Prototype Analysis on the Effectiveness of Mobile Equipment by Combining Deterministic and Probabilistic Approaches

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1. Introduction

As a follow-up action to the Fukushima accident the mobile equipment is being deployed at nuclear power plants in Korea. To estimate the effectiveness of mobile equipment in Level 2 PSA, an approach which uses both of deterministic and probabilistic methods are suggested in this paper [1].

The deterministic method adopts SOARCA methodology [2]. MELCOR code [3] is used for the deterministic analysis and SAREX code [4] is used for the probabilistic analysis.

2. Analysis method

Extended loss of AC power (ELAP) was selected as an accident sequence to be analyzed. The reason for the selection is that in the case of a station blackout (SBO), it contributes about 33% of the total core damage frequency in a typical nuclear power plant in Korea.

In the base case, it is assumed that a turbine driven auxiliary feed water (TDAFW) pump works during initial 8 hours after the station blackout occurs.

As shown in Table 1, two typical cases are analyzed here. In the first case the external water is injected to the secondary side by using mobile low pressure pump (MLPP). In the second case, MLPP is used for the injection of external water into the reactor coolant system (RCS).

The flow rate of MLPP is assumed to be 500gpm and the external water can be injected under the 20 kg/cm^2 of system pressure [5].

In case 1, external water can be injected when the steam generator pressure is lowered under the 20 kg/cm^2 by opening MSADV (main steam atmospheric dump valve) which can be open using hand pump at local.

In case 2 analysis, the reactor coolant system pressure should be decreased by opening safety depressurization system (SDS) valve, which needs electric power by mobile diesel generator.

3. Result and discussion

3.1 Deterministic analysis results

The deterministic analysis results for base case are shown in the Fig 2 through Fig 5.

During the TDAFW pump operation the RCS pressure cannot increase. When TDAFW pump stops at 8 hour, however, RCS pressure increase to the pressurizer safety valve set point (Fig 1). By the loss of reactor coolant through the pressurizer safety valve, the core temperature increases to the SAMG entry condition (650^{o}C) at 17.6 hour (Fig 2). The reactor vessel is failed after about 1.6 hours after SAMG entry condition reached (Fig 3). As shown in Fig 4, containment is pressurized by the released steam from the reactor coolant system. The hydrogen combustion and molten corium-concrete interaction (MCCI) occurred, too.

As shown in Fig 5 and Fig 6, analysis result means that the reactor vessel maintain the integrity if external water is injected into the secondary side of the steam generator within 1.5 hours. Reactor vessel failure and containment failure can be prevented by injecting external water to the secondary side of steam generator within 19.1 hour after SBO occurs.

As shown in Fig 7 and Fig 8, analysis result means that the reactor vessel maintain the integrity if external water is injected into the RCS of the steam generator within 1.5 hours. This case is assumed that the steam generator secondary side is unavailable. Therefore, in this case, RCS pressure should be reduced by the opening of SDS valves. To open the SDS valve, external electric power is need. The external electric power is supplied by mobile diesel generator operation. Then, external water can be injected into the RCS.

3.2 Probabilistic analysis results

To apply to the Level 2 PSA model, the heading and branch of external water injection into RCS and secondary side are considered in the plant damage sequence event tree (PDSET).

In addition, this heading is applied to PDS logic diagram (PDSLD) and decomposition event tree (DET) to describe the reactor vessel integrity maintaining for success branch.

There are various containment failure modes in Level 2 PSA models as follows:

- NOCF: No containment failure
- NOTISO: Not isolation
- BYPASS: Containment bypass
- BMT: Base-met melt through
- ECF: Early containment failure
- LCF: Late containment failure
- CFBRB: Containment failure before RV breach

Most of containment failure frequency (CFF) is contributed by NOCF. When apply the mobile equipment to the level 2 PSA, the frequency of containment failure modes except NOCF is decreased while the percentage of NOCF increases.

As shown in Fig 9, the CFF is reduced in both cases due to applied mobile equipment. This is because the reactor vessel failure frequency is lowered by external water injection into reactor coolant system and steam generator. If the reactor vessel integrity is maintained then containment failure due to over-pressurization, MCCI or steam explosion can be prevented.

However, there is a difference between the two results. In case 1, the CFF is calculated by considering the MLPP failure probability additionally. This is because external water is injected into steam generator by MLPP without any other safety features after core damage. However, in case 2, pressure reduction of RCS by SDS should be considered. Therefore, when evaluating the CFF, failure probability of power recovery and MLPP are considered together. For this reason, the CFF of case 1 is lowered than case 2.

3. Conclusions

As a result of the severe accident analysis considering the relevant strategies, the injection of external water into the steam generator or RCS by mobile equipment before reactor vessel failure has a positive effect on preventing reactor vessel failure. Furthermore, when the level 2 PSA model was revised based on a severe accident analysis for each case, it was evaluated that the reactor containment failure frequency, large early release frequency, and Cs-137 release frequency (over 100TBq) could be effectively reduced.

A hybrid approach using both of deterministic and probabilistic methods suggested in this paper can be effectively used in evaluation of effectiveness of MAST strategy.

ACKNOWLEDGEMENT

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Table I: Analysis cases

Case ID		Bleed	Feed	Timing
Base Case		N/A	N/A	N/A
Case 1	Case 1-1	ADV	External water injection into S/G using MLPP	SAMG entry
	Case 1-2			SAMG entry + 0.5HR
	Case 1-3			SAMG entry + 1HR
	Case 1-4			SAMG entry + 1.5HR
Case 2	Case 2-1	SDS	External water injection into RCS using MLPP	SAMG entry
	Case 2-2			SAMG entry + 0.5HR
	Case 2-3			SAMG entry + 1HR
	Case 2-4			SAMG entry + 1.5HR

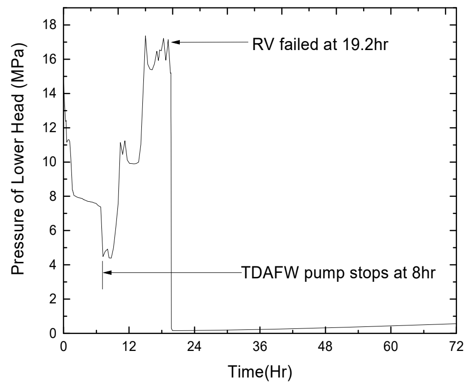

Fig 1. Pressure of Lower Header (Base Case)

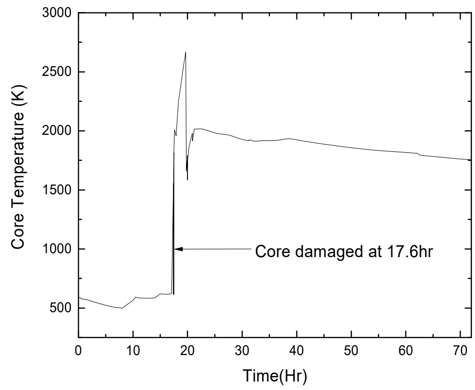

Fig 2. Temperature of Core (Base Case)

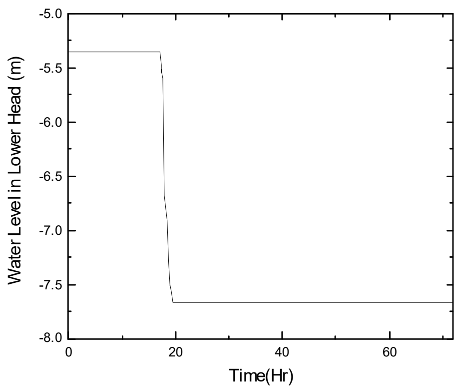

Fig 3. Water Level of Lower Header (Base Case)

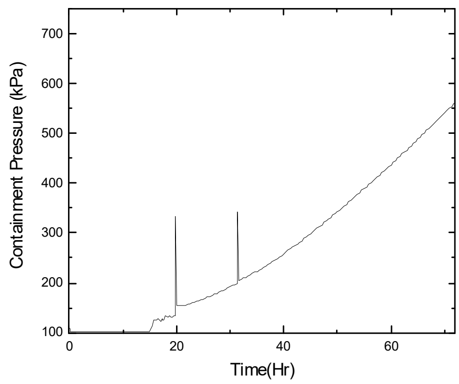

Fig 4. Containment Pressure (Base Case)

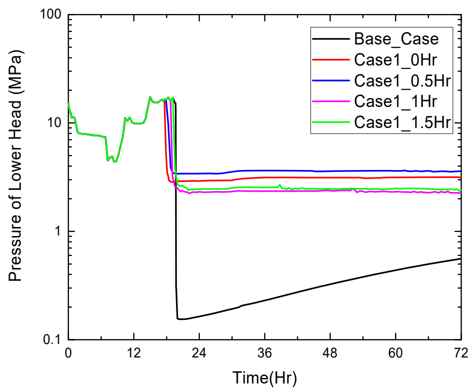

Fig 5. Pressure of Lower Header (Case 1)

(Note that Y-axis is expressed by log-scale)

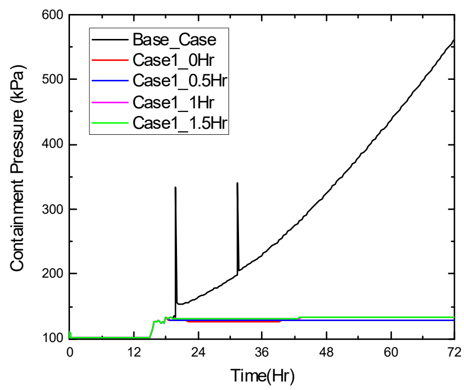

Fig 6. Containment Pressure (Case 1)

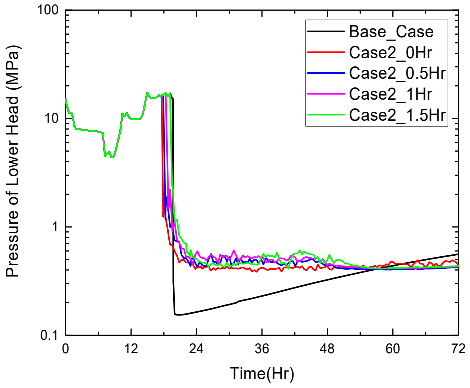

Fig 7. Pressure of Lower Header (Case 2)
(Note that Y-axis is expressed by log-scale)

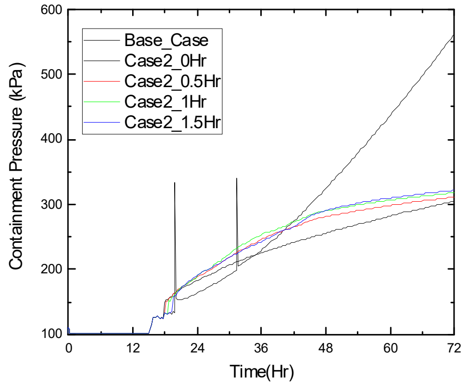

Fig 8. Containment Pressure (Case 2)

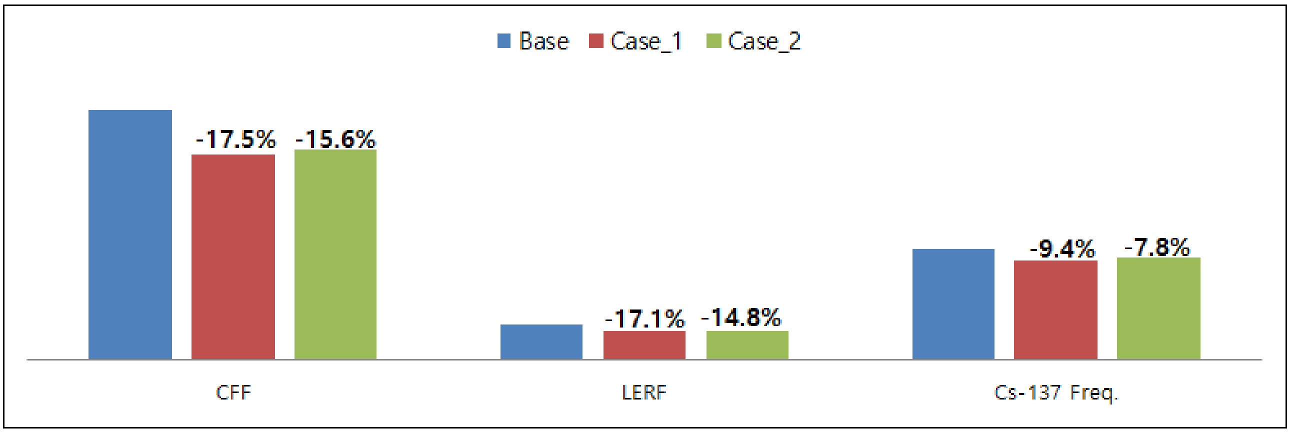

Fig 9. Level 2 PSA Results