Technical Advisory Committee of the Nuclear Risk Research Center
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SUBJECT: PRELIMINARY NRRC RESEARCH PLAN FOR FISCAL YEAR 2026

Dear Dr. Apostolakis:

During the 22nd meeting of the Technical Advisory Committee of the Nuclear Risk Research Center (NRRC), May 19-23, 2025, we met with the NRRC staff to review the proposed preliminary research plan for fiscal year 2026. 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 the preliminary research plan for fiscal year 2026, as well as the technical objectives of the constituent projects within each principal research domain, remain aligned with the NRRC's short-, mid-, and long-term strategic goals.

2. During our review, we identified one multifaceted research activity on external events PRA and one specific and targeted research activity on human reliability analysis that merit additional attention in the preliminary plans for fiscal year 2026 and subsequent years. Our recommendations for those activities are summarized in the Discussion section of this report.

BACKGROUND

One of the primary objectives of the research plan is to articulate the technical context of the identified research needs, including the rationale for prioritization and scope, the current state of knowledge, and the anticipated contributions and significance of the proposed research to the Center's overarching goals. Our review of the preliminary research plan focused on evaluating the objectives of each research project and its supporting tasks, the technical interrelationships and relative priorities among those activities, and the identification of any significant gaps

requiring further research. We did not undertake a detailed review of the technical content or specific milestones of individual research activities, except to the extent necessary to assess their integration within the broader plan. We intend to provide separate comments on the technical aspects of individual research projects in future, more detailed reviews.

DISCUSSION

During this review, we were briefed on 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 the preliminary research plan for fiscal year 2026, as well as the technical objectives of the constituent projects within each principal research domain, remain aligned with the NRRC's short-, mid-, and long-term strategic goals.

Based on our review of the preliminary research plans and our discussions with the research teams, we offer the following recommendations for additional research activities.

(1) Develop Guidance Documents for External Events PRA

A central NRRC research activity involves the development of methods and guidance to support good quality full-scope probabilistic risk assessments (PRAs) at all Japanese nuclear power plants. We recommend the following research activities that will fully complement and enhance the NRRC's current research activities that are focused primarily on developing specialized methods for addressing the unique characteristics of each hazard and their potential impacts.

i. It is essential to have a dedicated PRA guidance document for each category of external events (e.g., earthquakes, tsunamis, high winds, volcanoes, etc.). That guidance will complement ongoing efforts in developing detailed methodologies and models for hazard-specific occurrence and impact assessments. Those current activities provide critical input data on the frequency and physical impacts of specific external event phenomena. However, there remains a significant need for a structured framework to support the integration of these inputs into a comprehensive and technically defensible PRA. Such guidance would help ensure consistency and transparency in modeling approaches across different hazard types, facilitate traceability between hazard characterization and risk quantification, and support regulatory, operational, and risk-informed decision-making. Moreover, it would aid in addressing common challenges such as modeling hazards, plant-specific fragilities, and the treatment of uncertainties.

   The research plans for each external event should include distinct milestones for the development of an overall risk assessment guidance document. Those milestones should be established, and preparation of the preliminary guidance documents for each external event should begin in FY2026. These

efforts will ultimately enhance the robustness and credibility of the external event risk assessments.

ii. The PRA guidance document for each external event suggested in item "i" should address the following key needs:

a. The guidance should provide a systematic and holistic approach for identifying and modeling consequential events resulting from external hazards, such as seismically-induced fires or floods. It should emphasize the need to consider both direct and indirect impacts of external events, including cascading effects and interdependencies among safety systems and structures. Additionally, the guidance should to the extent possible leverage the guidance provided in other NRRC documents, such as the guidance for the analyses of internal flooding, internal fires, and human reliability.

b. The guidance should provide a risk-informed process for the use of progressively detailed analytical methods, ensuring that users can apply these methods effectively and appropriately. For example, it should clarify the progressive use of appropriate screening criteria, simplified models, detailed analytical methods, and associated uncertainty treatments. The guidance should also provide examples, decision-making frameworks, and practical considerations for tailoring the application of complex methods to plant-specific conditions and available data.

(2) Human Reliability Analysis Methodology for Actions Resulting in Undesirable Events

In the context of internal flooding PRA analyses, a critical type of operator error to consider is where an operator takes an action that either should not have been taken or is performed incorrectly. An example relevant to internal flooding is inadvertent actuation of the wrong system train or opening a wrong valve while a pressure boundary is open to perform repairs, replacement, or routine preventive maintenance.

This is in contrast to an error which involves failing to take a necessary action - such as not responding to a sump alarm or overlooking required isolation steps to limit flood propagation.

Maintenance-induced flooding initiators are typically addressed through simplified evaluations, often being screened out qualitatively or assigned conservative values to estimate their frequencies. This practice stems in part from the lack of detailed guidance for performing rigorous human reliability analyses specifically tailored to these types of scenarios.

As noted in the EPRI Internal Flooding PRA Guide and reflected in the ASME/ANS PRA Standard, maintenance errors should be included in the estimation of internal flooding frequencies. The use of generic data may be adequate for simplified, conservative analyses. However, a more detailed, plant-specific assessment of human-induced flooding requires careful evaluation of the plant configuration and

concurrent operations and maintenance activities which may result in errors, using appropriate human reliability analysis (HRA) techniques.

Importantly, the EPRI guide acknowledges the challenge of this requirement, stating:

> *"It is noted that such an evaluation would require consideration of human errors of commission. This aspect of HRA methodology is still evolving, and the estimation of plant-specific maintenance errors is beyond the current state-of-the-art."*

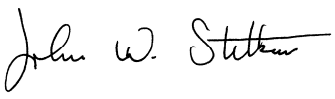
In practice, for the majority of Risk-Informed / Performance-Based (RIPB) applications, a simplified analysis may be sufficient. However, for certain RIPB programs - such as online maintenance, where real-time risk management decisions are integral - developing plant-specific analyses of maintenance-induced flooding can yield valuable insights. In such cases, using mature HRA methods to model scenarios that survive screening can support more informed decisions and can enhance safety.

Furthermore, the same HRA techniques developed to address errors of commission related to maintenance-induced floods can also be leveraged to assess other human-induced initiators - such as inadvertent drain-down events during plant shutdown modes, which involve similar human actions in abnormal configurations.

Therefore, it is recommended that the NRRC investigate the merits of developing a dedicated HRA methodology for estimating human error probabilities associated with maintenance-induced internal flooding and other similar events. Advancing this capability would strengthen the technical basis for modeling human-induced initiating events and enhance the realism and defensibility of internal hazards PRA models.

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

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2. Nuclear Risk Research Center, "NRRC Overview: Research Program for FY2026, Risk Assessment," Presentation to NRRC Technical Advisory Committee, May 19, 2025, Proprietary.

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4. Electric Power Research Institute, EPRI 1019194, "Guidelines for Performance of Internal Flooding Probabilistic Risk Assessment," December 2009.

5. American Society of Mechanical Engineers, American Nuclear Society, ANSI/ASME/ANS RA-S-1.1-2024, "Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," March 2024.