Numerical study on effect of recirculation operation strategy using portable facilities on preventing containment failure

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1. Introduction

In the event of a severe accident, there is a risk of damage to the containment building due to over-pressure in the containment, since a large amount of steam and molten corium are released into the containment. The containment building is the last barrier to prevent radioactive fission products from being released into the environment, and its integrity must be maintained in the event of a severe accident. The installation and utilization of mobile facilities has been considered to reinforce the multiple protection systems of nuclear accidents since the Fukushima accident.[1, 2] Mobile facilities include portable pumps that can supply water to RCS or spray systems, mobile generators that supply power to major safety facilities, and portable heat exchangers to prepare for loss of final heat sink. In the event of a station black out accident, cooling of containment atmosphere through the recirculation operation can be considered using mobile facilities, without considering the ventilation of the containment for the containment depressurization. In this study, the effect of the cooling of the water in the recirculation sump by recirculation operation on the prevention of containment failure was evaluated numerically.

2. Accident Analysis

2.1 Assumptions of Mitigation Strategy

If the power recovery fails during SBO, the secondary cooling by turbine-driven aux-feed water (TDAFW) system is not available after the depletion of DC batteries. Also the cooling water cannot be injected into the core, leading to core meltdown and reactor failure. Thereafter the containment is pressurized by discharging large amount of steam and hot core melt, thus containment integrity can be threatened. In this study, it is assumed that mobile equipment can be used as a strategy for preventing containment failure. When component cooling water pumps are failed in SBO, if a mobile generator is deployed to supply power to the safety injection pumps, water from the RWST can be supplied to the recirculation sump through the core. It is assumed that the recirculation operation can be performed and the water in the recirculation sump can be cooled using a portable heat exchanger.

2.2 Calculation cases

Table 1: Calculation Cases

Case	1	2	3	4	5	6
TDAFW	O	O	O	O	O	X
RCS depressurization	O	O	X	X	X	X
External SI injection	O	O	X	X	X	X
External spray injection	O	X	O	X	X	X
Portable power & heat exchanger	O	O	O	O	X	X
Containment flooding	X	X	X	X	O	X

Table 2: Assumed Recirculation flow rate

Period	Flow rate (gpm)
24 h ~ 72 h	3000
72 h ~	~ 500

Six calculation cases were considered and listed in Table 1 to evaluate the effect on the depressurization of containment building by recirculation operation. In all cases, it was assumed that the TDAFW was successful for eight hours. In case 1 and case 2, it was assumed that safety depressurization of the primary system and external injection by portable pumps can be made after core damage, and recirculation cooling is possible when the water level of the containment reaches the maximum allowable flood level. The difference between the two cases is the water supply to the spray system by high-pressure mobile pumps. Case 3 is a scenario that external spray and recirculation cooling are possible, and case 4 is a scenario that only recirculation cooling is possible. Case 5 is a scenario considered to investigate the effect of flooding the recirculation sump without recirculation cooling, with assuming the flooding is possible. Case 6 is a scenario in which no mitigation measures are performed, considered to identify the effect of the mitigation measures.

It was assumed that mobile facilities could be deployed after 24 hours. The flow rate of the portable heat exchanger is given in Table 2. The performance of the heat exchanger was assumed to have the same performance as the recirculation heat exchanger of the plant since the design specification of the portable facilities have not determined. MAAP 5.03 was used to analyze the above cases and the accident progression was analyzed for 144 hours after the accident.

3. Results and Discussions

As a result of the calculation, core damage occurred in the entire case, but the reactor failure occurred in case 3, case 4, and case 6. In case 1 and case 2, the reactor was not failed due to safety depressurization of the primary system and external injection into the core.

In case 5, creep rupture occurred in hot leg but reactor was not failed. After flooding the containment building, the reactor can be filled with water since the location of the creep rupture is submerged. Also the external surface of the reactor can be cooled by submerged water.

Figure 1 represents the transient pressure of the containment building for all cases. The pressure of the containment building was kept below the design pressure by 24 hours in all cases. In case 6, the pressure enable to fail the containment building reached before 72 hours. Whereas, in case 1, case 2 and case 3 where external injection or the external spray injection is performed the containment pressure was rapidly reduced and kept lower than 2 bar for 72 hours. Case 4 also, the containment pressure decreased after deploying mobile facilities and was kept lower than 2 bar. After 72 hours, the containment pressure is slightly increased as the recirculation flow rate decreases.

In case 5, the containment pressure decreased after the beginning of flooding because convective cooling and steam condensation occurred at the surface of the water pool. The containment pressure increased again, but was kept below the design pressure for 72 hours. The containment flooding strategy cannot completely prevent containment from failure. However it could delay containment failure so that time to mitigation measures could be prolonged.

If an external injection is performed, the pressure of the containment is kept slightly higher than 2 bar by core cooling, and the containment pressure is expected to be kept within the design pressure for 72 hours even if the recirculation operation is not performed. In case 3 where the external spray injection is performed, the containment pressure decreased more rapidly after 24 hours than in Case 4 where externally spray injection is not performed. However, when the water level of the containment reaches the maximum allowable flood level, it is no longer possible to spray, so it must be relied on recirculation operation for the containment depressurization. Therefore, if the cooling water cannot be injected into the core after core damage, the recirculation operation with cooling by the portable heat exchanger is could be effective mitigation measure for preventing containment failure. In addition, if the mobile equipment cannot be used in a timely manner, the strategy of containment flooding is able to delay the containment failure to 72 hours so that the mitigation action time can be prolonged and more mitigation options can be prepared.

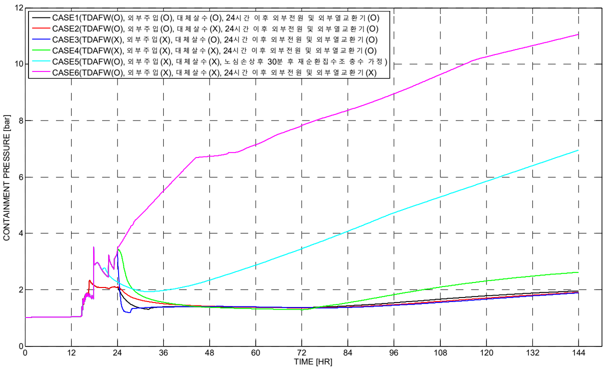

Fig. 1. Transient containment pressure

3. Conclusions

In this study, the effect of recirculation operation by the mobile facilities on the containment failure prevention was evaluated numerically. The effects of severe accident mitigation measures using mobile facilities, such as the external power supply, the external injection, the external spray injection, and the recirculation cooling by mobile heat exchangers, were evaluated for SBO scenario. Except for cases in which the core cooling through external injection is available, it is verified that recirculation operation can effectively maintain the pressure of the containment below the design pressure. In addition, the containment flooding strategy can extend the action time of the mitigation measures to prevent damage to the containment. For a more accurate assessment, uncertainty evaluation of uncertainty factors associated with the melt progression in the core and thermal hydraulic phenomena in the containment building should be performed and sensitivity of the cooling flow rate of the mobile heat exchanger should be analyzed.

REFERENCES

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[2] Emergency response Procedure and Guidelines for Extreme Events and Severe Accidents (NEI 14-01), Nuclear Energy Institute, Washington, DC, USA, 2014