Technical Advisory Committee of the Nuclear Risk Research Center
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SUBJECT: PROPOSED NRRC RESEARCH PLAN FOR FISCAL YEAR 2022

Dear Dr. Apostolakis:

In 2021, the ongoing COVID pandemic continued to present significant challenges to the Nuclear Risk Research Center (NRRC) research teams and the Technical Advisory Committee (TAC). We commend the entire NRRC staff for their efforts to continue progress on their important research during these very difficult conditions.

Since we could not meet with your team in our usual format, we used an alternative approach to conduct our review of the research plan for fiscal year 2022. In late October, the NRRC research teams sent us presentations that summarize the projects in each major research area. We reviewed that material and prepared our individual comments and questions on specific topics, as we would normally do before our meeting. We sent several of those individual member comments and questions to you for preliminary consideration by each research team. We then held two 2-hour video conferences to discuss our comments and questions on each major research area. The research teams also provided detailed and thoughtful written responses to supplement our oral discussions. We deliberated on those discussions and the teams' responses, and we developed the Committee's consensus observations, conclusions, and recommendations that are provided in this letter report. The purpose of our review was to provide comments on the technical merit of the research plan and its relevance for supporting the NRRC's current mission.

Our experience from this effort continues to reinforce the vital importance of the dynamic interactions during our face-to-face meetings. While the approach we used for this review achieved our basic objectives, the in-person technical exchanges provide clarification and understanding that benefit each of us in ways that cannot be accomplished through remote video conferences or written questions and answers. We sincerely hope that we can return to our normal meetings in 2022.

CONCLUSIONS AND RECOMMENDATIONS

1. We did not identify any major gaps in the overall technical research plan for fiscal year 2022.

2. We fully support the start of a new research project for Multi-Hazard Probabilistic Risk Assessment (MHPRA). The project addresses methods and models for evaluation of the risk from seismically-induced tsunamis. This is a complex topic, with very little international PRA experience. The NRRC research will be an important contribution to advance the state-of-the-practice for a comprehensive analysis of the risk from external natural events.

3. During our review, we identified a few individual research activities that merit additional attention in the plans for fiscal year 2022 and subsequent years. Our recommendations for those activities are summarized in the Discussion section of this report.

BACKGROUND

Since 2014, the NRRC research has made important advances in the scientific and engineering state of knowledge about events, phenomena, and accident scenarios that contribute to the risk from a nuclear power plant. That knowledge significantly improves realism in the methods and models that are used to evaluate risk. It also improves our understanding of risk and its contributors, and it supports confidence in the scientific basis for each utility's risk management activities. Those benefits are achieved through implementation of the research in the framework of an integrated probabilistic risk assessment (PRA) that provides a comprehensive and balanced evaluation of the risk from all internal events, internal hazards, and external events. The PRA is a vital tool to support effective risk-informed decision-making (RIDM) programs and practices that focus on the most important sources of risk at each nuclear power plant site. Therefore, it is essential that the scope and details of each research project are carefully tailored to meet the utilities' needs for integrated risk management.

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

The overall scope of research and the technical objectives of the individual projects within each major research area remain consistent with the NRRC short-, intermediate-, and long-term goals. We did not identify any major gaps in the overall technical research plan for fiscal year 2022. The discussion of Individual Research Activities contains our recommendations for specific elements of four research projects.

Research Applications

Most of the NRRC research activities have now achieved a level of maturity that allows practical demonstrations of how the methods and models are integrated into a full-scope PRA. In our report on the research plan for fiscal year 2021, we explained the technical reasons why the good quality PRAs for Ikata Unit 3 and Kashiwazaki-Kariwa Unit 7 should be used for those demonstrations. From our purely technical point of view, we continue to strongly recommend that the research teams should use those PRAs instead of the "model plant" approach. The "model plant" studies use diverse PRAs that are selected from a variety of plant sites and are currently developed to varying degrees of technical quality. The "model plant" analyses do not provide NRRC researchers or utility engineers with practical experience for the development of an integrated full-scope PRA. Furthermore, the results from those diverse studies do not demonstrate how insights about the overall plant risk and its contributors can be used for effective risk-informed decision-making.

The use of other "model plant" PRAs should be reserved only to demonstrate analysis methods and models for hazards that are not relevant for the Ikata and Kashiwazaki-Kariwa sites or the specific features of those plant designs.

Research Extensions

In our report on the research plan for fiscal year 2021, we noted that several research teams are now proposing further refinements and extensions for a variety of analytical methods and models. We also noted a distinct trend toward the development and use of increasingly detailed, computationally-intensive models to evaluate specific hazards and damage mechanisms. We remain concerned that those detailed models may lead to a belief in numerical precision that is not justified for an evaluation of the risk from phenomena that have inherently large uncertainties. Before more detailed analytical tools are developed further, each research team should describe and document how important sources of aleatory and epistemic uncertainty will be identified, characterized, and quantified as an integral part of the applied methods and models.

Experience has also shown that utility PRA engineers may have important technical and resource constraints which substantially limit their use of some very complex methods and tools. Simpler models which facilitate a careful treatment of the uncertainties often provide more meaningful and realistic support for practical PRA applications than the implied precision of complex computations. Therefore, we encourage the research teams to first develop simplified enhancements that provide an integrated evaluation of the technical issue and its associated uncertainties. The potential benefits that may be achieved from applying those improved methods, models, and tools should then be examined by demonstrating them in an integrated good quality PRA. Practical experience and insights from those initial applications should guide decisions about the needed scope and level of detail for the proposed refinements. More detailed methods and models should be pursued only if they significantly improve the understanding of overall plant risk and its contributors, and facilitate practical risk-informed decision-making by plant engineers and utility management.

In summary, the priorities and resources for further enhancements to specific analytical methods, models, and tools should be determined from an integrated risk-informed perspective. That perspective should consider how the specific technical issue and the proposed enhancements affect an understanding of Level 1 and Level 2 risk from all hazards and all plant operating modes, including the associated uncertainties. Utility engineers and managers should clearly understand how each proposed enhancement will improve their use of the PRA for practical risk-informed applications.

Individual Research Activities

The following items summarize our recommendations for re-examination of a few individual research activities.

(1) Low Power and Shutdown Modes

We were informed that the Japanese utilities have not identified any short-term priorities for research on generally-applicable methods or models for evaluating the risk from events that occur during low power and shutdown (LPSD) operating modes. Individual utilities are working to improve their plant-specific LPSD analyses. Therefore, the NRRC research plan for fiscal years 2022 through 2024 does not contain any specific activities in this area.

International experience has shown that the core damage frequency from events that occur during LPSD can be comparable to that during full power operation. Furthermore, the conditional probability of offsite releases may be much higher, due to the varying status of containment isolation and containment heat removal systems throughout an outage. Therefore, for a complete assessment and understanding of the risk at each nuclear power plant, it is essential that Japanese utilities should perform comprehensive and consistent Level 1 and Level 2 PRA assessments of the risk during LPSD.

To better understand the current status of LPSD risk assessment methods and practices, we recommend that the NRRC research plan for fiscal year 2022 should include a formal survey and structured high-level technical assessment of each utility's LPSD PRA.

The survey should first determine the scope and definitions of the LPSD plant operating states (POSs) that are explicitly modeled in the PRA. For each POS, the survey should then determine how the PRA models treat each of the following major issues:

- Normal system operating alignments
- Simultaneous (correlated) unavailability of multiple components or system trains due to inspections, maintenance, modifications, etc.
- Status of containment isolation
- Identification of initiating events caused by equipment failures
- Identification of initiating events caused by human errors during operations, testing, maintenance, and modifications
- Identification of initiating events caused by internal flooding, internal fires, and external events
- Definitions of success criteria and time windows for operator actions to prevent core damage and offsite releases

The results from this survey may conclusively confirm that no significant technical improvements are needed. That information will provide important confidence in the Japanese industry's LPSD risk assessment methods, and it will help us to resolve many questions that we have raised previously regarding this key element of a full-scope PRA. On the other hand, if the survey identifies possible knowledge gaps, sources of incompleteness, or inconsistency, that information will help the NRRC to formulate specific research or develop practical guidance.

(2) Spent Fuel

The NRRC spent fuel risk research is currently focused on refinements to deterministic analyses for specific issues such as possible recriticality conditions, modeling of fuel cladding behavior, and the effectiveness of alternative spray cooling and natural convection cooling. We understand that a planned activity for fiscal year 2022 includes a review of the potential risk importance of these issues, based on international PRA experience and insights. The research team will then use that information to help determine priorities for further detailed evaluations, if needed. We fully endorse that risk-informed perspective to guide the scope and level of detail for these focused activities.

International experience has shown that an integrated assessment of the risk from events that may damage stored spent fuel is an important and potentially challenging element of a full-scope PRA. The PRA must consistently account for events that affect spent fuel cooling during all plant operating modes. For example, many PRA initiating events such as losses of offsite power, support system failures, internal floods, internal fires, earthquakes, tsunamis, high winds, etc. may simultaneously affect cooling for the reactor core and the spent fuel. An integrated assessment of the resulting event scenarios must carefully evaluate the available mitigation options, and it must account for coordinated operator actions that are needed to prevent damage to fuel in the reactor, damage to the spent fuel, and possible offsite releases. The PRA must also account for other possible causes for spent fuel damage, such as reactivity effects due to boron dilution and mishaps that may occur during fuel movements for reactor refueling, reconfiguring the fuel pool storage pattern, loading of shipping containers or dry storage casks, etc.

As part of their reviews of international spent fuel risk assessment experience in fiscal year 2022, the research team should also examine methods and practices that are 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 spent fuel risk, supported by a practical PRA demonstration.

(3) Superposed Hazards

We fully support the new research project on Multi-Hazard PRA. This project addresses methods and models for evaluation of the risk from seismically-induced tsunamis. This is a complex topic, with very little international PRA experience. The NRRC research will be an important contribution to advance the state-of-the-practice for a comprehensive analysis of the risk from external natural events.

The scope of this research should first focus on the two most difficult elements of these analyses: (1) derivation of the composite site-specific hazard for seismic events and tsunamis, and (2) adaptation of the PRA models to quantify the risk from these events.

It is very important to demonstrate how an integrated PRA will consistently and completely account for the risk from all of the following types of events:

- Earthquakes that do not produce a tsunami (i.e., only seismic effects)

- Tsunamis that result from submarine landslides or earthquakes which do not damage any structures or equipment at the site (i.e., only tsunami effects)

- Tsunamis that result from earthquakes which may damage at least one structure, system, or component at the site (i.e., combined seismic and tsunami effects)

The hazard analyses should demonstrate how the exceedance frequencies for these events are quantified consistently. For example, the correlated hazard curves for seismically-induced tsunamis should evaluate conditional probabilities for a spectrum of tsunami wave heights that may result from tsunamigenic earthquakes, over the full range of the site-specific seismic hazard. In practice, this means each seismic initiating event that is quantified in the PRA should have a correlated probability distribution for a range of tsunami wave heights that may be produced by submarine earthquakes which contribute to that initiating event. That is a very complex assessment. It must carefully account for the locations, magnitudes, and displacements of numerous submarine seismic sources. It must also account for each source's contribution to the overall seismic hazard, and the range of tsunami wave heights that can be generated by the corresponding fault motions. A focused Senior Seismic Hazard Analysis Committee (SSHAC) evaluation may be needed to examine proposed methods to correlate the site-specific seismic and tsunami hazards, and to quantify the associated uncertainties in the combined hazard.

The research project should demonstrate how the PRA models are structured to provide a comprehensive and integrated assessment of the risk from earthquakes and tsunamis. It should also demonstrate how the models are structured logically to avoid "double counting" for some risk contributors. To satisfy these key technical objectives for a practical risk analysis, the demonstration should not be limited to an evaluation of only seismically-induced tsunamis. It should show analysts how to develop PRA models that correctly quantify the overall risk from all earthquakes and tsunamis (i.e., from all three types of events listed above).

(4) Volcanic Ash-Fall

The research plan indicates that a PRA demonstration of the methods and models to evaluate the risk from volcanic ash deposition will start in fiscal year 2022.

That risk analysis should account for the accumulation of ash during a volcanic eruption that may continue for several days or weeks. For example, the initial effects may result in an automatic plant trip or a forced manual (i.e., anticipatory) shutdown before or during the ash deposit. Those effects would be included in the PRA models for full-power operation. However, continued ash accumulation may affect systems that are needed to maintain decay heat removal for an extended period of time after the reactor is shut down (i.e., much longer than the 24-hour mission time that is typically used in a full-power PRA). Those effects can be included in the PRA models for plant shutdown modes, which account for the decay heat levels and plant-specific system operating configurations as a function of time after shutdown. Those models could also account for personnel actions that may be needed to clean or replace intake air filters (and perhaps cooling water filters) that become clogged over time. Therefore, the demonstration should use the combined PRA models for full-power operation and shutdown modes to illustrate how the overall risk from an extended eruption is evaluated.

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
Chairman

REFERENCES

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3. "NRRC Overview: Research Program for FY2022, RIDM Promotion," Presentation to NRRC Technical Advisory Committee, November 18, 2021, Proprietary.

4. Technical Advisory Committee individual members' comments and questions on "NRRC Overview: Research Program for FY2022, Risk Assessment," November 11, 2021, Confidential.

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