Case Study about Operator Manual Action Quantification for Fire PSA

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Abstract: This paper is to describe the quantification of OMAs(Operator Manual Actions) for a fire PSA (Probabilistic Safety Assessment) with a fire HRA(Human Reliability Analysis) developed by KAERI (Korea Atomic Energy Research Institute). Some OMAs are selected as measures to address MSOs (Multiple Spurious Operations) for the reference NPP(Nuclear Power Plant) by fire experts and HRA experts. The fire PSA model is modified to reflect the OMAs. To quantify those OMAs, interviews are performed with NPP operators to gather time information and related diverse environmental information. A quantification is performed for the case study.

Keywords: Fire PSA, Fire HRA, OMA

1. INTRODUCTION

Based on NUREG-1852, OMAs(Operator Manual Actions) are defined as operator actions conducted from outside the MCR(Main Control Room) to achieve and maintain a hot shutdown after a fire, excluding repairs [1]. The document further distinguishes OMAs into preventive actions and reactive actions, each described as follows:

- preventive actions: measures taken to mitigate potential equipment malfunctions or potential effects of a fire without additional diagnosis upon entering the fire procedure, immediately alleviating anticipated issues caused by the fire
- reactive actions: measures taken in response to undesirable changes in plant conditions during a fire, where operators detect abnormal changes, diagnose, and execute the correct actions according to procedures

The OMAs examined in this paper pertain to reactive measures. It involves detecting and responding to post-fire MSOs(Multiple Spurious Operations) following procedures, making it a reactive measure, not preventive. In the analysis of MSO, OMA is considered one of the possible solutions that can be established in the event of non-compliance with the requirements for important safety-related components during a safe shutdown by NEI 00-01 [2].

At Korea Atomic Energy Research Institute(KAERI), we developed a guideline for performing a fire HRA(Human Reliability Analysis) required for a domestic fire PSA based on the K-HRA method which is a standard method for HRA of a domestic level 1 PSA(Probabilistic Safety Analysis) developed by KAERI [3-4]. The development policy of the guideline was established to reflect the recent study of the NUREG-1921 series to meet the requirements of the ASME/ANS PRA Standard [5-7]. We performed a detailed analysis for fire-related HFE(Human Failure Event) quantification with the fire HRA method.

We are currently conducting OMA quantification with the fire HRA method. As mentioned above, OMAs can be one of the solutions to address MSOs. As MSOs were selected for domestic NPPs(Nuclear Power Plants), OMAs became major challenges. We established the modification of the existing fire HRA method for OMA quantification. In particular, we developed a timeline to implement the relationship between MCRA(Main Control Room Abandonment) and OMA situations [8-10].

This paper aims to describe the quantification of OMAs for a fire PSA with a fire HRA developed by KAERI. We selected some OMAs as measures to address MSOs for the reference NPP by fire experts and HRA experts. Then we modified the fire PSA model to reflect the OMAs. To quantify those OMAs, we interviewed NPP operators to gather time information and related diverse environmental information. We conducted OMA quantification for a case study.

2. OMA QUANTIFICATION

2.1. OMA Selection

As mentioned above, MSOs were selected for the reference NPP. Based on the fire protection report, safe shutdown analysis and safe shutdown equipment list, fire barrier design base drawings, and fire protection design drawings for the reference NPP, we choose OMAs for the selected MSOs with fire experts. The examples of OMAs for fire HRAs are like these:

- RCP(Reactor Coolant Pump) trip locally
  - In case of the RCP seal LOCA(Loss of Coolant Accident) due to a fire, operators should stop RCPs at the switchgear room when an operator cannot stop the RCPs in the MCR
- CSPs(Containment Spray Pumps) stop locally
  - In case of the RWT(Refueling Water Tank) depletion due to a spurious CSP operation during a fire, operators should stop CSPs at the switchgear room when MCR operators cannot stop the pump in the MCR
- ESW(Essential Service Water) discharge valve manually open locally
  - In case of the complete loss of ESW due to the valve's spurious close with LOOP(Loss of Offsite Power) by a fire in any area of the reference NPP, operators should open the ESW discharge valve at the CCW(Component Cooling Water) heat exchanger room when it cannot be opened in the MCR

Among the examples listed above, the last item can be considered a significant OMA, especially when overlapping with MCRA situations since the ESW discharge valves do not have controls at the RSP(Remote Shutdown Panel) in the reference NPP.

2.2. Fire PSA Model Modification

The existing fire PSA model for the reference NPP is investigated to check whether the selected OMAs are modeled. Then we modified the existing fire PSA model to reflect the OMAs we selected. Figure 1 shows an example of the fire PSA model modification.

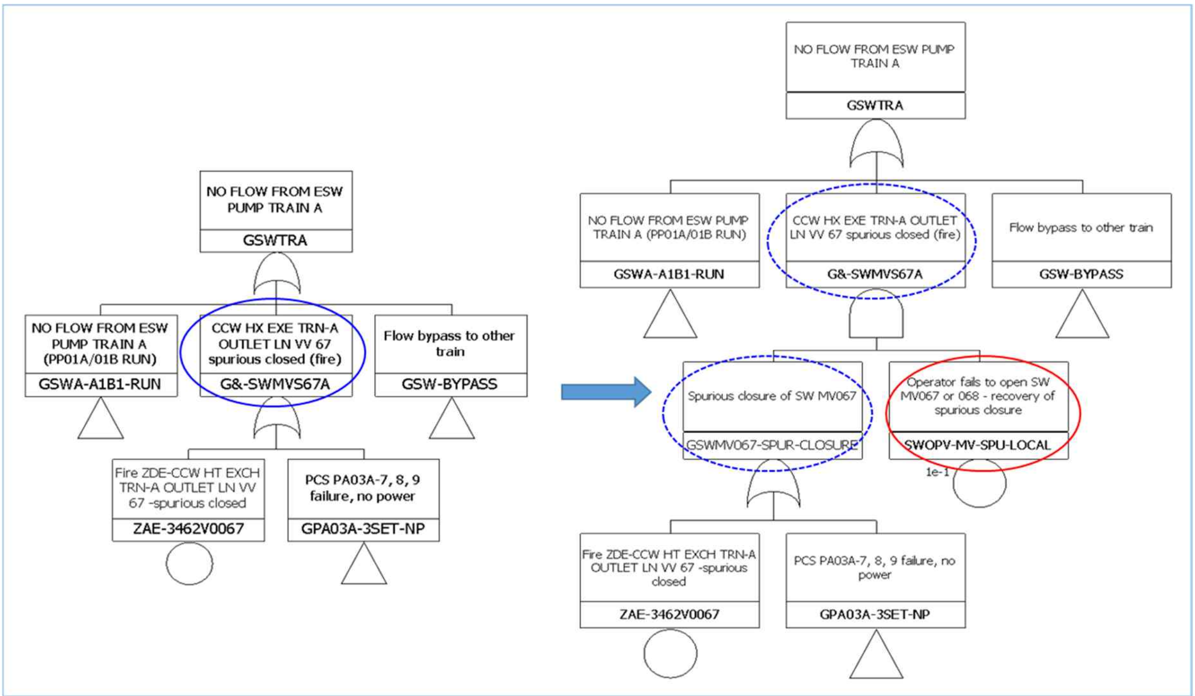

Figure 1. Fault Tree Modification for OMA Related to ESW Discharge Valve

In Figure 1, the existing fault tree only modeled the valve spurious closure, 'G&-SWMVS67A'. To reflect the related OMS, we added an operator action failure event, 'SWOPV-MV-SPU-LOCAL'. That is, the 'SWOPV-

MV-SPU-LOCAL' is for an operator's recovery failure to open the ESW discharge valve(SW-MV-067 or 068).

2.3. Case Study for Detailed Analysis

Table 1 shows the example of the input values for the case study related to an OMA quantification. The case study is related to the operator's CSPs stop at the local area.

Table 1. Example of Input Values for OMA Quantification

Input	**① In Case of Fire outside the MCR**	**② In Case of Fire inside the MCR**	**Basis**
Total time window for successful task completion	60 min.	60 min.	Thermo-hydraulic analysis
Time of cue	15 min.	15 min.	Operator's opinion (engineering analysis)
Time of cue recognition by operators	18 min.	20 min.	Existing K-HRA: time of cue + 1 min. ① Fire except for MCR: the line above + 2 min. (due to partial damage to the instruments) ② Fire in MCR: the line above + 2 min. (due to confusion in the concentration of operators)
Time allowed for task completion	42 min.	40 min.	① 60-18 ② 60-20
Time required for implementing required actions	20 min.	20 min.	Operator's opinion (CSP breaker open in the switchgear room)
Time for wearing SCBA(Self-Contained Breathing Apparatus)		5 min.	SCBA wearing time is considered only in case of fire inside MCR (operator's opinion)
Time available for diagnosis	22 min.	15 min.	① 42-20 ② 40-20-5
Primary task or not	Yes	Yes	Operator's opinion (operators can recognize the need to perform a task directly through procedures or relevant alarms/indicators)
Level of alarm/HMI(Human Machine Interface) for diagnosis	Medium	Medium	It was adjusted from 'High' (existing level) to 'Medium' to account for partial damage of instruments for both kinds of cases
Level of procedure for diagnosis for diagnosis or execution	High	Medium	② It was adjusted from 'High' (existing level) to 'Medium' for the situation where both the fire procedure and the emergency procedure were used.
Level of training/education for diagnosis	Medium	Low	② It was adjusted from 'Medium' (existing level) to 'Low' due to the low frequency of training in combination with fire and emergency scenario
Degree of decision-making burden	Low	Low	No decision-making burden for the task (operator's opinion)
Complexity of a unitary action	If-then	If-then	Proceduralized actions with if-then rule
Task type of a unitary action	Step-by-step	Step-by-step	Time duration from the time of cue to the time by which a required task should be completed
Time Urgency	T≥60	T≥60	Total time window for successful task completion
Scenario severity	Yes	Yes	Failure of a safety system
Environmental hazard	Local	Dangerous environment	The environment by the fire inside MCR is dangerous (operator's opinion)
Level of training/education for execution	Medium	Medium	Same place and method for ① & ②
Stress level	Very high	Extremely high	K-HRA method
Level of alarm/HMI for recovery	Medium	Medium	Same as for the 'Level of alarm/HMI ty for diagnosis'
Level of supervision for recovery	Yes	Yes	Operator's opinion

To collect input data, we first differentiated the fire location into inside the MCR and outside the MCR. As shown in Table 1 above, we gathered various information such as time and environment for the quantification through a thermo-hydraulic analysis, existing K-HRA rules, and operator interviews for a detailed analysis. The information becomes input values of the fire HRA method we developed. In the case of the MCR fire, we considered delayed cue recognition time due to confusion in the concentration of operators as well as due to partial damage to the instruments, additional time for wearing SCBA, and the lower level of procedure and training/education, more dangerous environment, and extremely high-stress level.

Based on the data from Table 1, we quantified an OMA with a fire HRA method for the case study. We calculated two kinds of HEPs for an OMA related to the CSP stop at the switchgear room by a fire outside the MCR and a fire inside the MCR. We first calculated a DEP(Diagnosis Error Probability) by multiplying the basic DEP and weighting factor for DEP. Next, we calculated the EEP(Execution Error Probability) by multiplying the basic EEP and weighting factor for recovery failure probability. Subsequently, we combined the DEP and EEP to calculate the final HEP.

Table 2. Example of Quantification for CSP Stop at the Local Area

Probability	**① In case of fire outside MCR**	**② In case of fire inside MCR**	**Basis**
Basic DEP(Diagnosis Error Probability)	6.40E-02	3.78E-02	Fire HRA method with time available for diagnosis (① considered STA(Shift Technical Advisor)'s absence)
Weighting factor for DEP	0.330	5.000	Fire HRA method with the level of HMI, procedure, and training/education for diagnosis
DEP	2.11E-02	1.89E-1	Basic Dep x Weighting factor
Basic EEP(Execution Error Probability)	2.00E-02	5.00E-02	Fire HRA method with task type and stress level
Weighting factor for recovery failure probability	0.2	0.2	Fire HRA method with time urgency, level of HMI, and level of supervision
EEP	4.00E-03	1.00E-02.	Basic EEP x Recovery failure probability
Final HEP(Human Error Probability)	2.51E-02	1.99E-01	DEP + EEP

From Table 2, we found that HEP in the case of fire inside MCR is approximately eight times higher than that of fire outside MCR. The primary contributing factor is a significant difference in stress level, procedure level, and training level between both cases.

3. CONCLUSION

The purpose of this paper is to describe the quantification of OMAs for a fire PSA with a fire HRA method we developed. We selected some OMAs as measures to address MSOs for the reference NPP by fire experts and HRA experts. Then we modified the fire PSA model to reflect the OMAs. To quantify those OMAs, we performed interviews with NPP operators to gather time information and related diverse environmental information. Based on the information, we conducted OMA quantification for a case study.

We quantified HEPs for CSP stop at the local area due to a spurious CSP operation in the case of a fire outside the MCR and the case of a fire inside the MCR. In the case of a fire inside the MCR, we considered additional considerations:

- Additional cue recognition time due to confusion in the concentration of operators
- Time for wearing SCBA
- Lower level of procedure quality than that of the fire outside the MCR for the situation where both the fire procedure and the emergency procedure were used
- Lower level of training/education than that of the fire outside the MCR for the low frequency of training in combination with fire and emergency scenario
- More dangerous environment than the fire outside the MCR

Due to the additional factors listed above, the HEP of a fire inside the MCR resulted in an eight times greater outcome than that of a fire outside the MCR.

NUREG-1852 requires demonstrating the feasibility and reliability of OMA (Operational Management and Analysis). However, it is challenging to prove the existence of extra time during OMA execution, especially when considering uncertain variables such as unexpected additional indicators, equipment malfunctions, and environmental effects that are difficult to simulate. Additionally, physical size and strength differences, as well as cognitive differences, may also impact the execution and need to be accounted for. In such situations, the quantification result of OMA can be interpreted as another means to demonstrate the reliability of OMA. That is, in deterministic methods, reliability regarding OMA is expressed as either acceptable or not, on the other hand, a HEP represents OMA reliability in terms of probability.

We plan to apply the same method to quantify all other selected OMAs following this case study. In particular, for the last OMA item described in section 2.1, the ESW discharge valve manually opens locally, we will pay closer attention and consider various situations, especially in consideration of the MCRA scenario. For example, in the event of a spurious closure of the ESW valve during the MCRA situation due to a fire in the MCR, it is essential to carefully consider the timeline of both MCRA and OMA.

Acknowledgments

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