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A Study on Quantification of Operator Manual Action for Fire PSA

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The purpose of this paper is to describe the fire HRA (Human Reliability Analysis) method for domestic fire PSA (Probabilistic Safety Assessment) at full power operation and considerations for quantifying OMA (Operator Manual Action) using the fire HRA method. OMAs are actions performed by operators to manipulate components and equipment from outside the MCR (Main Control Room) to achieve and maintain post-fire hot shutdown, but do not include "repairs" by NUREG-1852. NEI 00-01 classified impacted cable/component by MSO (Multiple Spurious Operation) as either a required or important to safe shutdown cable/component and established OMA as one of the measures to mitigate the effects of MSO of the important to safe shutdown cable/component for fire area assessment. More broadly NRC defined post-fire OMA as actions performed by plant personnel on plant equipment to recover from a fire outside MCR. Currently, domestic NPPs have selected OMAs to mitigate MSO by considering the feasibility and reliability factors in way of a deterministic approach based on NUREG-1852. In this study, the existing fire HRA method is reviewed to quantify OMA to model it into fire PSA. To achieve this goal, complementary factors of the fire HRA method for OMA quantification such as wearing SCBA (Self-Contained Breathing Apparatus) outside MCR and the need to establish detailed timelines to model the relation between MCRA (Main Control Room Abandonment) and OMA were derived.

Keywords: Fire Human Reliability Analysis, Operator Manual Action, Multiple Spurious Operation

1. Introduction

The importance of fire accidents at nuclear power plants (NPPs) has been recognized due to their significant impact on the safety of NPPs, as evidenced by the analysis of past fire incidents. Fire hazards have become a major challenge to the safe operation of NPPs, and therefore, much research has been conducted to quantify fire risks in NPPs. As part of these efforts, NUREG/CR-6850 was developed to document state-of-the-art methods, tools, and data for conducting a fire PSA for commercial NPP applications. USNRC (2005).

Following the publication of NUREG/CR-6850, the NRC released several reports aimed at expanding the data used in the report and improving its contents. USNRC (2020a, 2020b, and 2020c).

A human reliability analysis (HRA) is generally defined as a structured approach used to identify potential human failure events (HFE) and systematically estimate the probability of those errors using data, models, or expert judgment. An HRA is necessary for a probabilistic safety assessment (PSA) since it is needed to model the as-operated portion, and a PSA reflects the as-built and as-operated plant.

NUREG-1921 was developed to provide a method and associated guidance for conducting a fire HRA for a fire PSA. The purpose of this report is to offer explicit guidance for estimating human error probabilities (HEPs) for HFEs under fire conditions, building on existing HRA methods. USNRC (2012). Additionally, supplement 1 and 2 of NUREG-1921 have been developed to provide both qualitative and quantitative approaches for scenarios related to a main control room abandonment (MCRA). USNRC (2019 and 2020d).

In Korea, a fire PSA is currently underway for domestic NPPs, and it is expected that the NUREG/CR-6850 based fire PSA method will be applied once cable data of the domestic NPPs is developed. A guideline for a fire HRA required for a fire PSA of domestic NPPs at full power operation based on the NUREG-1921 with its supplement 1 and 2 has been developed by Korea Atomic Energy Research Institute (KAERI). Choi and Kang (2022). To develop the fire HRA method for domestic NPPs, we conducted a review of the K-HRA method in order to reflect it for detailed quantification of a HEP for fire HRA. The K-HRA is a standard method for HRA of a domestic internal event PSA that was developed by KAERI. Jung et al. (2005). We made efforts to modify the performance shaping factors (PSFs) of K-HRA to reflect the fire situation and its effects. Additionally, to reflect the MCRA status, we considered a diagnosis error for the MCRA decision due to loss of control (LOC) and a command and control (C&C) sequencing failure, and we applied their HEP estimation method based on the NUREG-1921, Supp.2.

Our recent research topic is the quantification of operator manual actions (OMAs) for modelling them into fire PSA. According to NUREG-1852's definition, OMAs are those actions performed by operators to manipulate components and equipment from outside the MCR to achieve and maintain post-fire hot shutdown, excluding "repairs." USNRC (2007). OMAs are considered one of the mitigation measures for fire area assessment of post-fire safe shutdown analysis. Currently, domestic NPPs selected OMAs based on a deterministic approach that considers feasibility and reliability factors, guided by NUREG-1852. However, the NRC's definition is more comprehensive than that of NUREG-1852 and is defined as follows:

- Post-fire OMAs are actions performed by plant personnel on plant equipment to recover from a fire
- Post-fire OMAs are written in procedures and generally include actions performed outside of MCR

The purpose of this paper is to describe the fire HRA method for domestic fire PSA at full power operation and discuss the considerations for quantifying OMA using the developed fire HRA method.

2. Fire HRA developed by KAERI

In this section, we summarize the fire HRA we have developed. Figure 1 explains the fire HRA method by reflecting the timeline of MCRA.

- Phase I: the time period before abandonment
- Phase II: the time for the decision to abandon due to LOC
- Phase III: the time period once the decision to abandon has been made

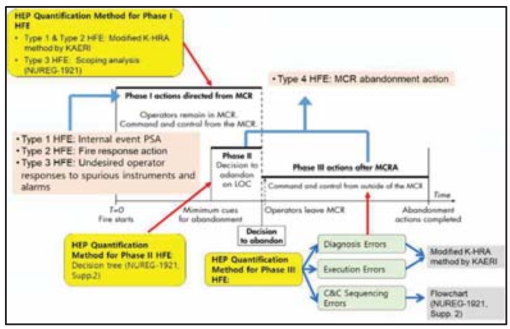

Fig. 1. fire HRA method by reflecting the timeline of MCRA

As described in Figure 1, we defined four types of HFEs for a fire HRA:

- Type 1 HFE: HFEs from the existing internal event PSA
- Type 2 HFE: HFEs from fire response action
- Type 3 HFE: HFEs from undesired operator responses to spurious instruments and alarms
- Type 4 HFE: HFEs from MCRA action

And then we established HEP quantification methods:

- Modified K-HRA method by KAERI
- Scoping analysis (NUREG-1921)
- Decision tree (NUREG-1921, Supp.2)
- C&C Sequencing Errors (NUREG-1921, Supp.2)

For the detailed quantification of HEPs, we modified the K-HRA which is a standard method for HRA of a domestic internal event PSA by reflecting a fire situation and fire effects.

- New operator action
  - Operator's task described in the fire procedure to respond to fire
  - Fire response strategy
  - the possibility of the operator's responding to false alarms as if they were "actual"
- PSF considering the environment caused by fire
  - Effects of smoke, heat, toxic gases, etc. on operators and their route to the location
  - Effect of respiratory and protective equipment on the performance of the operator (including communication)
- Complexity of situation
  - Effects of changes in the size, location, and duration of a fire on the system and function
  - Fully/partially damaged indicator due to fire
  - Shift technical advisor (STA)'s absence to command the fire brigade
- Other PSF related to MCRA
  - Remote shutdown panel (RSP) design
  - Communication
- Command and coordination

3. Considerations for Quantification of Operator Manual Action

The primary objective of fire protection programs at U.S. NPPSs is to minimize the effects of fires and explosions on structures, systems, and components (SSCs) important to safety according to RG.1.189. USNRC (2009). In response to the fire accident at the Browns Ferry in the United States, regulatory requirements for deterministic fire protection have been continuously strengthened. RG.1.189 for fire protection includes requirements for fire safety shutdown analysis, which considers circuit analysis including multiple spurious operations (MSOs) and approves the use of the guidance for post-fire safety shutdown circuit analysis, NEI 00-01 (Rev.2) to provide a deterministic method for performing post-fire safe shutdown analysis. NEI (2009). Therefore, NPPs operating based on deterministic fire protection requirements should perform the post-fire safe shutdown analysis considering MSOs.

In Korea, all NPPs shall perform a fire safety shutdown analysis including circuit analysis and MSOs in accordance with the regulations of the Korean nuclear regulatory body, Nuclear Safety and Security Commission (NSSC).

3.1. *HFE Type for OMA*

As mentioned earlier, OMAs are considered as one of the mitigation measures for fire area assessment of post-fire safe shutdown analysis. To quantify OMAs using the previously developed fire HRA method, we first defined the HFE type of OMAs. OMAs are associated with the three of the HFE types we defined in Section 2, except Type 3 HFE. Type 3 HFE is related to an undesired operation to recognize a spurious operation of I&C as a normal signal and performing an action suitable for the spurious signal. Examples of OMAs with each HFE type are as follows. As described in Figure 1, we defined four types of HFEs for a fire HRA:

- Type 1 HFE: operator fails to open atmosphere dump valve (ADV) locally
- Type 2 HFE: operator fails to recover containment spray pump spurious operation
- Type 4 HFE: operator fails to reopen the essential service water (ESW) discharge valve locally

Above, Type 4 HFE is related to moving to the RSP and performing OMA. It corresponds to the case where an MSO occurs while the operator is in the MCR, and moves to the RSP, but cannot operate a component to mitigate the MSO in the RSP for safe shutdown.

3.2. *Considerations for OMA quantification with the fire HRA method*

NUREG-1852 defined feasibility and reliability criteria including technical information for OMA in a deterministic approach:

- Adequate time available to perform the actions (to address feasibility)
- Adequate time available to ensure reliability
- Environmental factors
- Equipment functionality and accessibility
- Available indications
- Communications
- Portable equipment
- Personnel protection equipment
- Procedures and training
- Staffing
- Demonstrations

We investigated whether the previously developed HRA method met the feasibility and reliability criteria listed above for OMA. After comparing the criteria to the fire HRA method, we derived additional factors to be considered when quantifying the post-fire OMAs using the fire HRA method.

3.1.1. *Timeline for diagnose HEP*

The existing fire HRA method takes into account operator action in a local area when controlling the component in the MCR is difficult. However, it does not establish a clear relationship between the decision time for MCRA, the occurrence time of MSO, and related OMA implementation time. In some NPPs in Korea, the RSPs do not have component control switches required for safety shutdown after a fire. Therefore, in the event of an MCR fire, a situation may arise in which MCR abandonment and OMA may be considered at the same time. Considering this situation, it is necessary to establish a timeline according to the order of events. In other words, different timelines should be considered for the timing of MSO occurrence after the MCR fire: (1) before the decision to move to the RSP, (2) immediately after the decision to move to the RSP, and (3) after the decision to move to the RSP.

3.1.2. *Additional considerations regarding wearing the SCBA*

In the existing fire HRA method, the assumption that the operator would bypass the area where the fire occurred when moving to the area for a component operation, and only wearing the SCBA in case of fire in MCR was considered. However, in the case of OMAs selected from a domestic NPP, it was found that in a few cases, it was necessary to pass through a corridor shared with the fire area for a component operation to mitigate the fire situation. Therefore, it is necessary to consider PSFs associated with passing near the fire area to perform the OMA, which includes the following factors:

- Add delay time due to wearing SCBA in a local area to OMA implementation time
- Communication difficulty due to wearing SCBA to implementation time
- The higher stress level due to passing through a fire area

4. Conclusion

This paper highlights the importance of considering OMAs in fire PSA and suggests several considerations for quantifying OMA using the existing fire HRA method.

The existing fire HRA method only considered wearing SCBA in the case of fire in the MCR and did not consider the need to wear SCBA when passing through a fire area to perform an OMA. Therefore, it is necessary to consider the time required to wear SCBA in a local area, communication difficulties caused by wearing SCBA, and the higher stress level associated with passing through a fire area to perform an OMA. Additionally, the timeline for OMA implementation needs to be established, taking into account the relationship between the occurrence time of MSO and MCRA time for diagnosis of HEP.

As a further work, the HEP of the quantified OMA using the fire HRA method reflecting the considerations mentioned above, is planned to be applied to the fire PSA. This study is significant for quantifying OMA for inclusion in fire PSA. Furthermore, it is expected that if an OMA's HEP is derived considering the worst case for each PSF during the quantification process, it would meet the reliability criteria in the deterministic approach mentioned in NUREG-1852, where the worst case scenario of feasibility and reliability criteria for OMA should be demonstrated through a demo.

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