Technical Advisory Committee of the Nuclear Risk Research Center
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May 27, 2026

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SUBJECT: MULTI-UNIT PROBABILISTIC RISK ASSESSMENT METHODOLOGY

Dear Dr. Apostolakis:

During the 24th meeting of the Technical Advisory Committee of the Nuclear Risk Research Center (NRRC), May 18-22, 2026, we met with the NRRC staff to review the current status of the proposed methodology for evaluating the site-wide risk at a site which contains multiple nuclear reactors. This letter report documents our recommendations for enhancements to the NRRC's draft technical report on the methodology.

CONCLUSIONS AND RECOMMENDATIONS

1. Evaluation of the site-wide risk and its contributors at a site which contains multiple nuclear reactors is extremely challenging. The NRRC has made substantial progress on the development of methods and tools to support these analyses.

2. The technical report that will be completed in fiscal year 2026 should be enhanced to describe an analytical framework and methodology that can be applied to evaluate the site-wide risk from all hazards.

3. The NRRC should re-examine the proposed Level 2 risk significance metrics for screening out accident scenarios that involve offsite releases.

BACKGROUND

Evaluation of the site-wide risk and its contributors at a site which contains multiple nuclear reactors is extremely challenging. These analyses are often characterized as a Multi-Unit Probabilistic Risk Assessment (MUPRA). Comprehensive methods for performing these analyses are not generally available, and they are only now

being developed internationally. Very few applications of these methods have been performed for actual nuclear power plant sites.

The NRRC has been developing a proposed MUPRA methodology for several years. In 2023, the research team prepared an initial technical report on the methodology, which focused on methods and tools for an evaluation of the risk from internal initiating events. In 2025, the team issued an update of that report, which includes an extension of the analytical scope to include internal hazards, such as fires and flooding events. The team has also developed proposed methods to evaluate the risk from earthquakes.

We have been briefed on the continuing progress of this research. Our members have also provided personal comments on the draft technical reports. The NRRC has made substantial progress on the development of methods and tools to support these challenging analyses.

During our current meeting, we were informed that this research project will be suspended at the end of fiscal year 2026. At that time, the team plans to prepare a final update of the current technical report, which will document the methodology and tools.

DISCUSSION

We recommend the following enhancements to the technical report that will be prepared at the end of fiscal year 2026.

(1) Framework for Evaluation of All Hazards

The proposed MUPRA methodology has evolved in a piece-wise manner from initial consideration of only internal initiating events to extensions that address internal hazards and earthquakes. Each extension has been discussed in the context of a separate methodology, such as an "Internal Event MUPRA", a "Fire MUPRA", and a "Seismic MUPRA". However, a common general framework applies for the analyses of these hazards, and all others that may affect a particular site. That framework is anchored in a very useful conceptual taxonomy, which defines three general categories of multi-unit initiating events (MU-IEs).

- A Common-Cause MU-IE is a single initiating event which affects two or more units simultaneously.

- A Dependent MU-IE is an initiating event which occurs in one unit, with functionally dependent or cascading effects at one or more other units.

- Independent MU-IEs are initiating events which occur coincidentally at two or more units, but have no common or dependent functional effects.

Common-Cause MU-IEs typically include most initiating events that are caused by natural or man-made external hazards, such as earthquakes, tsunamis, accidents at nearby industrial facilities, etc. This category also includes internal hazards. For

example, fires or floods which occur in shared compartments may cause simultaneous damage in two or more units. The category also includes internal events which disable shared support systems, such as electric power supplies, cooling water, ventilation, etc.

Dependent MU-IEs include cascading failures in multiple units that result from an initiating event in the first unit. Identification of these effects typically requires a rather detailed examination of potentially subtle interactions between the units. For example, a turbine missile from one unit may cause damage in an adjacent unit. Smoke or toxic gases from a fire in one unit may enter the ventilation intake for another unit and cause an automatic shutdown or require a manual shutdown. A lightning strike at one unit or a severe internal electrical fault may induce potentials in a common floating ground grid, which result in an automatic trip of another unit. Dependent MU-IEs also include forced manual shutdowns of another unit, due to site-specific procedural guidance or administrative practices. For example, the site-wide procedures for specific internal fires or floods may require an immediate manual trip of adjacent units, as a precaution against possible effects from inter-unit propagation. Procedures may also require manual shutdowns for selected internal events, such as large breaks in main steam or feedwater systems, which may release steam or water into shared secondary plant compartments.

Independent IEs typically include most internal initiating events and most initiating events from internal hazards. Each Independent IE directly affects only one unit. In the context of a MUPRA, an example of Independent MU-IEs includes the combination of Initiating Event X which affects Unit 1, and subsequent occurrence of Initiating Event Y which affects Unit 2 during the Unit 1 event mitigation period. The effects from these coincident initiating events may alter the functional success criteria that are used for shared equipment in each Single-Unit PRA (SUPRA) model. They may require the use of permanently installed or portable alternative severe accident mitigation equipment that is shared by multiple units. These conditions may also require site-wide personnel responses which challenge the available staffing, and they may introduce sources of inter-unit cognitive dependence among operators and supervisors, or among emergency response personnel.

The proposed methodology describes techniques and tools that are used to (1) make appropriate modifications to the SUPRA models and analyses to account for the effects from inter-unit dependencies that are triggered by each hazard, (2) combine the resulting accident sequences from each SUPRA model, and (3) apply structured criteria to determine which accident scenarios are potentially most important to the site-wide risk. These basic techniques are used for the analyses of each hazard that has been examined to date. They are a fundamental element of the common MUPRA framework and analysis process, and they should apply for all other hazards.

Special methods are needed to evaluate issues that have an important effect on inter-unit dependencies. Examples of those issues are:

- Treatment of inter-unit common cause hardware failures, and the relationship with the models for intra-unit common cause failures. These evaluations apply for the analyses of all hazards.

- Treatment of inter-unit human cognitive dependencies during evolving accident scenarios. These evaluations apply for the analyses of all hazards.

- Treatment of inter-unit correlated seismic fragilities, and the relationship with the models for intra-unit correlated fragilities. These evaluations apply only for the seismic analyses.

These specialized analyses often involve technically challenging methods, and they can require significant analyst effort and computational capabilities. Therefore, a fundamental element of each methodology involves a risk-informed graded approach, which applies increasingly detailed analyses only for the most risk-significant accident scenarios. Details of the NRRC methods for each type of analysis are currently still evolving.

These focused evaluations of issues which affect inter-unit dependencies support implementation of the general MUPRA framework and methodology, in the same manner that best-estimate thermal-hydraulic analyses support the development of scenario-specific success criteria, or fire modeling tools support the analyses of fire growth and damage. Thus, the methods for each type of inter-unit dependency evaluation may be described in separate topical reports, which are referenced by the general MUPRA methodology. Furthermore, those detailed focused methods may continue to evolve over time, while the overall MUPRA framework remains applicable for all hazards.

The technical report that will be completed in fiscal year 2026 should be enhanced to describe a common MUPRA analytical framework and methodology that can be applied to evaluate the site-wide risk from all hazards. The current status of risk-informed graded methods for the evaluation of specific types of inter-unit dependencies should be documented in focused topical reports or appendices, which support implementation of the general methodology. As an option, the technical report could also identify how the MUPRA methodology may be used in future integrated risk assessments, particularly where common risk metrics, compatible PRA model outputs, treatment of dependencies, and risk-informed screening criteria may need to be coordinated to support effective site-wide risk management activities.

(2) Level 2 PRA Risk Significance Metrics

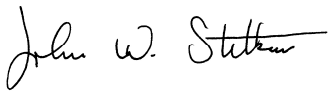
The proposed methodology includes a screening process to determine whether combinations of Independent IEs may be significant to the site-wide risk. The research team has considered our meeting discussions and members' comments on that process. The 2025 draft update of the technical report extends the methodology to include consideration of the Level 2 PRA contributions to offsite releases, in addition to the Level 1 PRA contributions to the core damage frequency (CDF).

The current proposed methodology uses Level 2 PRA screening criteria that are derived from the Nuclear Regulation Authority's (NRA) provisional performance objective that the frequency of a release of more than 100 TBq of Cesium-137 (Cs-137) should be less than 10^{-6} event per year.

We have had several discussions about the use of this criterion as a measure of offsite consequences in the context of the NRRC guidance for risk-informed applications, such as on-line maintenance (OLM) and extensions of the containment vessel leak rate testing (CVLRT) interval. Our letter reports on the methodologies for those initiatives discuss how that metric should be addressed as a supplemental consideration to other Level 2 PRA metrics, such as the containment failure frequency (CFF) and the conditional containment failure probability (CCFP).

During their preparation of the 2026 MUPRA methodology technical report, the NRRC research team should re-examine the proposed Level 2 PRA risk significance metrics for screening out accident scenarios that involve offsite releases.

Sincerely,



John W. Stetkar
Chairman

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