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SUBJECT: FIRE PRA GUIDE

Dear Dr. Apostolakis:

In June 2020, the Nuclear Risk Research Center (NRRC) published the "Fire PRA Guide – An Update of NUREG/CR-6850 for Use by the Japanese Nuclear Industry". This is a very important milestone for the NRRC fire risk research activities. We planned to conduct a review of the Fire PRA Guide during our November 2020 or May 2021 meetings. Unfortunately, due to the continuing challenges and uncertainties with the COVID-19 pandemic, we could not hold in-person meetings with your research teams. Therefore, we used an alternative approach to conduct our review of this report.

The complete report, in English and Japanese, is available on the NRRC website. In June, the NRRC research teams also provided us with presentations that summarize the main elements of the report and selected supporting research activities. We reviewed the report and those summaries, and we prepared comments and questions from each of our members, as we would normally do before our meetings. In lieu of the active meeting discussions that clarify our understanding of each topic, we sent those comments and questions to you for consideration by the fire research team. The researchers provided detailed and thoughtful written responses to our questions. We also had a 2-hour video conference with your team to further discuss specific issues and follow-up questions. We then deliberated on those responses and developed the Committee's consensus observations, conclusions, and recommendations that are provided in this letter report.

Our experience from this effort has reinforced 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 written questions and answers. We sincerely hope that we can return to our normal meetings in 2022.

CONCLUSION AND RECOMMENDATIONS

1. We commend the NRRC for completing this major milestone to develop a fire PRA methodology and guidance that is suitable for use by the Japanese industry. The Fire PRA Guide has advanced the international state-of-the-practice guidance for performing a fire PRA.

2. During our review of the Fire PRA Guide and the supporting research activities, we identified the following topics that merit additional attention. Our specific recommendations for each topic are summarized in the Discussion section of this report. The fire PRA researchers should address these topics while the current guidance is being used for the trial application. We would like to work closely with the NRRC fire PRA research team as they address these topics.
    - Integration of Japanese fire event data
    - Guidance for low power and shutdown modes
    - Main Control Room fires
    - Fire effects on digital systems

BACKGROUND

International experience has shown that fires are often an important contribution to nuclear power plant risk. That contribution depends very strongly on the plant-specific design, physical layout, cable routing, operating and maintenance practices, and fire protection program. Therefore, it is very important that each plant should include a comprehensive analysis of fires in a good-quality full-scope probabilistic risk assessment (PRA).

The development of fire analysis methods and guidance specific to the Japanese nuclear industry has been and continues to be a focus of the NRRC research activities. We have been engaged in discussions on this topic since the Technical Advisory Committee (TAC) was formed in 2014. On June 6, 2015, we wrote a letter report on the fire research activities, recommending certain priorities and test programs (e.g., realistic estimates of ignition frequencies). On May 27, 2017, we issued another letter report on the fire PRA research, highlighting, among other things, the need for an integrated pilot application of the proposed guidelines.

The NRRC completed the first draft of the Fire PRA Guide in September 2018. The Japanese utilities and vendors reviewed the draft guide and provided comments and recommendations. One of our members also provided his personal comments. During our May 2019 and November 2019 meetings, the fire PRA research team discussed the status of the draft guide, the nature of comments received, plans to revise the guide, and plans for a trial application. In our November 19, 2019 letter report, we supported issuance of the Fire PRA Guide for general use, without an intermediate trial application and iterative revision. We noted that we would comment separately on technical details of the guidance after the September 2018 draft version of the guide was updated. This letter report provides our observations, conclusions, and recommendations on the updated guidance.

DISCUSSION

We commend the NRRC for completing this major milestone to develop a fire PRA methodology and guidance that is suitable for use by the Japanese industry.

The NRRC Fire PRA Guide is founded on the extensive U.S. research and fire risk assessment experience that formed the basis for the guidance in NUREG/CR-6850. The original version of NUREG/CR-6850 was issued in 2005. Since that time, substantial additional experience has been gained from using that guidance to support risk-informed changes to the licensing basis and fire protection programs at almost half of the U.S. nuclear power plants. The U.S. NRC and industry have developed consensus clarifications of the guidance for several complex topics, and several major test programs have been undertaken to address specific issues. The NRRC Fire PRA Guide fully incorporates the results from this subsequent research, and it is organized to take advantage of the U.S. industry's practical experience. As such, it has advanced the international state-of-the-practice guidance for performing a fire PRA.

We understand that a trial application of the fire PRA guidance will be conducted using a "model plant". We have commented extensively on the selection and use of "model plant" PRAs to demonstrate proposed analytical methods and guidance. We understand the practical constraints that influence those decisions. If the trial application is performed according to the plan that was summarized by the fire PRA team, it will demonstrate all tasks and key elements of the Fire PRA Guide. However, from our technical perspective, we continue to recommend that these trial applications should use the good-quality PRAs for internal initiating events that are being developed for Ikata Unit 3 and Kashiwazaki-Kariwa Unit 7. That practice will provide the best demonstration of how each contribution to risk is consistently integrated into a full-scope PRA.

During our review of the Fire PRA Guide and the supporting research activities, we identified the following topics that merit additional attention. The fire PRA researchers should address these topics while the current guidance is being used for the trial application. The next update of the guide can then incorporate the combined benefits from the trial application practical experience and further enhancements to specific analysis methods and guidance. We would like to work closely with the NRRC fire PRA research team as they address these topics.

Integration of Japanese Fire Event Data

We understand that each Japanese utility has compiled data for fire events that have occurred at their nuclear power plants. We also understand that NRRC has evaluated those data and has developed initial estimates for industry-wide generic fire ignition frequencies. Of course, realistic estimates for the fire ignition frequencies depend completely on the scope and technical quality of the compiled fire event data. Therefore, it is essential to have confidence that the data are collected consistently at each plant and that fire events are not inadvertently excluded.

We have not performed an in-depth review of the guidance for collection and evaluation of the fire event data, screening and categorization of the fire events, or the process that has been used to derive the generic fire ignition frequencies. During our review of the Fire PRA Guide summary presentations, we provided very preliminary comments on some elements of the fire ignition frequency analyses. However, that effort is not related directly to the current version of the Fire PRA Guide. We will discuss that guidance separately with the fire PRA team, and it is not addressed in this report.

Experience has also shown that it is important to develop consistent integrated guidance for (1) compilation, screening, and categorization of fire events to support the fire ignition frequencies and (2) evaluation of fire growth, detection, and suppression in the PRA models and supporting analyses. In particular, if fire events are removed from the database because the fires were detected and suppressed before they grew to a "potentially challenging" or "challenging" size, those screening criteria affect the application of parameters for fire growth, detection, and suppression in the PRA models for the fire events that are retained in the database. If the guidance for these analyses is not carefully coordinated, there is a danger of inappropriately "double accounting" for rapid detection and suppression. For example, this issue can be especially important if plants have incipient fire detection systems, and the fire analyses include credit for those systems to quickly detect very small fires. In that case, the fire events database should include all recorded fires, regardless of their size.

In the Fire PRA Guide, some of the detailed fire modeling guidance in Task 14 and some of the specific numerical values that are recommended in the appendices for that task depend on consistency between the process that was used to derive the fire ignition frequencies in Table 8.1 and the corresponding assumptions about fire severity, detection, growth, and possible suppression. Those Task 14 numerical values in the current version of the Fire PRA Guide have been carefully coordinated with the process and assumptions that were used to derive the U.S. fire ignition frequencies. They should not be used independently with the Japanese fire ignition frequencies, without a very careful evaluation of the consistency of the applied analytical methods, assumptions, and supporting fire event data.

Furthermore, some of the recommended values in the Fire PRA Guide are derived entirely from U.S. operating experience, and they may not apply for typical Japanese plant designs and practices. One example is the probability distributions for manual fire suppression times that are tabulated in Appendix 14D. Another example is the guidance for evaluating the effectiveness of incipient detection and enhanced suppression to control specific fires before they damage any PRA items. The composite fire severity and non-suppression factors for Main Control Board fires that are recommended in Appendix 10A similarly depend on the supporting U.S. data and assumptions. Japanese plants may also use different guidance and criteria for personnel decisions to abandon the Main Control Room.

We request an opportunity to review the following topics:

- Guidance for the fire event data collection, screening, and categorization

- Development of the generic fire ignition frequencies

- How recommended numerical values in the Fire PRA Guide for fire growth, detection, and suppression will be revised to consistently account for the Japanese fire event data and Japanese fire protection practices

Guidance for Low Power and Shutdown Modes

Section 1.1 of Chapter 1 of Volume 1 of the Fire PRA Guide ("Introduction and Background") notes that:

> "Also, the focus of this guide is on core damage and containment failure possibility from a fire in an NPP when at power. Similar to NUREG/CR-6850 [Reference 1.1], the scope of the methodology and data presented in this guide does not include:
> - Non-power operating modes (i.e., low power and shutdown),
> - Accidents not related to the reactor core (e.g., spent fuel pool accidents), …"

With a few exceptions, as noted below, experience from full-scope PRAs has shown that essentially the same fire analysis methods and guidance can be used for all plant operating modes.

The fundamental guidance for Task 1 ("Plant Response Model for Fire PRA") does not depend on the scope of the baseline model. In other words, analysts must always use the same techniques to examine and modify the internal event PRA models to account for fire-induced failure modes, to revise the event tree and fault tree logic to evaluate the functional effects from specific fire scenarios, to define new human failure events, etc. Of course, details of the baseline plant response model for internal initiating events will differ, according to the corresponding scope of the PRA. For example, some equipment may be de-energized during specific shutdown plant operating states. Other equipment may be re-aligned from its normal power operation configuration. The internal event models for each plant operating state account for these conditions. Thus, the functional effects from fire-induced open circuits and spurious signals will also vary, depending on the status of specific components during each plant operating state. The current guidance for Task 1 emphasizes careful analyst evaluation of fire-induced failures when the internal event PRA models are modified. It appropriately does not provide prescriptive methods for how to revise specific parts of the models. Thus, in the context of this Fire PRA Guide, the same basic guidance and techniques that are currently summarized in Task 1 can be used for PRA models that include full-power, low-power, and shutdown modes; spent fuel cooling; and mitigation of offsite releases.

The guidance should be expanded to address three issues that pertain to the fire analyses during plant shutdown, compared to power operation: (1) differences in some fire ignition frequencies, (2) differences in the likelihoods that human-caused fires occur in specific plant compartments, and (3) differences in the status of compartment fire barriers.

The ignition frequencies for some fire categories apply only during specific plant operating modes. Operating experience has shown that:

- Most equipment-related fires may occur at any time, regardless of the plant operating mode.

- Some equipment-related fires may occur only during full-power and low-power operating modes. The frequencies of human-caused fires that occur during plant power operation depend on the amount and types of activities that are typically performed during those operating modes.

- Some equipment-related fires may occur only during plant shutdown modes. Different frequencies of human-caused fires apply during plant shutdown, accounting for the increased amount of work and types of activities that are performed when the reactor is not operating.

The scope of the Fire PRA Guide can be extended very easily to address these differences. Ignition frequencies for fire categories that apply only during plant shutdown modes can be derived from the Japanese industry operating experience. Chapter 8 of Volume 2 of the Fire PRA Guide ("Task 8 – Fire Ignition Frequencies") would then contain three tables of ignition frequencies: one for fires that may occur at any time, one for fires that may occur only during power operation, and one for fires that may occur only during shutdown.

Industry operating experience has shown that the amount and types of activities (e.g., maintenance, testing, system modifications, welding, cutting, etc.) and the quantities of transient combustibles in several plant locations are often significantly different during shutdown, compared to power operation. In practice, some activities are also performed only during specific plant operating states throughout an outage. Therefore, the guidance in Chapter 8 (e.g., Section 8.5.6.3) should alert analysts to re-examine the compartment-level allocations of these human-caused fire ignition sources during each shutdown plant operating state, compared to the allocations that apply during power operation modes.

Operating experience has also shown that the status of fire compartment barriers may be different during specific shutdown plant operating states, compared to power operation. For example, doors may be blocked open, equipment and personnel access hatches may be removed, and penetrations may be opened to facilitate outage-related work. The guidance for Step 12.1 in Chapter 12 of Volume 2 of the Fire PRA Guide ("Task 12 – Multi-Compartment Analysis") should alert analysts to examine the status of fire compartment barriers during each plant operating state and evaluate differences in the fire propagation scenarios.

The basic methods and guidance for all other tasks apply universally, regardless of the plant operating mode.

The fire PRA team should update the Fire PRA Guide as follows:

- Extend the scope of Chapter 8 to include ignition frequencies for equipment-related and human-caused fires that may occur only during plant shutdown modes.

- Expand the guidance in Chapter 8 to alert analysts to re-examine the types of activities and amounts of transient combustibles in each compartment during each shutdown plant operating state, compared to power operation.

- Expand the guidance in Chapter 12 to alert analysts to re-examine the status of fire compartment barriers during each shutdown plant operating state, compared to power operation.

- Make other editorial changes to remove the limitation that the analysis methods and guidance apply only for fires that occur during plant power operation.

Main Control Room Fires

We understand that the fire PRA team intends to enhance the methods and guidance for evaluating Main Control Room (MCR) fires after the trial application is completed. This section discusses our recommendations for specific elements of those analyses. To be most responsive to the Japanese industry needs, the fire PRA team should conduct supporting research and develop extensions of the current methods for these analyses in parallel with the trial application.

Two important issues for the evaluation of MCR fires are guidance for: (1) identification of PRA target sets for fires that affect the Main Control Board (MCB) or operator control consoles, and (2) analyses of fires that force the operators to abandon the MCR.

Several elements of the MCR fire analysis guidance in the Fire PRA Guide are based on assumptions and models that were developed for older-design U.S. nuclear power plant control rooms. For example, those designs typically contained very large central MCB panels with distributed displays, instrumentation, and large analog control switches. Several of the recommended qualitative assumptions and quantitative screening criteria for the size of an MCB fire that may cause potentially risk-significant damage are based on that general configuration.

The MCRs for newer plants typically contain more compact control panels. The MCBs for some older plants have also been upgraded with more modern analog or digital displays and controls. Furthermore, many modern MCRs contain stand-alone operator control consoles that are separated from the MCB. The guidance for a systematic process to identify PRA target sets for fires that affect the MCB or the operator control consoles should be re-examined and enhanced to remove implicit and explicit assumptions that apply only for older plant designs. Consistent guidance for a systematic evaluation and a progressive refinement process should apply for any MCR design.

Some fires that occur inside or outside of the MCR may force the operators to abandon the MCR, due to loss of reliable instrumentation and controls, or severely degraded habitability. In the Fire PRA Guide, one of the recommended MCR abandonment criteria relies on a specific size of MCB fire damage. As noted above, that recommendation seems to be based on assumptions about the functional damage that may occur from a fire in an older U.S. MCB design. It should be re-examined for consistency with newer plant designs and MCR configurations.

Furthermore, criteria for MCR abandonment due to habitability concerns should be based on Japanese guidance and practices, rather than U.S. criteria.

The Fire PRA Guide describes an initial simplified treatment of fires that force the operators to leave the MCR. That guidance focuses exclusively on estimating the total frequency of conditions that require the operators to abandon the MCR. It does not address how analysts should account for the functional impacts from the fire damage in the MCR and the progression of the consequential event scenarios that must be mitigated after the operators leave the MCR.

We are not familiar with details of the Alternate Shutdown System designs at Japanese nuclear power plants. In many U.S. plants, operation of only a limited set of equipment is possible from the Alternate Shutdown System panels. Furthermore, it may not be feasible to mitigate the effects from some fire-caused failure modes (e.g., spurious signals) by other local actions that can be accomplished within the available time windows (e.g., at switchgear, motor control centers, local manual operation of valves, etc.). Thus, in practice, depending on the plant-specific design and the specific fire damage, the MCR fire may functionally disable some equipment or cause plant responses that cannot be fully reversed by operations at the Alternate Shutdown System panels or other locations. The Fire PRA Guide should provide guidance for how the simplified analyses should account for those non-reversible failure modes.

The fire PRA team should improve the guidance for the following analyses:

- Systematic identification of PRA target sets for fires that affect the MCB or operator control consoles

- Recommended MCR abandonment criteria

- Treatment of the functional effects from MCR fire damage after the operators leave the MCR

Fire Effects on Digital Systems

We understand that the fire PRA team also intends to enhance the methods and guidance for evaluating fires that affect digital instrumentation, control, and protection system cabinets and their interconnecting cables after the trial application is completed. This section discusses our recommendations for specific elements of those analyses. The fire PRA team should conduct supporting research and develop preliminary methods for these analyses in parallel with the trial application.

The Fire PRA Guide does not contain any guidance for the analyses of fires that affect digital instrumentation and control systems. Two issues are particularly important for those analyses: (1) evaluating fire damage to fiber optic cables, and (2) determining the functional effects from fire damage to digital signal processing cabinets.

Some Japanese nuclear power plants contain fully integrated digital instrumentation, protection, and control systems. Based on international experience, it seems very likely that many plants also contain distributed digital instrumentation and controls for specific systems and functions (e.g., nuclear instrumentation, feedwater control, turbine-generator control, some electrical protection functions, newly-installed accident management systems, etc.). These digital applications will continue to increase as older plants are progressively upgraded with more modern controls. Of course, new plants will rely extensively on digital systems.

Fiber-optic cables are used extensively in digital systems and in some hybrid applications. A limited amount of research and testing has examined thresholds for thermal damage to fiber-optic cables. Other research has generally concluded that fire damage to fiber-optic cables will not produce spurious signals (or the conditional probability of a spurious signal is extremely low). To support comprehensive assessments of the risk from fires in Japanese plants, the Fire PRA Guide should provide analysts with a clear understanding of the available knowledge and guidance for how to treat fire damage to fiber-optic cables.

Fire damage and high temperatures in cabinets that contain digital signal processing modules may cause spurious signals. Therefore, the guidance should clearly distinguish between the failure modes that may be caused by fire damage to fiber-optic cables, and the failure modes that may be caused by fire damage inside a digital signal processing cabinet.

The analysis of digital systems is an evolving topic in the international PRA community. Methods to estimate the reliability of software, evaluate possible common cause failures, and identify unexpected software responses are not yet fully mature. However, substantial progress has been made, and analysts are developing models for these systems. Of course, as we gain more experience with these systems and their models, our collective knowledge will increase, and the guidance for these analyses will certainly be improved. The same perspective applies for many other topics in the science of risk assessment, which are currently included and quantified in contemporary PRA models. Conservative assumptions, bounding models, and careful assessments of uncertainties are used to compensate for incomplete knowledge.

Despite the evolving nature of some elements of digital systems analysis methods, it seems possible to provide analysts with practical guidance that can be used to evaluate the potential effects from fire damage and determine how those effects are included in the PRA models.

For example, in practice, analysts should have information about the specific input and output signals from each digital system cabinet, and they should have information about the functional logic of the signal processing modules. Therefore, it seems feasible to identify the possible effects from fire damage to the cabinet (e.g., loss of specific output signals or spurious actuation of those signals). For a very complex cabinet, it may not be practical to perform detailed analyses that determine the conditional probabilities for all possible combinations of the signal states. However, depending on the system design, the functions which are provided by each cabinet, and the cabinets' spatial configurations, those detailed analyses may not be necessary. It may be sufficient to simply assume that the "worst possible" combination of output signals occurs, based on the functional effects in the Level 1 and Level 2 PRA models. If the initial analyses indicate that fire damage to a particular digital signal processing cabinet may be important to risk, then the analysts will need to examine those circuits in more detail. Similar progressive methods have often been used for the analyses of fire damage to cabinets that contain analog signal processing circuits (i.e., relays and copper wires).

The fire PRA team should develop guidance for the following analyses:

- Thermal damage criteria and functional effects from fire damage to fiber-optic cables

- Evaluation of functional failure modes from fire damage to digital signal processing cabinets

We look forward to working with the NRRC fire research team as they continue to improve the guidance for this very important element of a good-quality full-scope PRA for each Japanese nuclear power plant.

Sincerely,

John W. Stetkar
Chairman

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