Application of the Scoping Fire Human Reliability Analysis on the Nuclear Power Plant

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1. Introduction

The fire probabilistic safety assessment (PSA) is used for evaluating the safety of the plant during a fire incident. This is because a fire accident can cause a reactor shutdown at a nuclear power plant (NPP) and simultaneously damage systems that perform safety shutdown or accident mitigation functions. Among them, performing the human reliability analysis (HRA) to calculate the human error probability (HEP) of the human failure event (HFE) has important implications. The reason for this is that safety shutdown and accident mitigation require the operator action. If operator error occurs, it could lead to severe accidents in the worst case, causing massive property, environment, and human casualties [1].

The NUREG/CR-6850, which is widely applied in fire PSA, provides high-level guidance that identifies the human error and reflects it in the PSA. NUREG/CR-6850 presents a method of applying a screening value to quantify identified HFE. This method considers the effects of performance shaping factors (PSFs) on human errors caused by fire and estimates the HEPs. However, the screening value method presented in NUREG-6850 does not estimate the most accurate HEP under some given conditions [2].

To compensate for this, EPRI and NRC have developed new guidelines for estimating HEPs in fire events, described in NUREG-1921, and published in 2009. Scoping fire HRA method developed are evaluated using factors such as the main control room (MCR) condition, action location, cue, and fire suppression time [3]. This study identifies assumptions about the fire initiating event onthe MCR in the fire PSA. Next, a summary of the NUREG-1921 fire HRA is presented. Considering the PSA assumptions in the MCR, how to carry out fire HRA is explained through examples.

2. Assumptions of MCR in the Fire PSA

The fire PSA applies conservative assumptions about the propagation of fire in the MCR [1] because PSA analysts do not have any real MCR fire data. Bench board (or cabinets) in MCR are responsible for controlling the systems that require action during normal operation of the NPP or an accident. Hence, an assumption is that a fire on the bench board can affect the operation of the NPP. Fire PSA defined the steps of fire propagation in the MCR, as shown in table 1.

These fire PSA assumptions should also change the assessment of the HFE. Figure 1 shows a top view example of bench board damage over time, in the case of a fire incident. At the start, the HFE that stops the low pressure safety injection (LPSI) pump can be controlled using BB01 (as this is a reactor coolant system). In the case of Growth, BB01 can also be damaged and cannot be operated in MCR. At the Spread stage, the MCR habitability is lost, so mitigation action should be carried out by moving to the remote shutdown room (RSR) and alternate shutdown (ASD). This means that HRA must be performed by applying different factors to each fire step to get a more realistic HEP.
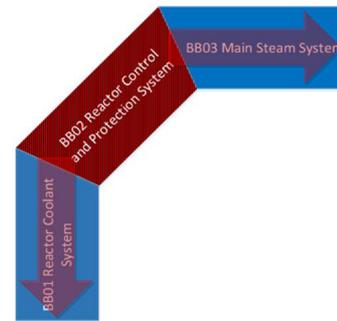

Fig. 1. Top view of bench board damage over time in the fire event

Table I: The Scenario of bench board damage over time in the fire event

Step	Time (mins)	Situation	Fire section
Start	T<5	- One section of the bench board or console has a fire - Inoperable or malfunction of equipment involved in bench board or console section	BB02
Growth	5≤T<15	- Fire spreads to nearby boards - The operator stays in the MCR, put out the fire, and takes necessary actions.	BB01, BB02, BB03
Spread	15≤T	- Unable to gain visibility due to combustion gas - Operators switch to the remote shutdown room for NPP operation.	MCR burned out

3. Summary of NUREG-1921 Fire HRA Method

NUREG-1921 proposes a method to calculate the HEP of the HFE in response to an initiating event caused by fire. The fire HRA process consists of six steps, as shown in figure 2.
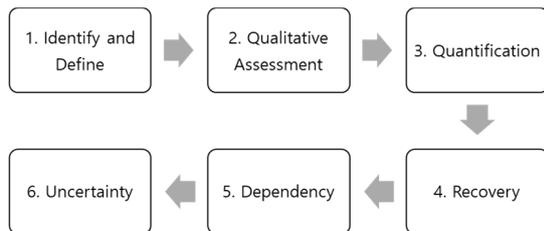
Fig. 2. Fire HRA method process of NUREG-1921

3.1 Identify and define

First, among the HFEs modeled in internal events, the HFE required as a response action in fire PSA is carried out. Next, the additional HFE required in the fire event is identified anew.

3.2 Qualitative assessment

Qualitative assessment means evaluating whether the identified and defined HFE can be performed in a fire event. The method evaluated whether it is a feasible operator action depending on the factors in the fire event.

3.3 Quantification

There are three methods of quantification proposed in NUREG-1921.

- Screening HRA
- Scoping fire HRA quantification method
- Detailed HRA quantification approach

The screening HRA method is a simple calculation of HEP considering a fire situation. Based on the assessment, the calculation is made by applying the same HEP as the internal event or multiplying the specific value. In contrast, the scoping HRA method performs a more detailed analysis of the screening HRA and takes into account various factors in the fire situation. This method also provides flowcharts for deriving HEPs. Detailed HRA is the most non-conservative method of analysis among the three methods, which is to analyze HFEs in detail according to the general HRA method chosen.

3.4 Recovery

Recovery action is identified, defined, and quantified according to the same process, all other HFEs in the fire PSA model. The main difference between fire HRA is operator impact on the ability to perform recovery actions related to fire scenarios.

3.5 Dependency

The combination of two or more HFE is identified within a cutset from the PSA result to evaluate the dependency between HFEs. The results are incorporated into the PSA model.

3.6 Uncertainty

Uncertainty is divided mainly into two categories; 1) uncertainty in the data used to evaluate HFE. 2) uncertainty in probability distribution exists because HEPs obtained from quantitation are based on the assumption of a particular distribution.

4. Application of NUREG-1921 Scoping Fire HRA

Depending on the impact of the fire event on operator performance, four conditions are divided, as shown in Figure 3.
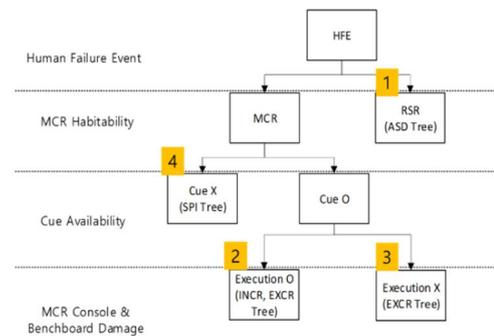

Fig. 3. The tree for applying scoping fire HRA method in the case of a fire in the MCR

4.1 MCR habitability

If the operator performs tasks in the RSR due to the loss of MCR habitability, it should be analyzed by ASD flowchart (1 in figure 3). Loss of habitability in MCR means that operators cannot stay due to combustion gases and smoke caused by fire. At this time, the MCR operator moves to the RSR and performs alternative control for the reactor shutdown. Therefore, in the spread step, the operator moves to the RSR and performs the analysis using the ASD flowchart. T_{delay} was assumed to be over 15 mins because the operators were unable to extinguish the fire within 15 mins at the MCR and moved to the RSR.

4.2 Cue availability

The cue means an alarm or procedure that the operator perceives the action. If the alarm or procedure is not available for the operator to perceive the required action in the fire situation, analyze it with spurious instrumentation (SPI). (4 in Figure 3) This analysis excludes SPI trees from the analysis target. It is relatively easy for operators to identify the instruments affected by fire in the MCR, and it is unlikely that operators make a wrong judgment.

4.3 MCR console bench board damage related to HFE

If an action location is the MCR, the bench board or MCR console related to the action is evaluated for damage. The MCR console or bench board may be damaged by fire, and the operator may not be able to operate the components necessary to act. In such cases, it should be evaluated that alternative action can be performed in the local. For example, in the event of a fire in the console operating the main steam air dump valve, the local operator can manipulate at the valve location. If

alternative action is possible in the local, it can be evaluated as EXCR. However, if the action location is MCR and the board manipulating is available, it is analyzed by INCR (2 in Figure 3). When the board is not available due to fire, any action that can replace the needed action is analyzed by EX-CR (3 of Figure 3). The tasks where the action location is local are evaluated by Ex-CR (EXCR) (2 or 3 in figure 3). Tasks that were action location in MCR would include local travel time. Hence, the analysis should assume 20minutes of travel time to the local.

5. Example Application of the Scoping Fire HRA

In this section, a Scoping HRA analysis was performed on an initiating event that caused the MCR habitability to fail by suppressing fire within 15 mins of a fire in the MCR. The detailed assumption about this initiating event for Spread is described in Table 1. The information required to apply fire HRA to HFE is given in Table II.

Table II: Information for analyzing HFE

HFE ID	HFE #1
HFE description	Operator fails to stop LPSI pump (SLOCA)
Applicable systems	Residual heat removal (RHR) pump
Sub-task	Stop RHR pump
Action location	MCR
Operable critical equipment of the RSR	LPSI (same as RHR) pump control
Related console & bench board	BB01
Timeline (mins)	T_{sw}: 65, T_{cog}: 20, T_{delay}: 15, T_{exe}: 1
Cue	Reactor coolant system (RCS) pressure

5.1 Case1: Moving the Remote Shutdown Room (PSA assumption: Spread)

5.1.1 Selection scheme (SS)

Figure 4 shows the HFE #1 evaluated in the SS. The decision (D)1 evaluates whether HFE has the minimum criteria been met, such as procedure, training, availability, and accessibility. Based on the data analyzed in the internal events, HFE #1 has positive assessments for the procedures, training, availability, and accessibility. Therefore, it is evaluated to "Yes."

The D2 evaluates whether the command-and-control is located outside the MCR. Since the MCR operator moves to RSR due to a fire for more than 15 minutes, it is necessary to assess whether the task is feasible (i.e. control) in the RSR. The HFE #1 sub-step is to stop the LPSI pump and is evaluate to "Yes" because there is LPSI pump control in the list of operable equipment in RSR.

5.1.2 Alternate Shutdown (ASD)

Figure 5 shows the ASD of HFE #1. The D40 evaluates whether all the necessary cues for the required actions are protected. The cue for performing the task is

evaluated to "Yes" because the operators can check the RCS pressure, a critical plant parameter, in the RSR.

The D41 evaluates whether, for the given action, the procedures match the scenario. HFE #1 matches the scenario as required by the EOP.

The D42 evaluates whether one of the following conditions met: 1) there are procedures for executing the action or 2) it is a skill-of-the-craft. HFE #1 is described in EOP and meets condition 1. Therefore, it was evaluated to "Yes".

The D43 evaluates whether both conditions are met: 1) the area is accessible and 2) there is no fire in the vicinity of the action. The operator can access the RSR panel and is evaluated to "Yes" because the fire in the MCR does not affect RSR.

The D44 evaluates whether the T_{avail} is greater than 30mins. T_{avail} is the time when T_{sw}-T_{delay}. As mentioned in section 4.1, it is assumed that T_{delay} takes an additional 15mins. Therefore, when calculated from the information in Table 2, T_{avail}=65-(15+15) =35mins is greater than 30mins, so it evaluates to "Yes."

The D49 evaluates whether the execution complexity is high. The sub-task of Table II is identified and evaluated to "No."

The D50 evaluates whether there smoke or other hazardous elements in the vicinity. Smoke or other hazardous elements are evaluated to "No" because there is no smoke in the RSR. And the final element suggests HEP lookup table AG.

Table III presents different HEPs according to Time margin (TM), which should be calculated using the Tmargin equation in Figure 6. Calculating using an equation, the TM of HFE #1 is 67%. That is, HFE #1 has the HEP of 0.2.

$$Time\ margin\ (TM) = \frac{T_{avail} - T_{reqd}}{T_{reqd}} \times 100\%$$

$$Time\ margin\ (TM) = \frac{[(Tsw - Tdelay) - (Tcog + Texe)]}{(Tcog + Texe)} \times 100\%$$

$$TM\ of\ HFE\ \#1 = \frac{[(65 - 30) - (20 + 1)]}{(20 + 1)} \times 100\% = 67\%$$

Fig. 6. Time margin equation and TM of HFE #1

Table III: ASD lookup table AG

HEP Lookup Table	Time Margin	HEP	HEP Label
AG	≥100%	0.04	ASD15
	50-99%	**0.2**	**ASD16**
	<50%	1.0	ASD17

6. Conclusions

This study analyzed the HRA of fire PSA for an MCR fire event by applying the NUREG-1921 scoping fire HRA method. Fire PSA has assumptions about MCR fire events and must provide appropriate HEPs. Therefore, along with an example, guidelines for applying the scoping fire HRA method were proposed. These guidelines can be used as a reference when conducting fire HRAs.

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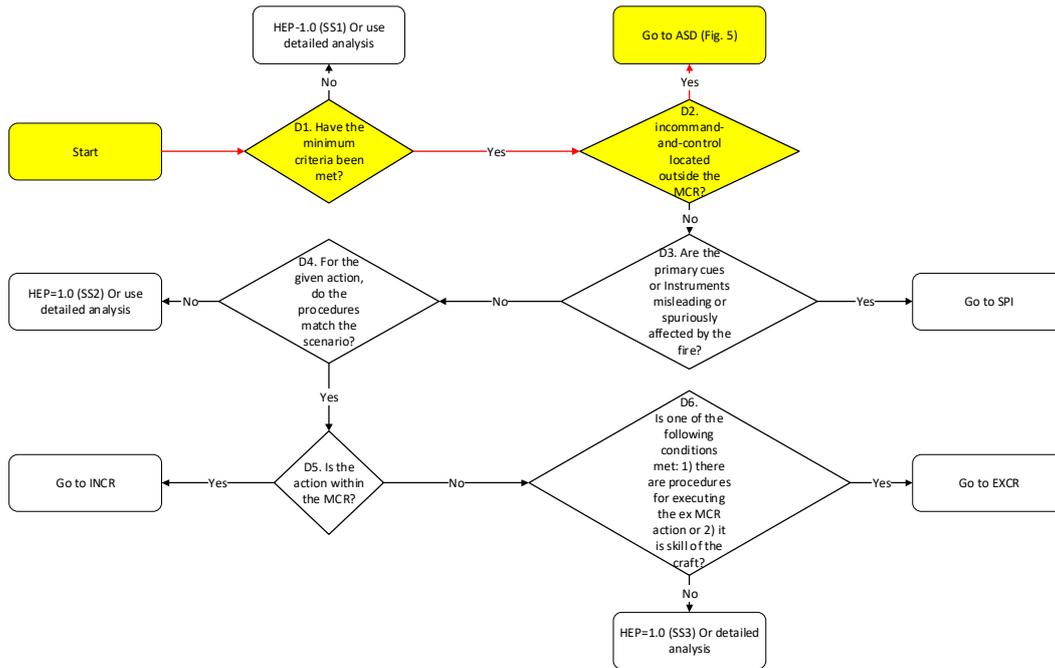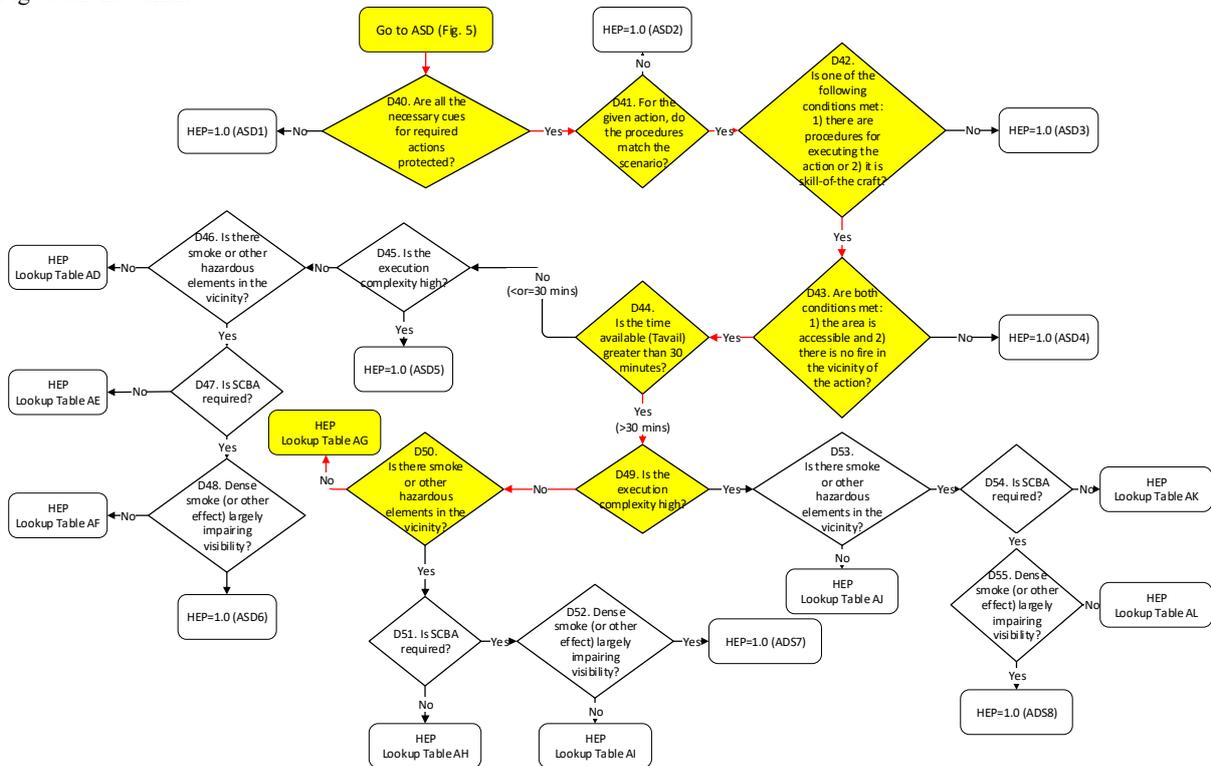
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Fig. 4. SS flowchart

Fig. 5. SS flowchart continued