An Approach to Human Reliability Analysis of SAMG Actions based on a Time Uncertainty Analysis

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1. Introduction

The purpose of this research is to propose a new time analysis method for reflecting SAM tasks using FLEX/MACST equipment for Level 2 HRA.

A need of time-related model has been identified [1], since human reliability analysis (HRA) researchers have revealed that human errors increase in time-constrained condition. However, current time-related approaches in HRA have some limitations due to the limited application only for Level 1 HRA. Thus, this paper reviewed existing methods and suggested the time analysis method for SAMG HRA.

2. Previous studies

The Electric Power Research Institute (EPRI) [2] adopted an approach that is the crew non-success probability for control room actions is broken into two parts: cognitive response of crews and the required response execution. As a part of cognitive response, the EPRI suggested the equation (1) for calculating the probability of crew non-response (P_2) in a time T. This equation (1) was developed based on the knowledge from human cognitive reliability (HCR) model and operator reliability experiments (OREs) projects.

$$P_2 = Prob(T_r > T) = 1 - \Phi\left[\frac{\ln(\frac{T}{T_{\frac{1}{2}}})}{\sigma}\right] \quad (1)$$

Where Φ is standard normal cumulative distribution, σ is the logarithmic standard deviation of normalized time and T_r is the time of response. However, the EPRI method is not easy to apply into the SAMG HRA because SAMG situation has large phenomenological uncertainties and time window of SAMG is very longer than the time criteria of the EPRI.

Kim and Ha [3] proposed a new approach to HRA evaluation of an accident management strategy. This method is pioneer research for SAMG HRA, but there are three limitations as follows. First, they only considered the implementation of a given SAM strategy, but the success probability of given strategy will be quite different depended on the time of pre-strategy implementation in real situation. In addition, the use of Weibull distribution should be re-considered since the ORE project revealed the lognormal distribution is more suitable than Weibull distribution for the representative of operator action in a timely manner.

The integrated human event analysis system (IDHEAS) method [4-5] suggested the approach for quantifying the error probability attributed to time uncertainty (Pt). Tn represents the time needed to perform the human action in a human failure event and Ta is time available for personnel to complete the action. The basic notion for calculating Pt is that personnel fail the human failure event if Tn is greater than Ta. Pt is the convolution of the probability density functions of Ta and Tn.

However, for the case studies of IDHEAS, Ta was assumed as point values even though their approach explained that Ta is the form of distribution. Despite the publication of the latest report in Feb 2020, the IDHEAS model did not suggest the quantification method only for lognormal distribution. Excepting for these limits, this model is deficient for SAMG HRA due to lacks of Level 2 data and quantitative approach.

3. A new time analysis method

To overcome these limitation of existing time analysis techniques, this study proposed the time-related analysis model which can be estimated by two time distribution: time required ($T_{required}$) and time available ($T_{available}$).

The time required ($T_{required}$) represents the time taken for the actions in the accident progress to be mitigated. This includes conducting each SAG (executing the action related SAG, diagnosis and judgment whether or not to implement a SAG, and verifying effectiveness of the strategy), and deploying and installation of portable equipment based on the SAMG entry point.

Similarly, because of various uncertainties associated with systems or structures (i.e., reactor vessel (RV), containment integrity), the time available ($T_{available}$) for the implementation of given strategies should also be described with a probability distribution function. For example, the RV failure probability may be different depending on the time to transport portable equipment or point of coolant injection and strategies taken. The time available represents the time available to conduct strategies during maintaining the intact systems or structures.

Our method proposed to calculate the human failure probability (HFP) due to a delayed SAM action (P_{Fr}) that occurs when the time required exceeds the time available. The P_{Fr} represents the probability that TSC fails the SAM strategies implementation for mitigating irreversible plant states (RV failure or containment failure). The P_{Fr} is the convolution of the probability density functions of $T_{available}$ and $T_{required}$. The P_{Fr} of given strategies can be obtained by the following equation (2):

$$P_{Fr} = Probability\left(T_{required} > T_{available}\right) = \int_0^{\infty} f_{T_{available}}(t) \cdot \left[1 - F_{T_{required}}(t)\right] dt = \int_0^{\infty} f_{T_{required}}(t) \cdot F_{T_{available}}(t)\, dt \quad (2)$$

Where $F_{T_{required}}(t)$ = cumulative distribution function of $T_{required}$, $f_{T_{required}}(t)$ = probability density function of $T_{required}$, $F_{T_{available}}(t)$ = cumulative distribution function of $T_{available}$, and $f_{T_{available}}(t)$ = probability density function of $T_{available}$.
Depending on the accident sequential situation, several scenarios timelines can be developed in one initiating events. The timeline can be changed even in the same accident depending on the external environment factors. Thus, this paper focused on the initial event of design-basis event (DBE) takes into account the case of entering SAMG. It also assumed that only portable pump is available for steam generator (SG) or reactor coolant system (RCS) injection for mitigation of the accident. The patterns of strategies implementation in responding to the accidents can be categorized to 4 cases as shown in Figure 1.

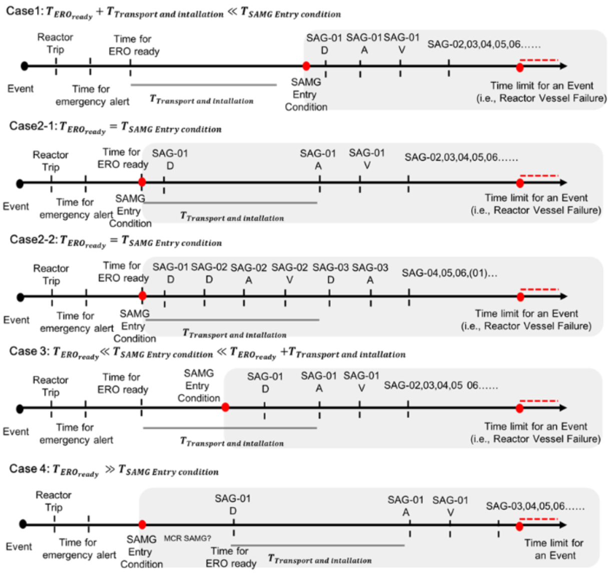

Fig.1 Timelines for representing the cases of SAGs implementation (The gray box is our focusing area)

At the entry point of SAMG, the TSC usually received information from the MCR to make a decision on which strategy should be selected and on how and when the strategy should be implemented. Then they take an action in a timely way before the plant reaches irreversible states (RV failure and containment failure). The case 1 represents transport and installation of portable equipment at the time prior to SAMG entry, so the equipment is in standby mode at SAMG entry point. In this case, the decision on SAGs using portable equipment and implementation of SAGs can be made at a right time on the guidance. The case 2-1 represents that time of ERO ready is similar to time of SAMG entry condition, then decision on SAGs using portable equipment will be delayed until installation of portable equipment is completed. The time to SAG-2 is too late, assuming that it is performed sequentially from SAG-1. In this case, SAG-2, RCS depressurization using SDS, may be implemented first. The case 2-2 represents SAG-2 starts after only SAG-1 situational judgment and decision time was completed since the SAG-1 takes time to complete. The case 3 represents that the transport of mobile equipment was carried out at the time before SAMG entry, but when SAMG entry was fast and the timing of deployment is still in motion. If the equipment is in transport, implementation of SAG-1 is expected to be nearly similar to case 2-1. If in deployment, the TSC will confuse whether SAG-2 may be implemented first or wait until the equipment is fully deployed. In this case, if performed from SAG-2, it would be similar to Case 2-2 and therefore perform a preliminary analysis of the case waiting for full deployment (Case 3). The Case 4 is for extreme or high-damage external events, ERO and installation of portable equipment will be late before entering SAMG. SAMG condition is reached before ERO is configured, and in this case, MCR SAMG (e.g., SACRG) might be performed. However, current SACRG does not include actions using portable equipment, but there exists RCS depressurization strategies, such as the opening of SDS, are included.

4. Conclusion

This paper introduced a new time analysis method to calculate the probability (P_{Fr}) that occurs when the time required exceeds the time available. The approach can classified into assessing time required distribution and time available distribution. The elements for identifying time required distribution are: 1) technical support center (TSC) diagnosis and decision time for each strategy, 2) emergency response organization (ERO)'s SAM strategies implementation time, 3) time to verify the effectiveness of the strategy, and 4) portable equipment transport and installation time. Time available function can be obtained by thermo-hydraulic code simulation (MAAP 5.03).
Our model can be applied into the level2 HRA as well SAMG HRA since the shortcoming of existing method overcomes with covering the longer time window.
However, the method should be discussed both uncertainty analysis, cognitive dependency and applicability through case studies.

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