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Considerations Related to Quantification of Operator Manual Action Based on Fire Human Reliability Analysis

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1. Introduction

The primary objective of fire protection programs at U.S. nuclear power plants (NPPs) is to minimize the effects of fires and explosions on structures, systems, and components (SSCs) important to safety. Due to the fire accident at the Browns Ferry in the United States, deterministic fire protection regulatory requirements have been continuously strengthened. Regulatory Guide for Fire Protection (RG.1.189, Rev.2) [1] includes requirements for fire safety shutdown analysis considering circuit analysis including multiple spurious operation (MSO) and approves the use of guidance for post fire safety shutdown circuit analysis (NEI 00-01, Rev.2) [2] to provide a deterministic methodology for performing post-fire safe shutdown analysis. Therefore, NPPs based on deterministic fire protection requirements should perform post fire safe shutdown analysis considering single and multiple spurious operations.

NEI 00-01 classifies components that affect plant safe shutdown in the event of MSOs due to fire as 'required for hot shutdown components' and 'important to safe shutdown components'. For the required for hot shutdown components, a resolution methodology shall be prepared with design changes such as re-design/re-analysis, cable protection, and cable re-route. For the important to safe shutdown components, additional solutions such as operator manual action (OMA), focalized fire- probabilistic safety assessment (PSA), and fire modeling can be used, including design changes applicable to hot shutdown essential components

Paragraph III.G.1 of Appendix R, 10 CFR Part 50 [3], "Domestic Licensing of Production and Utilization Facilities," states that one train of equipment needed to maintain hot shutdown conditions shall be free of fire damage and systems necessary to achieve and maintain cold shutdown from either the control room or emergency control station(s) can be repaired within 72 hours. Paragraph III.G.2 specifies the following three methods, any of which are acceptable, to provide reasonable assurance that at least one means of achieving and maintaining hot shutdown conditions will remain available during and after any postulated fire in the plant, when redundant trains of equipment required for hot shutdown are in the same fire area outside of the primary containment:

- a 3-hour fire barrier
- a horizontal distance of more than 6.1 meters (20 feet) with no intervening combustibles in conjunction with fire detectors and an automatic fire suppression system
- a 1-hour fire barrier combined with fire detectors and an automatic fire suppression system

In the early 1990s, to satisfy the criteria of Paragraph III.G.2, some NPPs compensated for III.G.2 by relying on OMAs, which were not reviewed and approved by the NRC. That is, operators either take preventive, local manual actions upon detecting a fire to protect critical safety equipment that might be failed or spuriously affected and rendered unavailable by the fire, or they locally and manually align critical safety equipment to perform its function when needed to maintain hot shutdown capability. The NRC recognized that these measures may be an acceptable way to achieve hot shutdown in the event of a fire under certain conditions.

In 2003, the NRC proposed rulemaking in SECY 03-0100 [4], "Rulemaking Plan on Post-Fire Operator Manual Actions," which states that, in certain circumstances, OMAs may be a reasonable alternative to the separation requirements of Paragraph III.G.2.

Meanwhile, in NUREG/CR-6850 [5], which describes the whole fire PSA process, Step 2.5 (Specific Review of Manual Actions) of Step 2 (Review the Internal Events PSA Model Against the Fire Safe Shutdown Analysis) and Step 3 (Identify Equipment with Potential Spurious Actuations that may Challenge the Safe Shutdown Capability), etc., are required to model the MSO scenario and OMA to preclude or mitigate the effects of the spurious operation. Therefore, KAERI had been conducted fire PSA including MSO scenarios and OMAs [6]. For the human error probability (HEP) of OMA, an assumed value reflecting expert opinion was applied.

The purpose of this paper is to describe the factors that should be considered for OMA quantification based on the fire human reliability analysis (HRA) methodology developed by KAERI [7-8] to reflect the HEP about OMA in the fire PSA model. When estimating the HEP of OMA, it is necessary to seek ways to evaluate the level of PSF and the time parameters for timeline analysis. To this end, we firstly investigated feasibility and reliability criteria by NUREG-1852 [9] which provides additional technical information related to the factors as a means to address the acceptability of post-fire manual actions using a deterministic approach. This technical information is aimed at ensuring that OMAs are both feasible and reliable. And then we compared the factors by NUREG-1852 and those by fire HRA method such as time parameters for timeline analysis and performance shaping factors (PSFs) for cognitive error, execution error, and command and control (C&C) sequencing error.

2. Fire HRA Method Developed by KAERI

We developed a guideline for performing a fire HRA 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 developed by KAERI. Additionally, for the MCRA phase, C&C sequencing failures were considered and their HEP estimation method was based on the NUREG-1921. The development policy of the guideline was established to reflect the recent study of the NUREG-1921 series [10-12] to meet the requirements of the ASME/ANS PRA Standard.

For a detailed quantification of HEPs, PSFs and time parameters for the timeline analysis of K-HRA were modified to consider a fire situation mentioned in NUREG-1921.

HRA issues considering fire effects are as follows:

- 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 main control room abandonment (MCRA)
  - Remote shutdown panel (RSP) design
  - Communication
  - Command and coordination

To reflect the above-mentioned effects of fire, the PSF considered in the existing K-HRA was modified as shown in Figure 1.

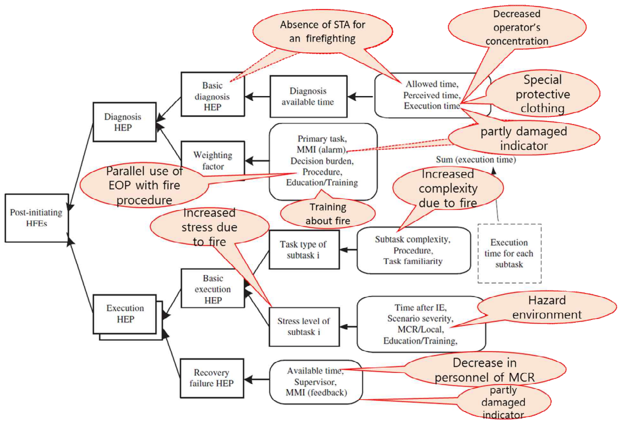

Fig. 1. Modification of K-HRA PSFs

3. Feasibility and Reliability Criteria of OMA by NUREG-1852 and Corresponding Factor by Fire HRA

The NRC developed NUREG-1852 as a reference guide for agency staff who evaluate the acceptability of manual actions, submitted by licensees as exemption requests from the requirements of Paragraph III.G.2 of Appendix R to 10 CFR Part 50 as a means of achieving and maintaining hot shutdown conditions during and after fire events. According to the definition of NUREG-1852, OMAs are those actions performed by operators to manipulate components and equipment from outside the MCR to achieve and maintain postfire hot shutdown, but do not include "repairs."

NUREG-1852 describes the feasibility and reliability criteria and their technical information for OMA

- Adequate time available to perform the actions to address feasibility

There should be adequate time for the operator to diagnose the need for action, to move to the location of the action, to perform the action, and to see the expected response before the undesirable result occurs.

- Adequate time available to ensure reliability

The analysis should ensure that there is additional uncertainty in the estimate of the time required to implement the manual action.

- Environmental factors

It must be demonstrated that the environmental conditions encountered by operators while traveling to and from action-related areas, accessing the area, and performing OMAs are consistent with human factor considerations established.

- Equipment functionality and accessibility

Equipment required to implement OMAs to achieve and maintain postfire hot shutdown should be accessible, available, and not damaged or adversely affected by the fire and its effects

- Available indications

Diagnostic indication instrumentation should be included in the identified equipment to the extent necessary to (1) enable the operators to determine the appropriate manual actions for a fire scenario, (2) inform personnel how to properly perform manual actions, and (3) if the direct observation is not possible, provide feedback to the operator to ensure that the manual action has produced the expected result.

- Communications

Appropriate communication capabilities should be described for OMAs that need to be coordinated with other plant operations and personnel.

- Portable equipment

Portable equipment, especially unique or special tools, may be essential to access and operate the SSC when performing OMAs

- Personnel protection equipment

Personal safety equipment such as protective clothing, gloves, and self-contained breathing apparatus (SCBA) must also be operational and accessible to the extent necessary to successfully implement operator manual tasks

- Procedures and training

To ensure the success of OMAs, procedural instructions for the actions should be readily available, easily accessible, and included in maintained and controlled procedures. Operators who may have to take action to reach hot shutdown should be properly trained on those procedures.

- Staffing

The persons involved in performing OMAs should be sufficiently numerous and qualified to collectively perform the desired action

- Demonstration

Each action needs to be demonstrated to show that the feasibility and reliability criteria have been and continue to be met.

As such, NUREG-1852 presented feasibility and reliability criteria for 11 factors. The purpose of this paper is to review the factors of NUREG-1852 except for demonstration and factors for diagnostic error, execution error, and C&C sequencing error required for quantification based on the fire HRA mentioned in Chapter 2. Table 1 shows the results of the comparison. From Table 1, it can be seen that most of the factors for feasibility and reliability of OMA by NUREG-1852 are covered in the fire HRA method by KAERI.

4. Conclusions

The purpose of this paper is to describe the factors that should be considered for OMA quantification based on the fire HRA methodology developed by KAERI to reflect the HEP about OMA in the fire PSA model. We investigated feasibility and reliability criteria by NUREG-1852 which provides additional technical information related to the factors as a means to address the acceptability of post-fire manual actions using a deterministic approach. And we compared the factors by NUREG-1852 and those by fire HRA method such as time parameters for timeline analysis and performance shaping factors (PSFs) for cognitive error, execution error, and command and control (C&C) sequencing error.

Based on the comparison, all factors considered by the deterministic approach for OMA are covered by the existing fire HRA method (Table 1). By the NUREG-1852, to select the criteria, they investigated reviews of fire-related operational events to identify important factors influencing human performance in fires and lessons learned from the development of HRA criteria for use in the ongoing fire quantification studies jointly conducted by the NRC and the Electric Power Research Institute (EPRI). Therefore, it seems that HEP quantification of OMA based on the existing fire HRA is possible.

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Table 1. Comparison of Factors between NUREG-1852 and Fire HRA method by KAERI

Factors by NUREG-1852	Factors of Fire HRA Method by KAERI			Considerations
	Factors for Diagnostic Error	Factors for Execution Error	Factors for C&C Sequencing Error	
1) Adequate Time Available to Perform the Actions for feasibility & 2) Adequate Time Available to Ensure Reliability	• Total time window for successful task completion • Time of cue recognition by the operators • Time allowed for task completion • Time required for implementing required actions	• Time urgency for stress level and recovery		• Effect of STA (Shift Technical Advisor)'s absence in MCR due to a fire brigade interaction • Fire effects on the operator's path to the local site
3) Environmental Factors		• Environmental hazard for stress level		• Radiation, lighting, temperature, humidity (caused, for instance, by water from sprinkler operation), smoke, toxic gases, and noise
4) Equipment Functionality and Accessibility		• Scenario severity for stress level		
5) Available Indications	• Level of MMI (Man-Machine Interface)	• Level of MMI for recovery		• Fully/Partly Damaged indicator/alarm
6) Communications		• Complexity of a unitary action for task type • Level of supervision for recovery	• Supervisor's responsibility for all communications to/from the field operators	• Sequential operator manual actions • Verification that procedural steps have been accomplished, especially those that must be conducted at remote locations • Time to delay performing action due to communication problem
7) Portable Equipment		• Environmental hazard for stress level		
8) Personnel Protection Equipment		• Environmental hazard for stress level		• Time to wear a protective clothing
9) Procedures and training	• Level of procedure • Level of training	• Quality of procedure for task type • Familiarity with task type • Training & education for stress level	• Training to shut down improperly functioning equipment • Compensatory measures	• Parallel use of EOP with fire procedure
10) Staffing			• Sufficient staffing	