

The following items summarize our recommendations for re-examinations of three planned research activities

(1) Level 2 PRA Model Plant Study

One planned research activity involves the development of a Level 2 probabilistic risk assessment (PRA) study of accidents that evolve from internal initiating events which occur at a model plant that is based on characteristics of Hamaoka Unit 4.

The scope of the Ikata Unit 3 and Kashiwazaki-Kariwa Unit 7 pilot plant PRAs includes integrated evaluations of core damage (Level 1 PRA), severe accident progression, and containment failure (Level 1.5 PRA) for internal initiating events that occur during full-power operation. Those studies are at an advanced stage of development. Their technical quality has benefited substantially from on-going reviews by teams of international PRA experts. Utilities are using the experience from those studies as examples of good quality state-of-the-practice methods to support updates and improvements to their current PRAs.

Kashiwazaki-Kariwa Unit 7 is an advanced boiling water reactor (ABWR). Hamaoka Unit 4 is a BWR5 with an advanced Mark I containment. Details of the progression of specific event scenarios, severe accident phenomena, and containment failure modes will be different for each of these BWR designs. An integrated Level 1 and Level 2 PRA study of severe accidents that are initiated by tsunamis has been completed for a model plant that is based on Hamaoka Unit 4. Our June 3, 2022 letter report on "Outcome of Hamaoka Model Plant Level 2 Tsunami PRA Project" contains our comments, conclusions, and recommendations for the Hamaoka study. An independent peer review of the study is planned for fiscal year 2023. The Hamaoka study has enhanced the knowledge and understanding of how to evaluate severe accident progression and containment performance in a Level 2 PRA for that plant design.

Substantial experience has been gained from the two pilot plant PRAs for internal initiating events and the model plant PRA study for tsunamis. It is not apparent that the planned additional model plant study will provide significant further technical knowledge or practical modeling insights that are needed to support the NRRC objective of developing methods and guidance that can be used to perform plant-specific Level 2 PRAs throughout Japan. We recommend that the NRRC should re-examine the need for this additional model plant study.

(2) Seismic PRA Model Plant Study

The NRRC research team has completed Phase 1 of a Level 1 PRA study of the risk from seismic events which occur during full-power operation for a model plant that is based on characteristics of Kashiwazaki-Kariwa Unit 6, which is an ABWR. That project has provided important experience with integration of the seismic hazard and consequential failures of structures and equipment in the PRA models. It has also provided practical insights and enhancements in techniques for evaluating site-specific features such as deformation of the foundation ground substrata and collapse of adjacent slopes. Phase 2 of the study began in fiscal year 2022, and it extends through fiscal year 2024. It will apply improved modeling techniques and refinements to the analyses of selected issues that were identified from the Phase 1 effort.

During our discussions, the research team indicated that it is necessary to conduct a companion study for a pressurized water reactor (PWR) model plant before a general methodology and guidance for evaluating the risk from seismic events can be developed. That study has not yet started, and it is not included in the research plan for fiscal year 2023.

It is not apparent that a second study for a PWR will provide substantial additional knowledge or practical experience that are needed to support the NRRC objective of developing methods and guidance that can be used to perform plant-specific analyses of the risk from seismic events. International experience from numerous PRAs and the experience from the in-progress NRRC research study have shown that the risk from seismic events depends very strongly on specific features of the site and design details of each reactor unit at that site. From that perspective, there is nothing inherent in the design of a PWR that would require fundamentally different seismic analysis methods or PRA modeling techniques, compared to those applied in the current research study. Of course, there would be differences in the site-specific seismic hazard, differences in the local ground foundations and slopes, and differences in the plant-specific structures and equipment that may be damaged during the event. However, those types of detailed differences apply for every site in Japan, regardless of whether the site contains a BWR or a PWR. The NRRC methodologies and guidance should provide practical analysis techniques that can be applied consistently to develop high-quality evaluations of the seismic risk at any site, accounting for the wide variety of site-specific and plant-specific differences that will be encountered in practice.

We recommend that the NRRC should re-examine why another seismic PRA study for a PWR model plant site is needed as a prerequisite to developing a general methodology and guidance that can be used evaluate the risk from seismic events.

(3) Detailed Analyses of Structural Failure Modes

The research plan contains an activity for the use of three-dimensional non-linear finite element analyses to evaluate the seismic fragility of a reactor building, accounting for both horizontal and vertical loading. The research team indicated that the objective of these analyses is to distinguish between partial damage and total collapse of the structure, as distinct failure modes that affect the conditional probability of core damage.

The terminology of "partial damage" is not reliable as a damage state, and it may convey unintended perspectives. In a PRA, the deformation, the local load-bearing capacity, and the resulting functional effects are the most important considerations. A detailed and realistic analysis, which will improve an understanding of progressive structural collapse, should also examine the effects of consequential damages at various intermediate loading levels to better understand the impacts on risk.

Depending on its physical characteristics and location, partial damage of the reactor building structure can have a significant functional impact on the availability of systems that are needed to prevent core damage and mitigate offsite releases. For example, building penetrations that contain critical piping systems, electrical power cables, and instrumentation and control cables may be displaced or damaged by falling debris. Debris may also damage other items inside the reactor building and in close proximity to the building exterior. The combined functional effects from that damage may lead directly to core damage, or the damage may significantly increase the conditional probability that core damage will occur if the remaining mitigation systems fail. Thus, it is not apparent how a nominal distinction between partial damage and complete collapse will facilitate a better understanding and improved models for evaluating the risk from a spectrum of possible structural damage conditions.

Without better consideration of the possible functional effects from a range of partial damage conditions in the context of a PRA model, it is not apparent how these finite element analyses will support a comprehensive and realistic evaluation of the risk from seismic damage at an actual plant. We recommend that the NRRC should confirm how the evaluation of partial damage and its consequences will be used in a practical PRA, before extensive finite element models are developed and detailed analyses are performed.

Research Extensions

The following items summarize our recommendations for two extensions of the NRRC research programs, beginning in fiscal year 2023.

(1) Spent Fuel Risk Assessment

The spent fuel risk research plan for fiscal year 2023 currently contains the same major activities, technical tasks, and schedules as the plan for fiscal year 2022. In our letter report for last year's research plan, we explained why it is important to extend this research to include a more comprehensive assessment of the contributors to spent fuel damage. We also explained why an integrated evaluation of the risk from events that may damage stored spent fuel is an important and potentially challenging element of a full-scope PRA. In particular, the PRA must consistently account for the composite effects from conditions that simultaneously compromise cooling for the fuel in the reactor vessel and cooling for the stored spent fuel during every combination of reactor and spent fuel pool operating modes.

The development of integrated PRA models that correctly account for the physical, functional, and human dependencies that affect the progression of these complex event scenarios can be a significant technical challenge. Furthermore, there is very limited international experience, with few reference PRA examples to demonstrate how this problem has been solved in practice.

The research plan for fiscal year 2023 should be expanded to include an explicit activity for development of methods and modeling practices that will be used to integrate the analyses of spent fuel risk with the PRA models for full power, low power, and shutdown modes. The objective of this effort should be the development of NRRC guidance for an integrated assessment of reactor core and spent fuel risk, supported by a practical PRA demonstration.

(2) Risk Integration

One of the fundamental goals of the NRRC is to provide support for the development of good quality full-scope PRAs at every nuclear power plant. Those PRAs should evaluate the frequency of damage to the reactor core and stored spent fuel (Level 1 risk) and the frequency of offsite radioactive releases (Level 2 risk) during all plant operating modes (full power, low power, and shutdown). The PRAs should systematically examine the contributions to that risk from a wide variety of sources:

- Internal events (plant transients, loss of coolant accidents, losses of offsite power, support system failures)
- Internal hazards (fires, floods, turbine missiles, toxic chemicals)
- External natural events (earthquakes, tsunamis, high winds, volcanic eruptions, cooling water intake blockage, other site-specific hazards)
- External man-made hazards (aircraft crashes, nearby industrial facility accidents, pipeline explosions, shipping accidents, railway accidents, highway accidents, other site-specific hazards)

The PRAs for sites that contain multiple units should also account for the risk from events that can simultaneously affect two or more units at the site.

Finally, the PRAs must explicitly quantify the uncertainties in the overall risk and its contributors. For example, experience has shown that uncertainties in the risk from internal events are often much smaller than uncertainties in the risk from very rare severe external events. Experience has also shown that the magnitudes and sources of those uncertainties can have an important effect on utility management decisions about how to most effectively manage specific contributions to the overall plant risk.

Since its founding in 2014, the NRRC has made substantial contributions to the development and demonstration of methods and PRA models to evaluate the risk from many types of internal and external events. However, that research has been focused primarily on detailed analyses of individual hazards and their associated technical issues in the context of isolated PRA models. Aggregation of the results from those individual hazard assessments to provide a comprehensive quantification of the overall plant risk and a balanced understanding of its contributors is not a simple task of addition. For example, to prevent inappropriate conservatism and bias in the results from a full-scope PRA, the combined models and their quantification process must avoid numerically accounting for the same risk contributions multiple times. Furthermore, the supporting models must be structured logically to provide a complete evaluation of all contributing hazards and accident scenarios. Consistent screening criteria must be used for each analyzed hazard, to ensure that the scope of the quantified risk contributors is transparent and well-understood, and that specific categories of events are not inadvertently omitted. Consistent methods must also be used to quantify the sources of uncertainty in each supporting analysis.

International experience has shown that systematic and comprehensive treatment of these risk integration issues is important, and it must not be left as an afterthought. As each element of the supporting analyses and models is developed, it should maintain a fundamental perspective on the need for an integrated assessment of overall plant risk. Those integrated assessments should also facilitate the needs for utility managers, regulators, and the Japanese public to understand the overall risk results, their contributors, and their underlying uncertainties.

The NRRC should initiate a research activity to develop methods and practical guidance for the integration of all supporting PRA models and results to provide a full-scope assessment of the overall plant risk and its contributors. The guidance should also explain how to interpret and cope with various ranges of uncertainty in the risk results. That activity should start in FY2023.

We look forward to our continuing interactions with the NRRC research team to review the overall research program and individual research projects, and to help the NRRC and the Japanese nuclear industry achieve their goals of comprehensive risk-informed decision-making.

Sincerely,

John W. Stetkar

John W. Stetkar
Chairman

REFERENCES

1. "NRRC Overview: Research Program for FY2023, RIDM Promotion," Presentation to NRRC Technical Advisory Committee, November 14, 2022, Proprietary.

2. "NRRC Overview: Research Program for FY2023, Risk Assessment," Presentation to NRRC Technical Advisory Committee, November 14, 2022, Proprietary.

3. "NRRC Overview: Research Program for FY2023, External Natural Events," Presentation to NRRC Technical Advisory Committee, November 14, 2022, Proprietary.

4. Technical Advisory Committee of the Nuclear Risk Research Center, "Outcome of Hamaoka Model Plant Level 2 Tsunami PRA Project," June 3, 2022.

5. Technical Advisory Committee of the Nuclear Risk Research Center, "Proposed NRRC Research Plan for Fiscal Year 2022," December 30, 2021.