Quantifications and Modeling of Human Failure Events in a Fire PSA

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1. Introduction

This paper introduces the human reliability analysis (HRA) process for a fire PSA of Hanul Unit 3. KAERI is performing a fire PSA for a reference plant, Hanul Unit 3, as part of developing the Korean total site risk profile. The previous fire Probabilistic Safety Assessment (PSA) [1] for domestic nuclear power plants (NPPs) did not explicitly address human failure events (HFEs) affected by an internal fire event. Recently, USNRC and EPRI developed guidance, "Fire Human Reliability Analysis Guidelines, NUREG-1921"[2], for estimating human error probabilities (HEPs) for HFEs under fire conditions. NUREG-1921 classifies HFEs into four types associated with the following human actions:

- Type 1: New and existing Main Control Room (MCR) actions
- Type 2: New and existing ex-MCR actions
- Type 3: Actions associated with using alternate shutdown means (ASD)
- Type 4: Actions relating to the error of commissions (EOCs) or error of omissions (EOOs) as a result of incorrect indications (SPI)

In this paper, approaches for the quantifications and modeling of HFEs related to Type 1, 2 and 3 human actions are introduced.

2. Approaches to the quantification of HFEs

NUREG-1921 provides three approaches to the quantification of HFEs: screening, scoping, and detailed HRA. Screening HRA is based on the guidance in NUREG/CR-6850[3], with some additional guidance for scenarios with long time windows. Scoping HRA is a new approach to quantification developed specifically to support the iterative nature of fire PSA quantification.

Type 1 and 2 human actions for a fire PSA of Hanul Unit 3 NPP were quantified mainly using the screening method of NUREG-1921. Table I shows the screening criteria of NUREG-1921. Type 3 human actions for this were quantified using the scoping analysis method of NUREG-1921.

Fig. 1 shows the process of quantifications of type 1 and 2 human actions. Pre-existing Type 1 and 2 human actions modeled in the internal PSA were re-quantified to include fire situations. Based on NUREG-1921, a multiplier of 10 was used to re-estimate the human error probabilities (HEPs) for the pre-existing internal human actions. Some pre-existing ex-MCR human actions cannot be accessible because of a fire of specific fire area. Thus, the HEPs for all ex-MCR actions were assumed to be 1. If the re-quantified pre-existing human action were identified to be risk-significant, the detailed approaches (modeling and quantification) were used for incorporating fire situations into them. New human actions related to MCR fire were quantified using the scoping or screening HRA method of NUREG-1921. Abnormal operation procedures were reviewed and operator interviews were conducted to identify critical human actions and estimate their performance time.

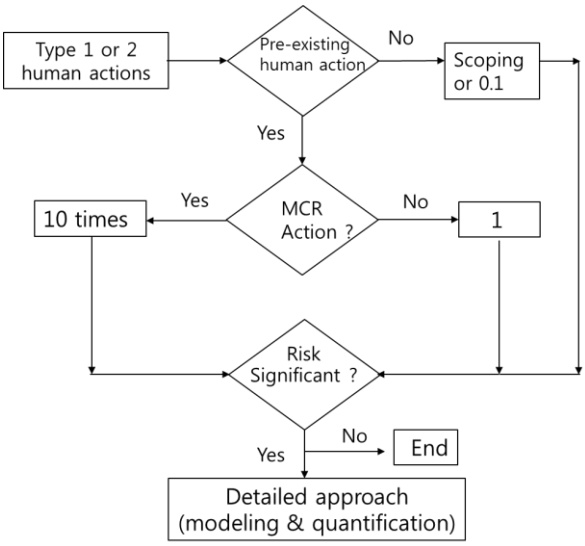

Fig. 1. Process of the quantification of HFEs related to Type 1 and 2 human actions.

3. Modeling of HFEs

Since the failure probability of instrumentation equipment is low compared with HEPs, instrumentation equipment failure is generally not addressed for HFEs in an internal PSA. However, a fire can damage the instrumentation equipment and its cables, and operator cannot take appropriate actions to mitigate the accident situations. Thus, instrumentation equipment failure is to be modeled for all HFEs in a fire PSA. Although the failures of instrumentation equipment lead to those of human actions, the operator can recover from them if there is ample available time and redundant instrumentation equipment. Based on operator interviews, available time, redundant instrumentation equipment, and the procedure review, an instrumentation equipment failure was modeled for

human actions related to bleed operations and manual actuations of ESFAS. Instrumentation equipment related to HFEs is modeled using an 'OR' gate. Fig. 2 shows an example of a fault tree representing the failure of instrumentation equipment for manual RAS (recirculation actuation signal) generation.

In a PSA, single HFE for single human action is generally defined and a single HEP is used. However, the HEP for a single human action can be estimated differently according to fire areas or scenarios because of different fire situations. Therefore, HEPs are in a conservative way quantified because single HFE for single human action is to include all fire scenarios related to single HFE. In a fire PSA of Hanul Unit 3, if the quantified human actions were identified to be risk-significant, the HFE for those human actions was classified into two or three HFEs to realistically incorporate fire situations into the HFEs. Fig. 3 shows an example of a fault tree representing three HFEs for the same MCR human actions differently estimated according to fire scenarios. For the case of an MCR abandonment fire scenario, feed and bleed operations are not feasible at remote shutdown panel. In this case, HEP for bleed operation is one. Ex-MCR human actions are not feasible if a fire is initiated at the same place or at their route. Therefore, initial HEPs for ex-MCR human actions were quantified to be one. When only specific fire areas or scenarios affect the feasibility of ex-MCR human actions and ex-MCR human actions are risk-significant, the following approaches were used:

- Identify the place and routes for ex-MCR human actions.
- Identify the fire initiating events related to the place and routes for ex-MCR human actions. If there are too many fire initiating events, review the cut-sets for core damage sequence and select the fire initiating events related to them.
- Set ex-MCR human actions for the fire initiating events related to the place and their routes one. 0.1 or 10 times of HEP for ex-MCR human actions were used for other fire initiating events not related to the place and routes for ex-MCR human actions
- Model HFEs like Fig.4.

4. Concluding remarks

This paper introduced the human reliability analysis process for a fire PSA of Hanul Unit 3. A multiplier of 10 was used to re-estimate the HEPs for the pre-existing internal human actions. The HEPs for all ex-MCR actions were assumed to be one. New MCR human actions were quantified using the scoping analysis method of NUREG-1921. If the quantified human action were identified to be risk-significant, detailed approaches (modeling and quantification) were used for incorporating fire situations into them. Multiple HFEs for single human action were defined and they were separately and were separately quantified to incorporate the specific fire situations into them. From this study, we can confirm that the modeling as well as quantifications of human actions is very important to appropriately treat them in PSA logic structures.

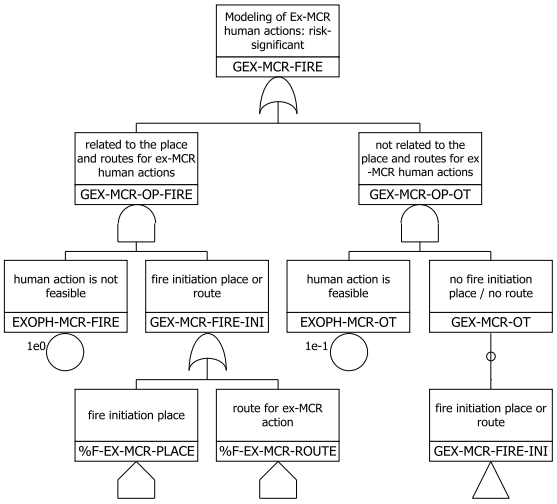

Fig. 4. Example of a fault tree representing two HFEs for the same ex-MCR human actions.

Acknowledgements

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[2] S.Lewis et al, "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines", NUREG1-1921, USNRC, 2012

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Table I. Screening criteria of NUREG-1921

Screening Criteria	Short-Term HFEs		Long-Term HFEs	
	Definition	Value	Definition	Value
Set 1: similar to internal events HFE but with some fire effects	Required within first hour of fire/trip	10x internal events HEP	Performed ~1 hour after fire/trip (fire effects no Longer dynamic, Equipment damage understood, and fire does not significantly affect ability of operators to perform action)	Same as internal events HEP
Set 2: similar to Set 1 but with spurious equipment or Instrumentation effects in one safety-related train/division		0.1, or 10x internal events HEP, whichever is greater		0.1, or 10x internal events HEP, whichever is smaller
Set 3: new fire HFEs or prior internal events HFEs needing to be significantly modified as a result of fire conditions		1.0		0.1, or 10x internal events HEP, whichever is smaller
Set 4: alternate shutdown (including MCR abandonment)	1.0 for initial screening (per Section 5.1.1.4), or 0.1 following qualitative analysis (per Section 5.1.3)			

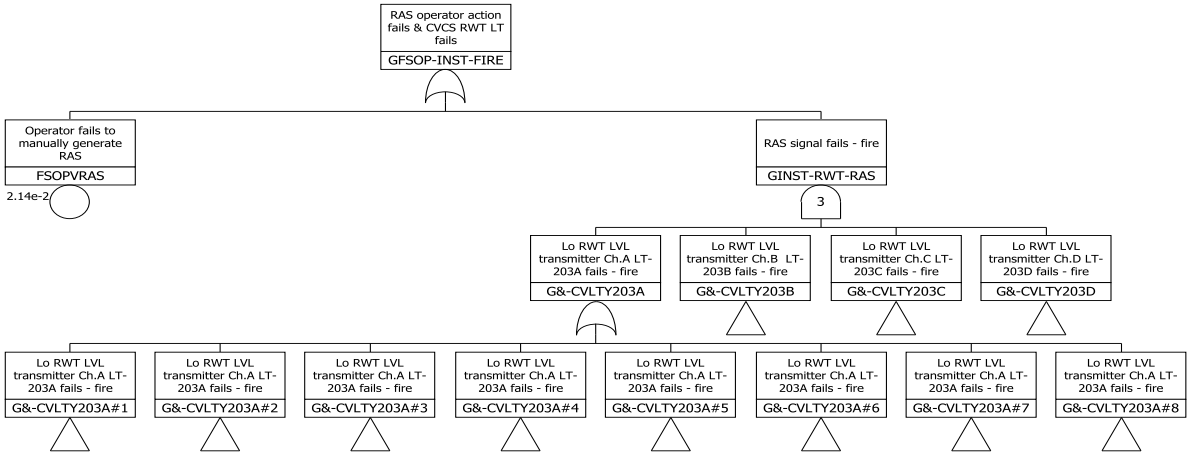

Fig. 2. Example of a fault tree representing instrumentation equipment failure.

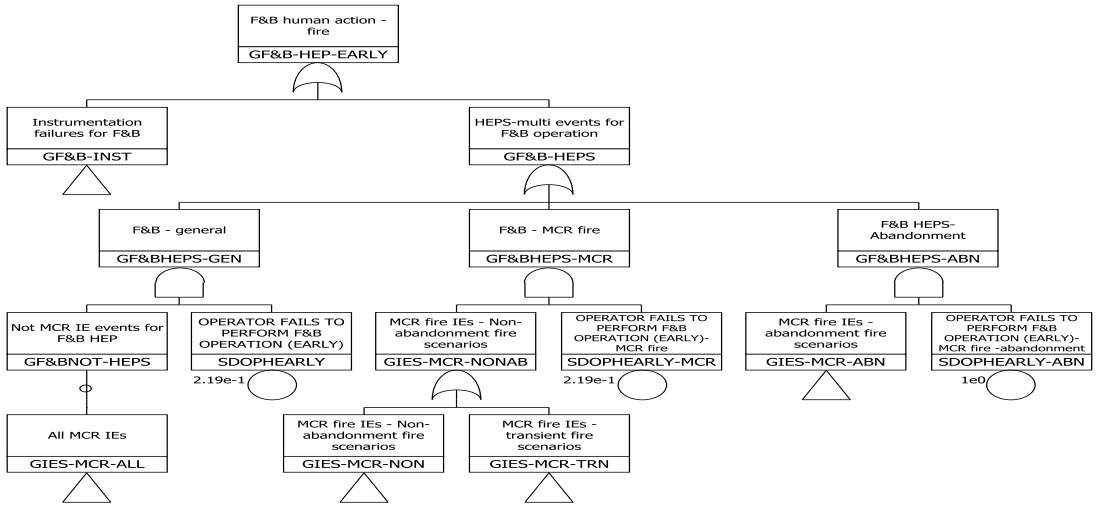

Fig. 3. Example of a fault tree representing three HFEs for the same MCR human actions.