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SUBJECT: IMPLEMENTATION GUIDE ON HUMAN RELIABILITY ANALYSIS (HRA) FOR PRA

Dear Dr. Apostolakis:

During the seventh meeting of the Technical Advisory Committee of the Nuclear Risk Research Center (NRRC), May 22-26, 2017, we met with representatives of the NRRC staff to discuss the status of guidance for improved methods for human reliability analysis (HRA) in Japanese nuclear power plant probabilistic risk assessments (PRAs). This letter report documents our review of the draft "Implementation Guide on Human Reliability Analysis (HRA) for PRA".

CONCLUSION AND RECOMMENDATIONS

1. The draft guidance is an important milestone for the application of modern HRA methods in Japanese nuclear power plant PRAs.

2. The following recommendations should be addressed before the guidance is issued for trial use:

    - To the extent possible, these methods should be used to evaluate personnel actions in the models that quantify PRA initiating event frequencies, in the Level 1 plant response models, and in the Level 2 severe accident mitigation models.

    - The guidance should describe how to develop a realistic scenario timeline, the types of information that should be documented in the timeline, and how the timeline is used in the qualitative assessment, operational narrative, and human error probability (HEP) quantification.

    - The guidance should describe how to perform a "time uncertainty analysis" and how to account for that analysis during quantification of the scenario-specific HEPs.

- The guidance should be enhanced to place more emphasis on observations of carefully selected simulator scenarios to supplement the information obtained from the operator interviews. Simulator runs should also be conducted for critical operator actions to confirm realistic scenario time windows (e.g., delay time, time to perform an action, time to get to a location, etc.).

- Appendix G of the guide should include one or more instructional examples that show how deviation scenarios are developed and applied in a practical HRA.

BACKGROUND

In our November 1, 2014 letter report, we recommended that the NRRC staff should explore possibilities for collaborative research with the U.S. Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI) to support completion and piloting of the Integrated Human Event Analysis System (IDHEAS) methodology. Those improvements are needed to replace the outdated Technique for Human Error Rate Prediction (THERP) methodology, which has been used in the past by Japanese utilities.

To support near-term needs for improved Japanese nuclear power plant PRAs that are currently in progress, the NRRC has developed draft interim guidance that combines important elements of the IDHEAS methodology with the quantification tools from the EPRI HRA Calculator.

DISCUSSION

The draft guidance is an important milestone for the application of modern HRA methods in Japanese nuclear power plant PRAs. Experience from international benchmark studies has emphasized the importance of a structured qualitative assessment for consistent understanding of the role of personnel actions during a complex evolving scenario. Development of a scenario operational narrative is a key element of the analysis process. In practice, the narrative clarifies understanding of the scenario, and it provides the necessary context for a systematic evaluation of factors that can have an important influence on cognitive performance. The NRRC guidance combines the contemporary concepts of a qualitative assessment and operational narrative from the IDHEAS methodology with the Cause-Based Decision Tree Method (CBDTM) for quantifying scenario-specific human error probabilities (HEPs) using the EPRI HRA Calculator.

It is very important that the NRRC guide should contain comprehensive guidance and supporting examples for the qualitative assessment and the operational narrative, because analysts are less experienced with these elements of the HRA methods. The following recommendations should be addressed before the guidance is issued for trial use.

Scope of the Guidance

The draft guide indicates that the scope of this guidance applies only to post-initiator human failure events (HFEs) in a Level 1 PRA for internal initiating events that occur during plant power operation. That scope is unnecessarily restrictive. Improved PRAs that are currently under development in Japan use modern methods to quantify the frequencies of initiating events that are caused by failures of plant-specific support systems. Some of those models evaluate personnel actions that may prevent a plant trip from occurring (e.g., start a standby pump, realign a ventilation system, etc.). The improved PRAs also include Level 2 models for containment performance and offsite releases during a severe accident. Those models typically evaluate personnel actions to alter the accident progression or to mitigate its consequences (e.g., reduce pressure, close containment isolation valves, open a hardened vent path, etc.).

Personnel actions in the initiating event models, the Level 1 models for core damage prevention, and the Level 2 models for severe accident mitigation have the same functional characteristics. They are typically prompted by scenario-specific cues, they involve the need for cognitive decisions and equipment manipulations, they must be completed within a time window that is determined by the evolving plant conditions, and they are often supported by written procedures or other structured guidance. The qualitative and quantitative analysis framework in the NRRC guidance should be directly applicable to many of these actions throughout the entire scenario. Use of the same HRA methodology will avoid inadvertent inconsistencies and possible analyst confusion about the most appropriate methods to apply at the interfaces between parts of a continuous scenario that are successively evaluated within an initiating event model, a Level 1 model, and a Level 2 model.

Some actions in the Level 2 PRA models may be directed by supervisory personnel using severe accident management guidelines or other guidance that is less prescriptive than the emergency operating procedures. The HRA qualitative assessments and scenario timelines apply for these actions, but other methods may be needed to quantify the HEPs. In particular, the quantification models in the HRA Calculator are most readily applied for actions that are directed by well-developed procedures.

To the extent possible, the NRRC guidance should indicate that these HRA methods apply for personnel actions throughout the entire event scenario, from the initial upset condition through mitigation of a severe accident. In cases where alternative quantification models may be needed, the guidance should caution analysts to ensure that evaluations of personnel performance during scenarios that span the Level 1 and Level 2 models consistently account for the influencing factors that affect crew dynamics and integrated cognitive decision making.

Guidance for Scenario Timeline

The draft guidance does not describe how to develop a scenario timeline, the types of information that should be documented in the timeline, or how the timeline is used in the qualitative assessment, operational narrative, and HEP quantification. It is crucial for the guidance to include this information, so that analysts fully understand its importance and its relation to the overall HRA methodology.

Development and documentation of the scenario timeline are essential elements of the qualitative assessment and operational narrative. The timeline is also used to define some of the input parameters to the HRA Calculator. Experience has shown that development of a realistic timeline provides a key focal point for the PRA models. It facilitates consistent understanding of the scenario progression and the operational context for personnel performance among the analysts who are responsible for the event trees and fault tree models, the thermal-hydraulic analyses that provide information about the event timing and functional success criteria, and the human reliability analyses.

The NRRC guidance should emphasize the use of plant-specific best-estimate thermal-hydraulic analyses to evaluate the scenario progression. The timeline should clearly identify the realistic timing of relevant plant conditions and cues that may influence personnel actions (e.g., pressures, temperatures, levels, alarms, etc.). The timeline should also clearly identify the time at which plant conditions reach a state that functionally precludes success of the modeled action. The timeline can then be used to consistently evaluate important parameters such as the total functional time window, times at which salient cues occur, time available for personnel response (T_{avail}), and time required to complete the necessary cognitive decisions and equipment manipulations (T_{reqd}). A careful description of the event scenario timing and functional success criteria can also clarify the modeled actions and illustrate how multiple actions during an integrated scenario interface with each other (e.g., sequentially, in parallel, partially overlapping in time, etc.).

Time Uncertainty Analysis

The IDHEAS general methodology and the guidance for its first U.S. application describe how an evaluation of uncertainties in T_{avail} and T_{reqd} can affect the overall HEP. In particular, the HEP should account for the probability that T_{reqd} may exceed T_{avail}, which simply means that not enough time is available to complete the action reliably. Experience has shown that this consideration can be very important during scenarios when the available time window is relatively short, when there are factors that contribute to large variations in personnel response times, and when personnel must perform actions that require substantial time and attention to achieve the desired end state (e.g., cool down and reduce pressure according to a specified maximum rate).

In practice, the overall HEP accounts for this "time uncertainty analysis" according to the following general formula.

$$HEP = Pt + (1 - Pt) * Pc$$

Where

HEP = Overall human error probability for the action
Pt = Human error probability due to insufficient time
Pc = Human error probability due to cognitive responses and implementation

In this formula, Pt accounts for the probability that the amount of time that is required to complete the action (T_{reqd}) may exceed the amount of time that is available (T_{avail}). The probability that $T_{reqd} > T_{avail}$ is a direct contribution to the HEP. The factor (1 – Pt) accounts for the probability that sufficient time is available to perform the action. The term Pc is quantified by the analyses that evaluate the cognitive responses and implementation actions for the HFE.

This framework is directly compatible with the quantification methodology that is described in the NRRC guidance. In particular, the CBDTM models presume that sufficient time is always available to complete the action (i.e., $T_{avail} \geq T_{reqd}$). The available time margin will vary according to the particular action and the scenario progression. That time margin affects the evaluation of some parameters in the CBDTM quantification models. However, those models and parameters assume that the margin is always positive. Thus, implementation of the "time uncertainty analysis" framework does not require any changes to the draft NRRC guidance for use of the CBDTM models in the HRA Calculator.

Use of Operator Interviews and Simulator Observations

The draft guidance emphasizes the importance of conducting interviews with plant operators and training personnel to confirm the analysts' understanding of the scenario, expected personnel actions, procedural guidance, and interactions among supervisors and crew members. The guidance contains draft versions of specific questions and templates to facilitate and document the interviews. It also contains examples of how to use the interview results to prepare input information for the HRA Calculator.

Experience has shown that observations of personnel performance during simulator runs of challenging scenarios can be extremely useful. In some cases, the interview questions may not appropriately challenge the operators to consider how they might respond during a complex event. Observations of real evolving scenarios can reveal important aspects of inter-personal communications, ease or complexity of using the procedures, density and types of alarms and their timing, distractions or potentially conflicting priorities, and other factors that affect crew performance. These observations are extremely valuable to support and supplement the information obtained from the interviews.

The draft guide indicates that analysts should observe crew performance during simulator runs of PRA scenarios. The example analysis in Appendix C contains some information that is derived from observations of the base case feed and bleed scenario. However, the draft guide does not adequately emphasize the importance of these simulator sessions in comparison to the operator interviews, and it does not provide guidance for selection of the types of challenging scenarios that are most useful to test the crew response. The guidance should be enhanced to place more emphasis on observations of carefully selected simulator scenarios to supplement the information obtained from the operator interviews.

Variant (Deviation) Scenario Guidance

The guide uses the terms "variant scenario" and "deviation scenario" interchangeably to address conditions that can affect personnel performance differently from the conditions which are evaluated in the nominal base case scenario. The discussions about deviation scenarios are conceptually comprehensive, but they would benefit from additional clarity. It is important for analysts to understand these concepts and how they are applied in practice. Appendix G of the guide extends the general discussions, but it does not contain any examples to illustrate how deviation scenarios are developed and applied in a practical HRA.

Appendix G should contain one or more instructional examples that show how analysts can use these concepts. In particular, it would be very beneficial to expand the feed and bleed scenario that is developed in Appendix C to illustrate how one or more deviation scenarios can be derived from that base case analysis. The examples should show how different conditions regarding the timing of equipment failures, availability of cues, use of procedures, etc. can alter factors which affect the quantified HEP. The examples should also explain practical options for how analysts can address these issues in a realistic HRA (e.g., use the most conservative HEP, use probabilistically-weighted HEPs, modify the event trees or fault trees, etc.).

We look forward to continuing our review of this benchmark NRRC project as the guidance is completed and used in the first pilot applications.

Sincerely,

John W. Stetkar
Chairman

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