EPRI/NRC-RES Fire Human Reliability Analysis Guidelines

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Abstract

In 2007, the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research (RES) embarked upon a cooperative project to develop explicit guidance for estimating probabilities for human failure events under fire-generated conditions. This collaborative project produced draft NUREG-1921, "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines." The guidance presented in this report is intended to be both an improvement upon and an expansion of the initial guidance provided in a previous collaborative effort, NUREG/CR-6850 (EPRI 101989) [1], "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities."

This paper summarizes the fire human reliability analysis (HRA) guidance developed through this project, which addresses fire-specific influences on crew performance (e.g., use of fire procedures; misleading indications due to fire-induced instrument failures, electrical spurious actuations; smoke, heat and other fire-induced hazards). The guidance includes: 1) process steps for performing HRA, 2) discussion and tools for performing qualitative HRA tasks, and 3) a three tiered, progressive approach for fire HRA quantification. The three quantification approaches consist of: a screening approach per NUREG/CR-6850 guidance, a scoping approach, and detailed quantification using either EPRI's Cause-Based Decision Tree (CBDT) and Human cognitive Reliability/Operator Reliability Experiment (HCR/ORE) [7] or NRC's A Technique for Human Event ANAlysis (ATHEANA) [8] approach with modifications to account for fire effects.

Keywords: HRA, Fire, PRA

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1. INTRODUCTION[3]

Over the past two decades, the nuclear power plant (NPP) fire protection community has been transitioning toward risk-informed and performance-based (RI/PB) practice in design, operation and regulation. To make more realistic decisions for risk-informed regulation, fire probabilistic risk analysis (PRA) methods needed further development. In order to address this need, beginning in 2001, the U.S. Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI) collaborated under a joint Memorandum of Understanding (MOU) to develop NUREG/CR-6850 (EPRI 101989)[1], "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," a state-of-art fire PRA methodology. The methodology provided in NUREG/CR-6850 included some guidance for the performance of human reliability analysis (HRA) as part of the fire PRA. The fire HRA guidance provided in NUREG/CR-6850 included: (1) a process for identification and inclusion of the human failure events (HFEs), (2) a methodology for assigning quantitative screening values to these HFEs, and (3) initial considerations of performance shaping factors (PSFs) and related fire effects that might need to be addressed in developing best-estimate human error probabilities (HEPs). However, NUREG/CR-6850 did not identify or produce a methodology to develop these best-estimate HEPs given the PSFs and the fire-related effects.

In order to address a need for explicit guidance for estimating HEPs for human failure events under fire-generated conditions, EPRI and RES embarked on another cooperative project that resulted in the development of draft NUREG-1921, "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines" [2]. It is anticipated that this guidance will be used by the industry as part of transition to the risk-informed, performance-based (RI/PB) fire protection rule, 10 CFR 50.48c, that endorsed National Fire Protection Association (NFPA) 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants" and possibly in response to other regulatory issues such as those relating to multiple spurious operations (MSOs) and operator manual actions (OMAs). This paper summarizes the efforts to produce this guidance and the resulting report[4].

2. OBJECTIVE

The overall objective of the joint EPRI/NRC-RES efforts was to fill the gap left by NUREG/CR-6850 with respect to an HRA methodology and approach suitable for more detailed treatment of HRA in a fire PRA. This effort produced a fire HRA methodology that addressed all relevant HRA tasks and described the technical bases for the methodology.

The result of this effort is documented in the joint report NUREG-1921 (EPRI 1019196), "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines which was published as a draft for public comment in December 2009.

This joint report serves a complete reference for fire HRA as part of a PRA. The joint report is intended to be a stand-alone reference that supplements and extends the guidance in NUREG/CR-6850 Task 12 by providing additional guidance for the development of probabilities for human failure events modeled in fire PRA via detailed and scoping HRA quantification approaches.

3. SCOPE

In general, the purpose of fire HRA is to identify, define and quantify Human Failure Events (HFEs)in the fire PRA model. . The scope of this fire HRA methodology is focused on post-initiating event human failure events (HFEs). These HFEs are grouped into the following categories:

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[4] At the time this paper was prepared, NUREG-1921 was undergoing public review. While some elements of the technical tasks may be revised as a result of feedback obtained from this review, it is expected that the overall methodology as outlined in this paper will be retained.

- Existing HFEs in internal events PRAs
- Fire response HFEs
- Main control room abandonment HFEs (considered as a special sub-set of the fire response HFEs)
- HFEs that result from undesired operator responses to spurious indications (errors of commission)

Human actions that are outside the scope of this methodology include those that could give rise to pre-initiator HFEs (as described in NUREG/CR-6850) and fire brigade responses (for which failure is assessed through the use of empirical data)..

4. DEVELOPMENT APPROACH

The joint EPRI/NRC team performed the following three major tasks in order to develop the fire HRA methodology:

1. Data collection,
2. Method development, and
3. Peer review and testing.

The purpose of each of these development tasks is discussed briefly below.

4.1. Data Collection

The principal purpose of collecting data in this joint effort was to determine whether PSFs or other fire effects existed that should be addressed by the fire HRA methodology but that were not identified in NUREG/CR-6850. Historical data for fire events were reviewed and plant interviews were performed. Also, the joint team considered a range of fire response strategies.

The team determined that the PSFs and other fire effects that were identified in NUREG/CR-6850 were adequate for the development of this fire HRA methodology. Essentially, this check established that our general understanding of important influences on human performance in fires is adequate as represented by the fire-related PSFs and other effects identified in NUREG/CR-6850.

4.2. Method Development and Technical Basis

A review of existing HRA methods concluded that none explicitly accounted for all of the fire-related PSFs addressed in NUREG/CR-6850, and that it would be useful either to create a new method or to provide guidance on how to modify an existing method to capture the fire effects. Ultimately, the joint team decided to do both.

The team began its efforts with a review of:

- A draft EPRI Fire HRA Guideline.
- NRC HRA reports, including the good practices for implementing HRA [3] and the evaluation of HRA methods against the good practices [4].
- EPRI's "SHARP1: A Revised Systematic Human Action Reliability Procedure" [5].
- NRC's ATHEANA HRA method (especially, it's HRA process) [8].
- ??? [9]

The joint team also remained abreast of and incorporated insights from on-going fire PRA efforts. Such efforts included development and revisions to the ASME/ANS PRA Standard [6].

The basic philosophy for the development of a fire HRA methodology was to use or adapt existing HRA guidance where possible. At the same time, this methodology would have to address a variety of fire-specific or fire-unique factors and situations.

Several of the team members had experience applying the NUREG/CR-6850 HRA criteria. As a result, this report provides an update to the screening HEPs.

The team also developed a new scoping fire HRA approach that was intended to produce less conservative HEPs than the NUREG/CR-6850 screening but required fewer resources than a detailed analysis.

Finally, NRC-RES and EPRI have expanded the guidance for two HRA approaches, the ATHEANA HRA method and the EPRI HRA approach, that are intended to be used when detailed fire HRA analysis is needed.

4.3. Technical Review and Testing

The joint fire HRA guidelines included technical reviews and testing at various points in its development.

Following initial development of the fire HRA guidelines, peer review and testing phases were conducted. These included the following elements:

- Review by an independent peer review team consisting of both NRC and industry reviewers.
- Application testing at two nuclear power plants.
- Internal review by NRC and EPRI.

The primary objectives of the independent peer review were: (1) to evaluate the methodology to ensure that it was technically sound and would meet the needs of the intended users, (2) to identify any significant deficiencies in the proposed approach early enough in the development process such that the methodology could be modified in time to meet the needs of the intended users, and (3) to ensure that the methodology was documented in a manner that is clear, concise, logical and usable for the intended audience.

The objective of the application testing exercise was to subject the methodology to a process to help determine whether the assumptions used in developing the guidance would hold up when applied to actual plant specific fire scenarios. This process also provided a high-level "reasonableness" check for the HEP values generated by the method. Other objectives of testing the methodology included identifying any limitations or unexpected results, and assessing the methods usability when practically applied.

Based on the substantial feedback from the peer review and plant testing, the joint development team revised certain aspects of the guidelines, especially its new scoping approach for quantification. Following these revisions, the guidelines were further reviewed and tested (e.g., internal NRC reviews, informal peer reviews and plant-specific trials by industry groups). Finally, the joint development team will make any necessary further revisions after receiving public comments on the draft guidelines published in December 2009.

5. SUMMARY OF THE FIRE HRA GUIDELINES

The joint EPRI/NRC fire HRA guidelines build upon the information documented in NUREG/CR-6850, Volume 2, Section 12 [1], providing more details for the performance of HRA tasks. It is intended that these guidelines comprise one approach that would be consistent with the requirements of the ASME/ANS PRA Standard [4].

In particular, the fire HRA guidelines provide three major developments:

1. a process for performing fire HRA that is consistent with other HRA processes,

2. guidance on the identification, definition and feasibility assessment of operator actions to be incorporated into the FPRA,

3. guidance for performing qualitative HRA tasks that is suitable for supporting fire PRA, and

4. more explicit guidance for performing HRA quantification, including approaches for more in-depth and realistic treatments of crew performance for key fire-induced influencing factors.

5.1. The Fire HRA Process

The fire HRA guidelines follow a standard HRA process that consists of the following tasks and associated activities:

- Task 1: Identification of relevant actions and definition of corresponding human failure events (HFEs), including an initial assessment of the feasibility of each new action
  - o Actions and HFEs previously considered in the internal events PRA that are relevant to the fire PRA
  - o HFEs that reflect failures of responses unique to fire scenarios
  - o HFEs corresponding to undesired operator responses to spurious actuation or spurious instrumentation caused by fire damage to cables
  - o Actions associated with scenarios that lead to abandonment of the main control room
- Task 2: Qualitative analysis, including:
  - o Development of narrative descriptions of HFE scenarios (e.g., initial conditions and other context factors relevant to crew performance for a specific HFE)
  - o Identification and assessment of relevant performance shaping factors
  - o Collection of operations information (e.g., interviews of operators and operator trainers)
  - o Collection and assessment of relevant operating experience
- Task 3: HRA Quantification, using one of the following:
  - o Screening approach
  - o Scoping approach to quantification
  - o Detailed approach to quantification
- Task 4: Recovery
- Task 5: Dependency evaluation
- Task 6: Uncertainty analysis
- Task 7: Documentation

In addition to detailed discussion of the tasks in the fire HRA process, the joint EPRI/NRC report provides several supporting appendices:

- *Appendix A* correlates the guidance in NUREG-1921 (by section) to the requirements from the ASME/ANS PRA Standard [4].
- *Appendix B* documents a limited review of historical fire events in the U.S. nuclear power industry that was made to provide the authors insights into operator response during a fire. .

- *Appendices C* and *D* provide guidance for detailed quantification of HFEs using EPRI HRA Cause-Based Decision Tree (CBDT) and Human Cognitive Reliability/Operator Reliability Experiments (HCR/ORE) methods, and the ATHEANA method, respectively.
- *Appendix E* contains the definition of terms used in this report.
- *Appendix F* contains a summary of the testing, including scope and insights.
- *Appendix G* contains guidance on how to identify and define HFEs for fire-related electrical bus clearing and restoration procedures.
- *Appendix H* provides the justification for the scoping human error probabilities.

The guidance for qualitative analysis tasks and HRA quantification are discussed further in the subsections below.

5.2. Qualitative Analysis for Fire HRA

The results of HRA qualitative analysis are inputs to HRA quantification. To this end, the chapter on qualitative analysis in the joint guidelines provides a useful understanding of the issues associated with the fire context and some specific guidance on the specific qualitative analysis tools or approaches that can be used to support the development of quantification inputs.

However, practically speaking, qualitative analysis is performed throughout the HRA process up until all HFE quantification values are finalized. Consequently, discussion of HRA qualitative analysis activities also is embedded in the discussion of other fire HRA tasks (e.g., identification and definition of HFEs, quantification). In particular, the section on the identification and definition of HFEs provides substantial guidance (e.g., "screening" rules) to assist the analyst in the task of eliminating unlikely potential operator actions (e.g., proceduralized operator actions that might result in an error of commission, **but** meet certain criteria, may be modeled but are assumed to be noncredible).

Three major guidance topics comprise the qualitative analysis discussion:

1. What information is needed to develop an HFE narrative (or description of context for the purposes of HRA quantification)?
2. What performance shaping factors are relevant and how are they to be evaluated (especially for fire)?
3. What plant operations information and insights from historical experience are relevant?

5.3. Fire HRA Quantification

NUREG-1921 offers a stepped approach for quantification which progresses from a simpler screening method to more detailed methods. Although the stages are presented sequentially, it is left to the analyst to select which method best meet the needs of the PRA for a particular fire scenario and HFE. For example, as for any other PRA study, the HRA analyst may find that a screening HRA approach is adequate for certain HFEs. Similarly, the HRA analyst may choose to perform detailed fire HRA analyses for certain HFEs without ever performing a screening or scoping analysis, when it is clear that more detailed analysis is needed to characterize important risk contributors properly.

For each HFE, the analyst has the following options for HRA quantification:

- A screening HRA approach similar to that presented in NUREG/CR-6850 [1].
- A new scoping fire HRA quantification method.

- Two detailed HRA quantification approaches modified for application in fire PRAs.

The screening approach described in the joint EPRI/NRC fire HRA guidelines is similar to that documented in NUREG/CR-6850 [1]. The approach assigns conservative screening based on the type of HFE and some of its characteristics. The screening approach in NUREG-1921 extends that provided in NUREG/CR-6850, in particular by providing for less restrictive values to be applied for actions for which the time frame is long.

In those instances where a less conservative analysis is required, the next stage presented is a scoping analysis. The scoping fire HRA approach is a simplified quantification approach developed specifically for the guidelines that addresses fire-specific aspects of operator performance. This approach was developed to aid in the reproducibility and reviewability of fire HRA analyses. To use the scoping approach, certain criteria must be satisfied regarding the characteristics of the fire scenario of interest. If the criteria are met, the scoping analysis allows focusing on the most relevant performance shaping factors. A companion paper describes the scoping approach in greater detail.

The scoping analysis approach uses decision-tree logic as well as descriptive text to guide the analyst to the appropriate HEP value. Figure 1 provides an illustration of one of the scoping trees.

Although it has similarities to a screening approach, the scoping quantification process requires a more detailed analysis of the fire PRA scenarios and the associated fire context, as well as a good understanding of several factors likely to influence the behavior of the operators in the fire scenario. Given this more detailed analysis, it is expected that the scoping approach can be used to perform quantification for many of the HFEs being modeled.

For those cases in which the scoping approach cannot be used (e.g., the criteria for its use cannot be satisfied) or a more detailed and possibly less conservative analysis is desired, analysts have the option of performing a detailed HRA analysis using:

1. EPRI detailed HRA methodology [7], or
2. ATHEANA HRA method [8].

6. STATUS OF PROJECT

The joint EPRI/NRC-RES report on fire HRA guidelines was released as a draft for public comment in December 2009. The public comment period closed in March 2010. Following resolution of public comments and final reviews, it is expected that the guidelines will be released as a final report in the latter part of 2010.

Furthermore, training on the guidance provided in NUREG-1921 will be offered as part of the joint EPRI/NRC-RES Fire PRA Training Course in Fall 2010, paralleling other Fire PRA training tracks.
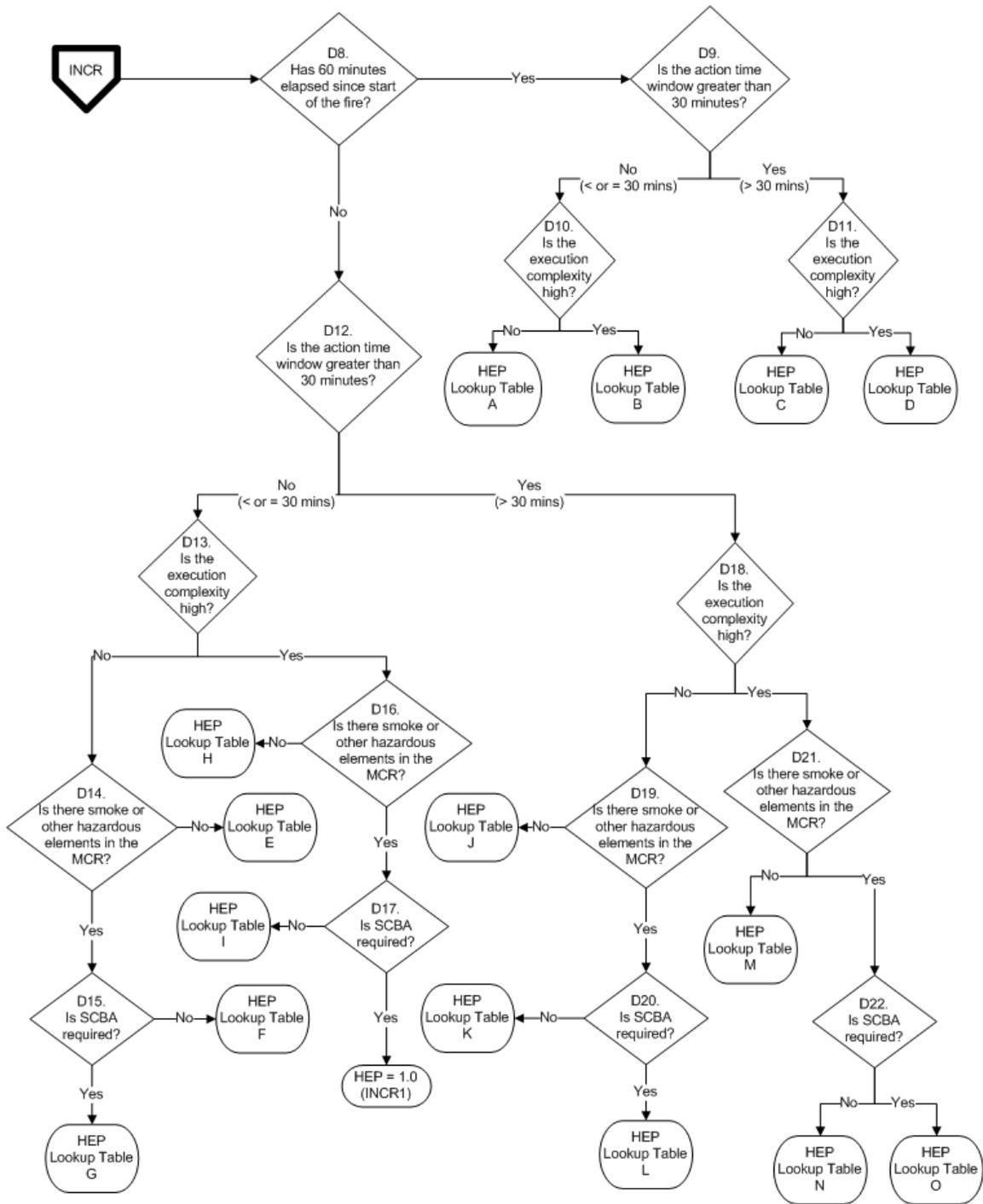
Fig. 1 Example of a Scoping HRA Quantification Flowchart

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