Technical Advisory Committee of the Nuclear Risk Research Center
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SUBJECT: RISK-INFORMED ON-LINE MAINTENANCE GUIDELINE

Dear Dr. Apostolakis:

During the 23rd meeting of the Technical Advisory Committee of the Nuclear Risk Research Center (NRRC), November 17-21, 2025, we met with representatives of the NRRC staff to discuss the guidance for implementation of risk-informed on-line maintenance programs at Japanese nuclear power plants. This letter report documents our review of the guidance in the September 2025 version of Report NR24001, "On-Line Maintenance Guideline".

Mr. Afzali worked closely with the NRRC Risk-Informed Decision-Making Promotion Team to implement several important improvements to this version of the Guideline. He did not participate in our deliberations for this letter report.

CONCLUSIONS AND RECOMMENDATIONS

1. The September 2025 version of Report NR24001, "On-Line Maintenance Guideline," contains enhancements that adequately resolve the comments and recommendations in our January 13, 2025 letter report.

2. The Guideline should be issued for trial use.

3. Pilot applications of the guidance should be performed for at least one or two plants. Those applications should demonstrate all elements of the guidance.

4. During our review, we identified a few topics that merit further consideration before the next revision of the Guideline is issued. Those topics are summarized in the Discussion section of this report.

BACKGROUND

International experience has shown that performance of equipment inspections and preventive maintenance during plant power operation improve plant safety and operating efficiency. In Japan, these types of maintenance activities are currently conducted only when a plant is shut down for refueling. That practice involves complex and difficult coordination of these activities with other inspections and maintenance which cannot be performed during power operation. All of these activities must also be accomplished under the pressures of outage time constraints and schedules that affect the plant's availability to produce power.

Implementation of on-line maintenance (OLM) allows plant personnel to better monitor equipment performance and respond to evolving conditions throughout the year, without the time and schedule pressures that apply during the periodic outages. This improves overall equipment performance and its availability to provide plant safety functions. It also reduces the risk during plant shutdown modes, because less equipment is removed from service during each plant refueling outage.

Implementation of risk-informed OLM is a pioneering risk-informed initiative by the Japanese nuclear industry. A comprehensive assessment of the risk from each proposed maintenance activity provides assurance that the overall plant risk remains very low. That assurance is further improved by the implementation of additional risk management measures for specific activities and by careful monitoring of the plant safety status throughout the OLM period.

We have had several briefings on this topic and information exchanges with the NRRC staff. We have reviewed draft versions of the supporting methods and guidance, and our members have provided individual comments on specific details. Our January 13, 2025 letter report on "Interim Review of Risk-Informed On-Line Maintenance Guideline" summarized recommended enhancements for some elements of the guidance. The NRRC research team has updated the guidance to address our comments and recommendations. This report summarizes our review of the September 2025 version of Guideline.

For general reference, the Guideline uses the term "external events" to include hazards from internal plant sources (e.g., fires, floods, etc.), external natural sources (e.g., earthquakes, tsunamis, high winds, etc.), and external man-made sources (e.g., accidental aircraft crashes, transportation accidents, accidents at nearby port and industrial facilities, etc.). In this letter report, we use "external events" in the same context.

DISCUSSION

The following sections summarize our comments and the technical bases for each item in our Conclusions and Recommendations.

Guidance for Risk-Informed On-Line Maintenance

The NRRC guidance for implementation of OLM programs is based on the fundamental principles of risk-informed decision-making (RIDM). Those principles are described in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.174, International Atomic Energy Agency (IAEA) TECDOC-1909, and Atomic Energy Society of Japan (AESJ) Standard AESJ-SC-S012E:2019. The NRRC guidance also benefits from the Nuclear Energy Institute (NEI) guidance in NUMARC 93-01, which is endorsed by U.S. NRC Regulatory Guide 1.160.

The Guideline contains guidance and methods for evaluations of how removal of equipment for OLM affects the plant risk. It indicates that quantitative evaluations should be performed for all internal events and external events, to the extent that is supported by a plant's current PRA models. The applied quantitative risk acceptance criteria account for changes in the core damage frequency (CDF) and containment failure frequency (CFF). The criteria are consistent with those recommended in NUMARC 93-01, although there are differences between CFF and the large early release frequency (LERF) metric that is used in the U.S. The acceptance criteria are endorsed by the U.S. NRC and are used in U.S. risk-informed maintenance programs.

The Guideline indicates that qualitative assessments of the risk should be performed for external events that are not currently included in the plant's PRA models. Those assessments include an evaluation of how the maintenance activities may increase the frequency of each hazard that may occur in the work location, increase its severity, or affect barriers which prevent propagation of the damage outside of the work location. They also include an evaluation of how the maintenance activities may reduce the number of available safe shutdown success paths, based on the equipment that is removed from service. The combined assessments provide a comprehensive qualitative examination of the risk.

The Nuclear Regulation Authority (NRA) has reached a consensus on a provisional performance objective that the average annual frequency of a release of more than 100 terabecquerels (TBq) of cesium-137 (Cs-137) should remain below 10^{-6} event per year. This performance objective extends beyond the risk considerations that are used in the reference U.S. guidance and methods. The Guideline indicates that this issue should be addressed during the OLM evaluations, and it summarizes considerations for a general methodology. It also notes that further discussions and clarifications are needed before a more detailed assessment method can be developed. This level of guidance is appropriate, considering the evolving understanding of this performance objective.

The Guideline contains guidance and methods for performing defense-in-depth assessments. Those "deterministic" assessments examine how the OLM affects the available levels of redundancy and diversity for mitigation of plant challenges. The defense-in-depth assessments provide a complementary perspective to the risk information, and they are an important input to the integrated RIDM process. The guidance describes how a safety function assessment tree (SFAT) can be used to systematically organize and document those assessments.

The Guideline contains guidance and methods for how the plant's multi-disciplinary RIDM panel should use the information about risk and defense-in-depth considerations to determine whether the proposed OLM should be performed. The guidance describes quantitative and qualitative criteria that are used to identify enhanced measures which are applied during the OLM period to effectively manage specific sources of risk.

The Guideline contains extensive guidance and examples that describe how each OLM application should be planned, organized, and managed, including the responsibilities for each plant department. It also describes the monitoring of overall plant safety during the OLM period, and the need for pre-planned contingencies if the safety situation changes.

The Guideline should be issued for trial use

Pilot Applications

Experience has shown that these types of pioneering initiatives benefit significantly from the performance of trial applications at one or more power plants. Those trial applications provide valuable practical experience with the use of the methods and guidance, and integration of the assessment results to support the risk-informed OLM program. The trial applications often result in refinements of the methods and guidance that are difficult to anticipate without that practical experience.

We have been briefed on elements of the trial applications of the guidance that have been performed at Ikata Unit 3. We are very encouraged to know that members of the NRA staff are observing that process and have provided feedback to the plant and the NRRC. The lessons learned and feedback from these trial applications will provide valuable input for future refinements of the Guideline.

Considering the importance of this initiative and the complexity of the guidance, additional pilot applications should be performed for at least one or two other plants. The intent of those applications is to provide improved assurance that all utility analysts and decision makers will clearly and consistently understand and apply the guidance. In that context, the pilot applications should fully exercise all elements of the Guideline, including the quantitative risk evaluations, both types of qualitative assessments of the risk from external events, the defense-in-depth assessments, and engagement of the plant's RIDM panel to identify specific risk management measures and formulate the OLM plan.

It would be useful if one pilot application examines a proposed OLM configuration that simultaneously removes equipment from service in multiple systems which provide different functions within the same safety train. That application would confirm how the guidance is used for a configuration that is more complex than maintenance on a single component.

Topics for Further Consideration

We recommend that the current version of the Guideline should be issued for trial use. The experience from the pilot applications will identify specific areas for

improvement and clarifications which will be implemented in the next revision of the guidance. During our review, we identified a few topics that merit further consideration before the next revision of the Guideline is issued.

Qualitative Assessments of the Risk from External Events

The guidance for qualitative assessments of how the OLM configuration affects the number of available safe shutdown success paths is specifically focused on only the hazards from internal fires and internal floods. Experience has shown that those hazards may be very important to risk, depending on the specific equipment that is removed from service. Plant-specific vulnerabilities to other external events may also result in significant sources of risk. The OLM configuration may have a different effect on the risks from those hazards, compared to the risks from internal fires and internal floods.

We were informed that plants which have restarted operations and completed their Safety Analysis Report (SAR) have a PRA that quantifies the risk from earthquakes and tsunamis. Other external events which may affect a site include high winds, volcanoes, other site-specific natural hazards, and site-specific man-made hazards. Depending on the damage from each hazard and the corresponding PRA success criteria, the OLM configuration will affect the number of safe shutdown paths that remain available to prevent core damage and offsite releases. Experience has shown that it is often possible to conclude that the risk from many of these hazards is very low, based on other types of quantitative or qualitative assessments. However, if that is not feasible, the safe shutdown success path assessment methodology can be used to provide an alternative qualitative evaluation of the hazard risk. Therefore, the guidance should indicate that the safe shutdown success path assessment methodology should be used to evaluate the risk from all external events which cannot be addressed adequately by other considerations.

The Guideline contains detailed guidance and methods to derive quantitative risk indices, such as the incremental core damage probability (ICDP) and incremental containment failure probability (ICFP). It also contains an extensive discussion of the qualitative assessments of how the maintenance activities may increase the frequency of each hazard which may occur in the work location, increase its severity, or affect barriers that prevent propagation of the damage outside of the work location. The Guideline does not contain similar guidance and methods for the qualitative assessments of how the OLM configuration affects the number of available safe shutdown success paths. In principle, the Guideline might refer analysts to other references that contain more complete descriptions of this methodology. However, utility analysts would benefit substantially if the Guideline provides similar guidance for all three basic assessment methods in one concise reference. The team should consider including expanded guidance for the safe shutdown success path assessment methodology, with appropriate explanatory examples as needed.

Evaluation and Monitoring of Cumulative Risk Impacts

A previous version of the Guideline contained a requirement to confirm that the cumulative effects from OLM do not result in a significant increase in the plant's average annual CDF or CFF, compared to the proposed performance goals. The

guidance also summarized a method for how to perform those comparisons, by transforming the incremental risk that is accrued during the OLM period to an equivalent average annual risk. The guidance indicated that these cumulative effects should be updated after the completion of each OLM outage, and they should be considered in decisions about the performance of subsequent maintenance.

Tracking and trending the cumulative risk effects is an important element of the performance monitoring guidance in Regulatory Guide 1.174. It provides assurance that the overall effects from "small and short" increases in risk during successive OLM activities do not significantly affect the plant's average annual risk.

The requirements to perform these updates and a summary of the supporting methods have been removed from the current version of the Guideline. The team should restore the previous guidance or provide alternative guidance to ensure that the cumulative risk updates are performed consistently.

Defense-in-Depth Assessments

Various references use the term "defense-in-depth" to describe somewhat different, but related, concepts of multiple barriers and levels of safety. In this letter report, we use defense-in-depth in the context of an assessment of how the OLM configuration affects the plant's available redundancy and diversity to achieve key safety functions.

The Guideline indicates that the defense-in-depth assessments can be used as a substitute for the quantitative or qualitative risk evaluations for specific hazards. That is not consistent with the guidance in Regulatory Guide 1.174 and AESJ Standard AESJ-SC-S012E:2019. That guidance specifically indicates that an integrated risk-informed decision should account for estimates of how the OLM affects overall plant risk from all hazards, ***and*** it should account for assessments of how the OLM affects defense-in-depth. The defense-in-depth assessments are complementary to the risk evaluations. They may contain similar conclusions, but they provide a different safety perspective for consideration by the plant's RIDM panel. The team should clarify the guidance to indicate that the defense-in-depth assessments are not a substitute for the quantitative and qualitative evaluations of how the OLM affects plant risk.

The current guidance for these assessments is focused exclusively on considerations of how the OLM affects the available defense-in-depth for mitigation of internal events. The functional success criteria to prevent core damage and offsite releases for some external events may be different from the success criteria which apply for the internal events that are evaluated in the plant's PRA models. Therefore, the guidance should indicate that these assessments should address how the OLM affects the available defense-in-depth for mitigation of internal events and external events.

Initial Screening Criteria

The Guideline describes a screening assessment that is used to initially determine whether the OLM can be performed. That assessment is based on estimates of how the risk during the OLM configuration compares with quantitative screening criteria

for CDF and CFF. Two different screening criteria are used, depending on whether the estimates include the risk from external events or internal events.

The evaluation process in NUMARC 93-01 contains a similar screening step. However, that guidance uses only one criterion, which applies for the total risk from internal events and external events. That combined assessment is consistent with the guidance in Regulatory Guide 1.174, which indicates that risk-informed decisions should account for the risk from all hazards.

Utility analysts may not clearly understand how the two screening criteria should be used in practice. The criteria may also not be applied consistently, depending on the scope of external events that are included in each plant's PRA models. The team should re-examine the technical rationale for these screening criteria. If the Guideline retains the separate screening criteria, the guidance should be enhanced to ensure that they are interpreted and applied consistently.

Risk from Anticipated Conditions during On-Line Maintenance

The plant safety status is monitored continuously. The Guideline indicates that contingency plans should be available to address possible sources of increased risk from unanticipated changes to the plant status or unexpected conditions which occur during the period while equipment is removed from service for OLM. That guidance is very important for proactive management of plant safety.

During the planning process for each OLM activity, quantitative and qualitative assessments are performed to evaluate how the OLM configuration will affect plant risk. Those assessments should carefully account for all planned activities which may increase risk. For example, we were informed that the plant Technical Specifications may require that redundant equipment must be tested while the OLM is in progress. Depending on the specific requirements, those tests may functionally disable equipment for some period of time. The tests may also introduce demands which increase the likelihood of equipment failures. (These are often called "test-induced failures".) Therefore, if these types of situations apply during a proposed OLM configuration, the pre-planning risk assessments should account for them and include them as a known contribution to the OLM risk.

The Guideline should clearly indicate that the risk assessments should account for required testing and any other planned activities which remove equipment from service or introduce the possibility of test-induced failures during the OLM period.

Risk Achievement Worth Thresholds

The Guideline contains guidance for the identification and implementation of enhanced risk management measures, based on quantitative estimates of the risk significance of specific equipment, systems, and functions. "Green", "White", and "Yellow" thresholds are used to distinguish among three levels of risk significance which require progressively more comprehensive measures.

The risk achievement worth (RAW) is one metric that is used to determine an item's risk significance. Guidance that is used in the U.S. typically applies a value of RAW $\geq$ 2 to determine whether an item's risk significance merits enhanced attention.

The Guideline summarizes an alternative method to estimate threshold RAW values which prompt the implementation of risk management measures. The guidance and the example calculation do not seem to be consistent with the thresholds that apply for a "White" or "Yellow" level of risk during the OLM period. The team should re-examine the guidance for use of these alternative RAW thresholds and their applicability for each level of risk management measures.

Summary

This Guideline is a pioneering contribution to the Japanese industry's use of risk-informed decision-making to improve nuclear power plant safety and operations. We look forward to continuing our discussions with the NRRC staff as the pilot applications are completed, and the guidance is updated.

Sincerely,

John W. Stetkar
Chairman

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