Considering the availability of required staffs in terms of the human reliability analysis of multi-unit accidents

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1. Introduction

The role of human reliability analysis (HRA) from the perspective of probabilistic safety assessment (PSA) or probabilistic risk assessment (PRA) is to provide the likelihood of human errors that could occur in the performance of safety-critical tasks. In this regard, many researchers have proposed diverse HRA methods over several decades that can support the PSA of a single unit (i.e., single-unit HRA). However, due to many technical issues raised from the Fukushima Daiichi accident in 2011, it is emphasized the multi-unit PSA that considers "the dependencies across reactor units co-located at the same site" [1]. This directly implies that an HRA method supporting the multi-unit PSA (i.e., multi-unit HRA) is required.

2. Context of single/multi-unit HRAs

It is reasonable to expect that the context of the single-unit HRA would be largely different from that of the multi-unit HRA. For example, Table I shows a part of important factors that should be properly considered in estimating the likelihood of human errors in the context of the multi-unit HRA.

Table I: Important factors in estimating the likelihood of human errors under the context of the multi-unit HRA

Important factor	Ref.
• Staffing and equipment for dealing with multiple site hazards	[2]
• Responsibility shared among MCR (main control room) and other organizations (e.g., emergency response organizations) • Decision to deploy shared systems and mobile equipment • Harsh environment (e.g., radiation from a damaged adjacent unit)	[3]
• Shared staff with their availability • Treatment of different or multiple decision makers • Inter- and intra-dependency among multi-units	[4]

From Table I, it seems that the availability of required staff is one of the key aspects in terms of conducting the multi-unit HRA. In other words, since all kinds of crucial decisions should be drawn in accordance with various kinds of interactions among many organizations including MCR (main control room)

and emergency organizations. In addition, in terms of installing mobile equipment, the availability of required staff is critical because the deployment of diverse mobile equipment should be accomplished with the limited number of workers.

This strongly alludes to the fact that the availability of required staffs who are responsible for both decision-makings and the deployment is the prerequisite for conducting the multi-unit HRA. In other words, if the number of workers who are responsible for the accomplishment of a safety-critical task (e.g., the installation of a specific mobile equipment) is insufficient, it is reasonable to say that the failure probability of the given safety-critical task is 1. Similarly, even though sufficient number of workers is available, the failure probability of the given safety-critical task should be 1 when an organization that plays as a control tower for coping with a multi-unit accident do not its function due to the absence of decision-makers.

3. Emergency response organizations

According to The Act on Physical Protection And Radiological Emergency, all Korean domestic nuclear power plants have to establish dedicated emergency response organizations with specific roles and responsibilities (R&Rs) that are needed for coping with diverse multi-unit accidents [5]. Figure 1 depicts the hierarchy of the emergency response organizations.
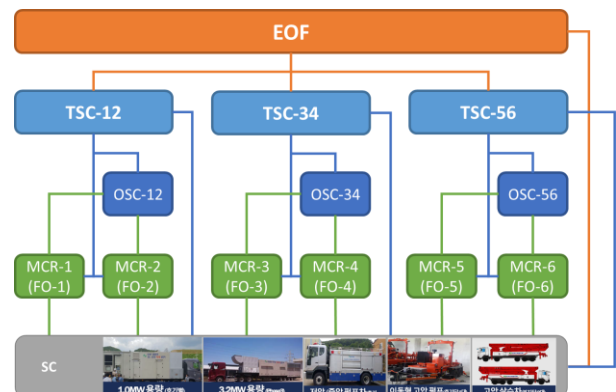

Figure 1. Representative emergency response organizations; adopted from [5]

As can be seen from Fig. 1, EOF (emergency operations facility) takes the governance of emergency responses when a multi-unit accident occurs. This means that the timing when the EOF begins its R&Rs is crucial in dealing with the progression of the multi-unit accident. Similarly, the establishment timing of TSC (technical support center) is also important because detailed recommendations that are needed for mitigating the consequence of the multi-unit accident are provided based on the decision-making of TSC members.

When a specific countermeasure is identified by the TSC, actual implements should be carried out based on the cooperation of staffs belonging to both OSC (operational support center) and SC (safety center). For example, in the case of installing a mobile equipment (e.g., mobile pumps), local operators who belong to individual MCR (e.g., FO-1 or FO-2) have a responsibility for its operation when SC and OSC staffs who are responsible for its delivery and installation. Here, similar to the EOF and TSC, it should be noted that OSC are non-permanent organizations that are constructed only when radiological emergencies are declared. This strongly indicates that the establishment timing of OSC is critical for determining the success/failure of a mobile equipment installation.

4. Difficulty in predicting the establishment timing of emergency response organizations

As briefly explained in the previous section, the establishment timing of the emergency response organizations strongly affects to the availability of required staffs. Since the likelihood of human errors can be directly influenced by the availability of required staffs, it is indispensable to soundly predict the change of available staffs. Unfortunately, this prediction seems to be troublesome because a multi-unit accident is usually caused by extreme events such as a strong earthquake or super typhoon. In other words, if the required staffs do not stay on site, it is necessary to consider their convocation time to the site.

The problem is that this convocation time should vary with respect to the nature of an external event. For example, when a powerful earthquake occurs, required staffs who are living in off-site towns or cities could be injured. In addition, even though the required staffs are not injured, they could not arrive at the site if existing roads are severely damaged due to the earthquake. Indeed, Jang et al. suggested several key factors that affect the convocation time of the required staffs based on Japanese case study [6]. This implies that the determination of the convocation time should be resolved by a simulation approach. For this reason, several researchers suggested that Monte-Carlo Agent-Based Model (MCABM) could be a relevant way to address this issue [7, 8]. Figure 2 exemplifies the results of MCABM simulations.
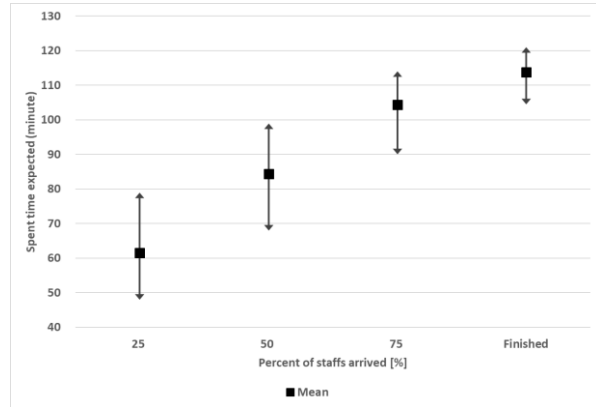

Figure 2. Typical distribution of convocation times based on the combination of diverse influence factors

5. Future work

It is evident that the availability of required staffs who belong to the emergency response organizations is crucial for conducting the multi-unit HRA of Korean domestic nuclear power plants. This implies that the convocation time of the required staffs should be soundly predicted with respect to an external event resulting in a multi-unit accident. In this regard, since the distribution of convocation times strongly depend on diverse factors that are influenced by the nature of a given external event (e.g., the magnitude of an earthquake affecting the damage level of roads), a simulation-based approach would be a relevant solution to address this issue.

From this concern, an MCABM is available for predicting the distribution of convocation times pertaining to the required staffs of EOF and TSC. Accordingly, it is necessary to develop an MCABM that deals with the convocation times of required staffs who belong to OSC. Once the convocation times of all emergency response organizations are soundly determined, it can be used as an important information for the multi-unit HRA.

Acknowledgement

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The paper describes the importance of considering the convocation times of TSC and OSC staffs in multi-unit HRA, and proposes an evaluation method(MCABM) for the convocation times. In order to enhance the paper's overall quality, the reviewer suggests adding one more aspect.

- The reviewer suggests explaining the insights that can be derived from Figure 2 in the paper.