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A Framework of Human Reliability Analysis for Incorporating SAMG Strategies and Actions into Level 2 PSA

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1. Introduction

Level 2 PSA (L2PSA) has become more important than before since the newly established nuclear safety legislation in 2015 defines the safety goal in terms of 'risk' as follows:

- *The prompt fatality or cancer fatality risks of the population near a nuclear power plant (NPP) from the accident should not exceed 0.1% of the sum of risks resulting from all other causes, and*
- *The sum of frequencies for the accident scenarios in which the amount of Cs-137 release exceeds 100 TBq should be less than 1.0E-06/ry.*

One of the major issues in enhancing the L2PSA model is an adequate modeling of severe accident management guidelines (SAMGs) into the L2PSA framework. A key technology for an adequate modeling of SAMGs into L2PSA is the human and organizational factors reliability analysis (HOFRA) of SAMG strategies and actions which are requested under severe accident conditions. Human reliability analysis (HRA) has been conducted in the PSA to identify human failure events (HFEs) to be incorporated into the PSA model and assess the likelihood of those HFEs in a probabilistic way.

On the other hand, as summarized in Fig. 1, most of the HRA methods have been focused on Level 1 accident scenarios and EOP context. A few methods such as HORAAM, MERMOS, and IDHEAS-G deal with Level 2 accident scenarios and SAMG context, but these methods do not consider highly complicated situations associated with decisions and actions when using portable or mobile equipment in SAMGs.

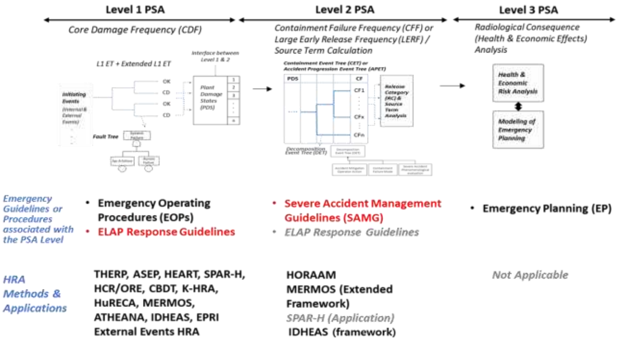

Fig. 1. Status of HRA methods for Level 1&2 PSAs

2. Characteristics of SAMG Actions

The literature on SAMG HRA suggests that an adequate modeling of SAMG actions into L2PSA should take into account the following characteristics specific to severe accident management [1,2]:

- Transfer of some responsibilities from the main control room (MCR) crew to the technical support center (TSC)
- Timing of the entry into SAMG, after the entry conditions are satisfied, and possible delay of emergency response organization (ERO) such as TSC/OSC/EOF to effective readiness
- Transition from preventive & prescriptive nature of emergency response (e.g., EOPs) to mitigative & less-prescriptive nature of SAMGs
- Choice of a SAM strategy/measure depends not only on hardware system availability but also on the decision of the ERO (e.g., TSC) to pursue the SAM measure in a given accident condition.
- Complex decision-making situation may arise, and distributed decision process and coordination of multiple teams (e.g. MCR crew, local operators, fire brigade, etc.) are required.
- Phenomenological uncertainty about plant state.

Also some technical challenges for adequately assessing and modeling human and organizational factors (HOFs) under extreme events and severe accidents are listed up as follows [3]:

- The decision-making model of the TSC while following SAMG and estimation of their decision probability
- The entry time into SAMG and the level of composition of the emergency response staff as the event progresses
- The time required to conduct each of SAGs of the TSC SAMG
- The availability of staff and the time required to deploy and install portable equipment (especially under external events)
- Guideline for decomposing or analyzing the tasks or activities using portable equipment
- The staffing assessment method for long-duration accident scenarios
- The potential for errors of commission during extreme events and severe accidents progression
- Modelling of coordination and collaboration activities between multiple emergency teams/organizations

- Consideration of psychological and physiological stress due to long-term accident management activities and external hazards

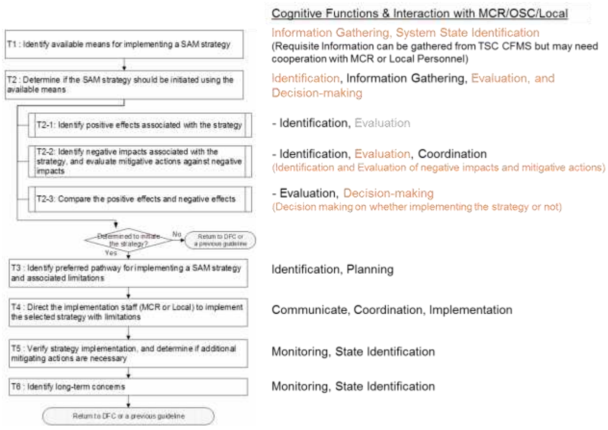

Fig. 2. A task structure of a severe accident guideline (SAG)

3. Framework of Level 2 HRA for SAMG Strategies and Actions

A new Level 2 HRA method was developed on the basis of plant-specific severe accident management guidelines (SAMGs) [4]. The SAMG-based, a new Level 2 HRA method, which is named SAM-L2HRA, consists of two parts of analysis: the first part deals with a time uncertainty analysis to the failure of a SAM strategy, of which probability is estimated from the convolution between two time distributions, i.e., time available and time required, and the second part is composed of task-based analysis of error potential or decision-making likelihood.

The time elements considered in the time uncertainty analysis include the distribution of time available with consideration of phenomenological uncertainty associated with a severe accident event such as a reactor vessel failure, the time elapsed (or required) (and its distribution) for each individual SAM strategy and the total integrated time (and its distribution) from the entry point into SAMG and to the completion point of implementation of a strategy under consideration. Fig. 3 shows the conceptual schematics of the time-based estimation of reliability associated with implementation of SAM strategies. The actual application of the concept was illustrated in Suh et al. [5].

The task-based analysis part deals with error potential or decision-making likelihood associated with critical steps or activities needed for decision-making and successful implementation of a strategy. The steps or activities to be analyzed include the availability or survivability of essential information needed for recognition of a strategy implementation and monitoring the progress and effectiveness of a strategy implementation, the impact of negative effects associated with a strategy on a decision-making of a strategy implementation and its probability of likelihood, and the reliability of the implementation activity in which coordination and cooperation between distributed organizations such as the technical support center (TSC), the main control room (MCR) and the local operating personnel in charge of actual implementation using installed equipment or portable/mobile equipment are of critical importance to the success of an implementation. Fig. 4 shows the conceptual schematics of the task-based estimation of reliability associated with implementation of SAM strategies.

4. Conclusion

An adequate modeling of SAMGs is of critical importance for a realistic assessment of safety in a nuclear power plant. A comprehensive framework is suggested in this paper. This framework of Level 2 HRA (SAM-L2HRA) comprising task-based analysis and time-based analysis enables the analysts to identify major task characteristics and vulnerabilities associated with a SAM strategy impeding high reliability of a strategy implementation, as well as quantify the probability of failure to successfully complete the strategy.

Acknowledgement

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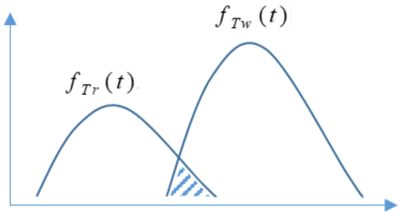

$$P_{Fr} = \Pr(T_r > T_w)$$
$$= \int_0^{\infty} f_{T_w}(t) \cdot [1 - F_{T_r}(t)]\, dt$$
$$= \int_0^{\infty} f_{T_r}(t) \cdot F_{T_w}(t)\, dt$$

$f_{T_r}(t)$=*probability density function of the time required for implementing a SAM strategy*
$f_{T_w}(t)$= *probability density function of the time available for a SAM strategy*
$F_{T_r}(t)$=*cumulative distribution function of the time required for implementing a SAM strategy*
$F_{T_w}(t)$= *cumulative distribution function of the time available for a SAM strategy*

Fig. 3. Convolution of two time distributions to obtain time-based reliability for a SAM strategy

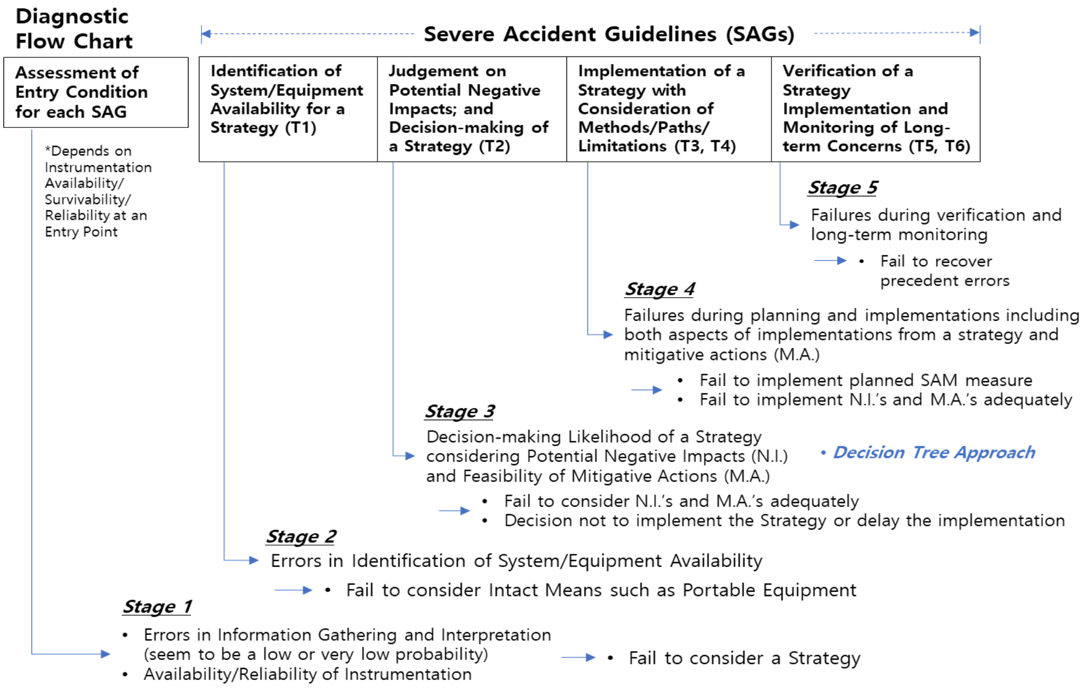

Fig. 4. Task-based analysis of human error potentials and decision-making likelihood of SAM strategies