Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

A Study on Quantification of Human Error Probability Related to MCRA Due to Fire

Sun Yeong Choi*, Dae Il Kang, Yong Hun Jung
Korea Atomic Energy Research Institute, Risk Assessment and Management Research Team, Daedeok-daero 989-111, Yuseong-Gu, Daejeon, Republic of Korea, 34057
**Corresponding author: sychoi@kaeri.re.kr*

***Keywords :** human error probability, fire HRA, MCR abandonment

1. Introduction

The significance of fire incidents in Nuclear Power Plants (NPPs) has been acknowledged due to their substantial influence on NPP safety, as evidenced by the analysis of past fire-related occurrences in these facilities. In accordance with this, quantitative risk assessment studies related to the hazards posed by fires have been actively conducted both domestically and internationally. Under a joint research between the U.S. Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI), NUREG/CR-6850 was developed to conduct of a fire Probabilistic Safety Assessment (PSA) [1]. For a fire Human Reliability Analysis (HRA), NUREG-1921 was developed to complete a fire HRA proposed by NUREG/CR-6850 [2]. NUREG-1921 addresses additional Human Failure Events (HFEs) incorporating fire effects and considerations for fire-induced Performance Shaping Factors (PSFs). The document discusses qualitative and quantitative analyses related to these aspects. While NUREG-1921 extensively addresses fire HRA, it provides limited coverage of Main Control Room Abandonment (MCRA) scenarios. Numerous fire PSA/HRA experts have highlighted the significance of MCRA scenarios, leading to research efforts. In response, NRC/EPRI published Supplements 1 and 2 of NUREG-1921 [3-4] investing qualitative and quantitative analyses of human actions associated with MCRA scenarios based on the preliminary research such as FAQ 13-0002 to model an MCRA on LOH [5-6].

The MCRA involves scenarios where an MCR is abandoned due to Loss of Habitability (LOH) or Loss of Control (LOC) conditions. The focus was predominantly on LOH scenarios in the early stages of MCRA quantification research. However, with the introduction of Supplement 2 of NUREG-1921, attention shifted towards quantifying the failure probabilities of MCR abandonment decisions under LOC conditions. Furthermore, post-MCRA operation at the Remote Shutdown Panel (RSP) emphasizes the significance of Command and Control (C&C), prompting proposals for quantification approaches in this regard.

This paper aims to introduce the research status of NRC and EPRI in evaluating the failure probability of human actions related to MCRA. Additionally, it aims to describe approaches to achieve more realistic results when incorporating the HEP quantification method in this research into domestic fire HRA.

2. Quantification Approach for HEP Related to MCRA Actions by NRC and EPRI

In the context leading to MCR abandonment and aiming to prevent core damage, the scenario involves various human actions including:

- The decision to abandon the MCR.
- The necessary actions to transition control from the MCR to the RSP(s) and local area(s) where shutdown procedures will be executed.
- The actions related to any required supervisory coordination and communication at the RSP and local area
- The proper operation of the equipment for the successful shutdown process.

In this section, the quantification approach by NRC and EPRI to evaluate HEPs related to MCRA human actions due to fire is presented.

2.1. Screening Analysis

In NUREG/CR-6850, it is suggested that for failures to achieve safe shutdown using alternative means such as RSP, an overall HEP can be utilized. This approach proposes assigning a screening value of 1.0 to this overall HEP. Meanwhile, NUREG-1742 described that some plants assigned screening values (generally around 0.1, but ranging to 1.0 for events that might be directly influenced by the fire) based on Individual Plant Examination of External Events (IPEEE) experience [7]. Based on this, NUREG-1921 suggests screening values of 0.1 (following qualitative analysis) and 1.0 (for initial screening). However, the application of 0.1 is limited to cases where the feasibility assessment elements outlined in Section 4.3 are in an appropriate state.

2.2. Scoping Analysis

The scoping analysis is a simplified HRA method that requires only a few PSFs to be assessed and is intended to provide less conservative HEPs than screening but requires less time and effort than a detailed HRA analysis. The scoping analysis provides four kinds of flowcharts which consist of 'in MCR (INCR)', 'ex-CR (EXCR)', 'alternate shutdown (ASD)', and 'spurious instrumentation (SPI)'.

In certain MCRA scenarios, the scoping analysis results (applying the 'ASD' flowchart) exceed 0.1. For example, when the time available for any MCRA action is not greater than 30 minutes, scoping flowchart ('ASD') generally produce HEPs of 0.2 and 0.4. This highlights the necessity for alternative approaches, and considerations for relaxing the scoping analysis criteria are addressed. For instance, if the design of the RSP closely resembles that of the MCR in terms of capability, an 'EXCR' flowchart with a lower HEP than the 'ASD' flowchart would be applied.

2.2. Detailed Analysis

NUREG-1921, Supplement 2 categorized the timeline for the MCRA scenario into three phases:

- Phase I – Time period before the operators recognize that abandonment may be required
- Phase II – Time period associated with the decision to abandon
- Phase III – Time period after abandonment during which the transitional and post-abandonment shutdown actions are performed

<u>Quantification for Phase I</u>

The calculation of HEP for HFEs during Phase I applies the same methodology as that used for fire HRA, which is unrelated to MCRA. Additionally, in cases where a Phase I HFE coincides with the Phase II decision to abandon, the context of the Phase I HFE should consider the circumstances, added workload, and temporal delays linked with the concurrent tasks.

<u>Quantification for Phase II</u>

As mentioned in the introduction, during the initial stages of fire HRA research, the focus was primarily on MCRA due to LOH scenarios. However, the conditions associated with LOH involve prompt decision-making by operators, and also the criteria for abandonment are clearly defined. Consequently, the possibility of failure in the decision to abandon the MCR due to LOH has been perceived to be negligible. This perception led NUREG-1921, supplement 2, to address only the failure of MCR abandonment decisions resulting from LOC scenarios.

NUREG-1921, supplement 2 developed a decision tree to quantify an MCRA decision failure based on the potential failure mechanisms identified in NUREG-1921, Supplement 1. In Phase II, the operator's reluctance in the decision to abandon the MCR was recognized as a critical factor. It was determined that the impact of the reluctance can be somewhat mitigated through high-quality procedures and effective training. As a result, these influences were explicitly modeled in the decision tree. Excluding the HEP of 1.0 for extreme scenarios (such as no training), the range of HEP values for MCRA decisions is between 2.0E-2 and 2.0E-1.

<u>Quantification for Phase III</u>

The quantitative HRA approach for Phase III HFEs is similar to that used for other non-MCRA fire scenarios, and it suggests utilizing existing HRA methods as much as possible. Additionally, NUREG-1921, Supplement 2 highlighted the importance of C&C in Phase III, for which the quantification of C&C sequencing errors has been proposed using a flowchart. When performing the flowchart for human actions requiring C&C functionality, the final C&C sequencing HEP is assigned based on the presence or absence of compensatory measures in the relevant procedures. Specifically, HEPs of 1.9E-2 and 9.4E-2 are assigned, respectively, for the cases with and without compensation measures.

3. Proposals for realistic HEP in MCRA Context

In the previous section, we have described the current state of quantitative research on HEPs for MCRA-related actions and the range of HEP values. In Korea Atomic Energy Research Institute (KAERI), quantification approaches for Fire HRA have also been developed based on the content of NUREG-1921 and Supplement 1 and 2. The screening analysis and scoping analysis methods are employed [8-9]. For the screening value, the HEP of 0.1 is considered too optimistic as a screening value, so only 1.0 is applied. For a detailed analysis of the Phase I and III, we apply the K-HRA method, which is utilized in HRA for domestic internal event PSA, and incorporate the effects of fire incidents into the K-HRA. Additionally, the HEP to abandon MCR due to LOC in Phase II and the C&C sequencing HEP in Phase III are determined by applying the relevant decision trees and flowcharts from NUREG-1921, Supplement 2.

In this section, with the above methodologies, various approaches to achieve more realistic HEPs associated with MCRA have been proposed as follows:

- Enhancing Procedures

To reduce the probability of MCRA decision failures caused by LOC in Phase II, the following measures are proposed:

  - Explicitly defining the criteria for MCR abandonment based on LOC conditions
  - Providing limited guidance when clear criteria are difficult to establish (e.g., MCR

abandonment in the event of a cable spreading room fire)

For mitigating C&C sequencing errors in Phase III, the following strategies are suggested:

- Within the procedures, incorporating 'holding points' or 'warnings (cautions)' to ensure proper alignment of necessary components before an MCRA operation

- Strengthening MCRA Training
  - Enhancing the quality of training for MCR abandonment due to LOH/LOC (talk-through).
  - Providing training on the shutdown of components' spurious operation caused by fire incidents.
- Implementation of MCRA Simulations
  - Validation of feasibility through precise simulations to complete the MCRA-related timeline.
  - Calculation of time required for each key point in the timeline

4. Conclusions

This paper aims to introduce the research status of NRC and EPRI in evaluating the failure probability of human actions related to MCRA. Table 1 shows the summary of the HEP quantification approach and values. Results of fire HRA experiences for domestic NPPs performed by a Korean utility are included.

Table I: Summary of Quantification Approach and Values for MCRA HEP

Report ID	Quantification Approach	HEP
NUREG-1782	Screening analysis	0.1
NUREG/CR-6850	Screening Analysis	1.0
NUREG-1921	Screening analysis	0.1 or 1.0 (for initial screening)
	Scoping analysis (ASD)	0.04~0.8 (except for 1.0)
	Scoping analysis (EXCR)	0.02~0.5 (except for 1.0)
NUREG-1921, Supplement 2	Using the existing HRA method Phase I and Phase III	
	Decision tree for HEP of MCRA decision due to LOC for Phase II	0.02~0.2 (except for 1.0)
	Flowchart for HEP of C&C sequencing error in Phase III	0.019 (with compensating measures) or 0.094 (without compensating measures
Korean NPP	Detailed analysis	0.1 or 1.0 (except for a few NPPs)

We suggested some proposals for achieving more realistic HEPs about MCRA scenarios such as 'enhancing procedures', 'strengthening MCRA training', and 'implementing MCRA simulations.' It is expected that when the proposals we mentioned in this paper are provided, more realistic HEPS can be calculated.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government, Ministry of Science and ICT. (Grant Code: RS-2022-00144204)

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