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Sensitivity Analysis of Mitigation Action Time on Extended SBLOCA and TLOFW for APR1400

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1. Introduction

In Korea, as the Nuclear Safety Act was revised in 2015, an accident management program was added to the documents submitted for operating license of the nuclear power plant. In 2019, the accident management programs of all operating nuclear power plants in Korea were submitted and they are currently under review. According to 'Notice of the Nuclear Safety and Security Commission No. 2017-34' (Reactor.42, Regulation of the Scope of Accident Management and the Detailed Criteria for Evaluating Accident management Capabilities), nine multiple failures must be considered, among which Small Break Loss Of Coolant Accident with loss of Safety Injection (SBLOCA with loss of SI) and Total Loss Of Feed Water (TLOFW) are included. TLOFW is an event that occurs when an auxiliary feed water system loses its function after the main feed water system is suddenly stopped. In SBLOCA with loss of SI, a failure of a safety injection system is assumed after a small break at the reactor coolant system, literally [1]. In progress of the events, appropriate mitigation measures are taken by operators following emergency operating procedures in order to cool down and stabilize the reactor core. And the time point when the operator action is taken could significantly affect the consequence of the event. In this study, the results of TLOFW and the extend SBLOCA were analyzed according to various mitigation action time using the MARS-KS code. This study can be utilized to identify allowable maximum operator action time and time margin that does not cause the damage of reactor core.

2. Input model and details of the events

2.1 Input Model for APR1400

Major primary system and secondary system of APR1400 which is a two-loop 3,983MWth pressurized water reactor was modeled using the MARS-KS code. The nominal values of the design such as pressurizer pressure, Reactor Coolant System(RCS) flow rate, core inlet temperature, which were written in the safety analysis report [2], were used as initial conditions in this analysis. Especially, the modeling of Pilot-Operated Safety Relief Valve (POSRV) and Main Steam Atmospheric Dump Valve(MSADV) were carefully reviewed and modified because they were key components mitigating the events. The effect of the coefficients in the Henry-Fauske critical flow model in the MARS-KS code was also reviewed.

2.2 Small Break LOCA with loss of safety injection

A 2-inch break at a cold leg is assumed for SBLOCA with loss of SI in this analysis. Since failure of safety injection system is assumed, the system is not available except for safety injection tank that passively works. Major mitigation measure is to manually open MSADVs for each steam generator. As the MSADVs are opened, the pressure at the secondary system is rapidly decreased and then the feed water in the shell side of the steam generator is aggressively evaporated. And feed water is replenished by the auxiliary feed water system. Through the steam generator, the coolant in the RCS cools down until its temperature and pressure reach the conditions that allow a shut-down cooling system (SCS) to operate. The SCS serves as the ultimate heat sink in this event. The reactor coolant pumps were assumed to operate for 10 minutes after the reactor trip.

2.3 Total Loss of Feed Water

Simultaneous failure of main feed water system and auxiliary feed water system is assumed for TLOFW. Due to the failure, feed water in the secondary side of the steam generator becomes exhausted, and the low feed water level of the steam generator causes reactor trip. Since there is no heat removal by the secondary side, decay heat from the reactor core is removed by feed-and-bleed operation. For the operation, safety injection system supplies coolant into the reactor core and the coolant with removed decay heat is discharged to the outside of the RCS through the opened POSRVs at the top of the pressurizer. However, sufficient depressurization of the RCS through manual opening of the POSRVs must be preceded to enable safe injection before the feed-and-bleed operation. Therefore, the mitigation action for TLOFW is to open the POSRVs manually. SI system works after actuation signal automatically if the shut-off pressure condition is satisfied. The reactor core and RCS are cooled down until cooling through the SCS is possible. In this analysis, it was assumed that only half of four POSRVs was available and two trains of SI system among four trains worked in the feed-and-bleed operation. The reactor coolant pumps were also assumed to operate for 10 minutes after the reactor trip.

3. Calculation results and effect of mitigation measures

3.1 Results of SBLOCA with loss of SI

Sensitivity analysis on mitigation action time was conducted for SBLOCA with loss of SI, where mitigation measure was to manually open MSADVs. As described above, with the 2-inch break at the cold leg as the initial event, the reactor was tripped. After a certain time, MSADV was opened to alleviate the consequence of the event. The analysis was performed by gradually increasing the time to open the MSADVs based on the time of reactor trip and some of the results were depicted in Figs. 1 and 2. As shown in Fig.1, after the MSADV was opened, the coolant in the RCS was rapidly cooled by the steam generator, and the coolant temperature at the core inlet dropped sharply within tens of seconds.

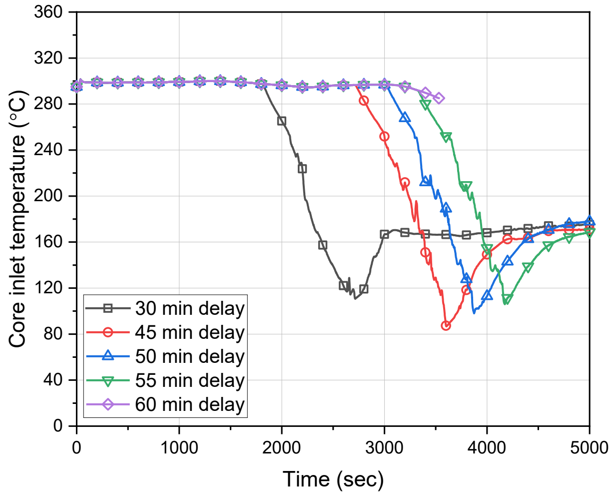

Fig. 1. Core inlet coolant temperature according to MSADV opening time in SBLOCA with loss of SI

Referring to Fig. 2, peak cladding temperature (PCT) did not show a significant change until about 45 minutes after the initial event since coolant in the core remained. After that, however, the amount of coolant in the core was depleted and the PCT started to rise rapidly. When the MSADV was opened up to 55 minutes after the reactor trip and the coolant was rapidly cooled, the PCT did not exceed 1204 ℃, which was the maximum cladding temperature allowed in 'Notice of the Nuclear Safety and Security Commission No. 2017-23' (Reactor.24, Standards for the Performance of the Emergency Core Cooling System of Pressurized Light Water Reactors). However, if the operator action was taken after that time, the PCT exceeded that allowable temperature. Therefore, it was confirmed that the operator action to manually open the valve should be performed before 55 minutes in SBLOCA with loss of SI.

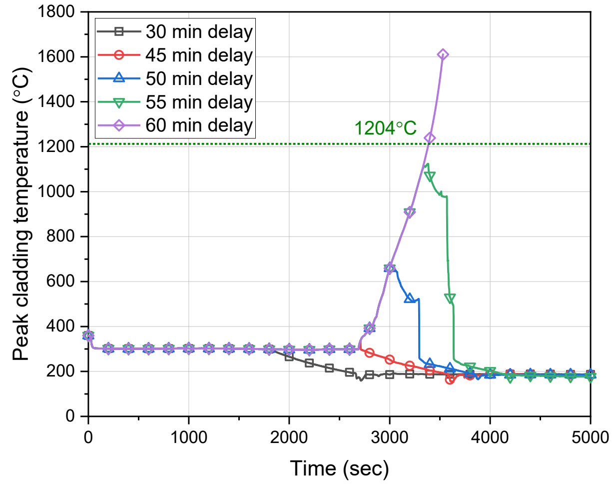

Fig. 2. Peak cladding temperature according to MSADV opening time in SBLOCA with loss of SI

3.2 Results of TLOFW

Similarly, sensitivity analysis according to operator action time was performed for the TLOFW event. As described above, the mitigation measure in TLOFW was feed-and-bleed operation through the SI system after RCS depressurization, so this analysis was performed by gradually increasing the POSRV opening time after reactor trip, and the results are shown in Figs. 3 and 4. As shown in Fig. 3, if the pressurizer pressure reached automatic opening pressure of POSRV before the manual opening, the opening and closing of the valve were repeated automatically, and the pressure rose and fell accordingly. After that, the POSRV was fully opened by operator action and the pressurizer pressure was rapidly decreased below the SIP shut-off pressure, enabling the feed-and-bleed operation.

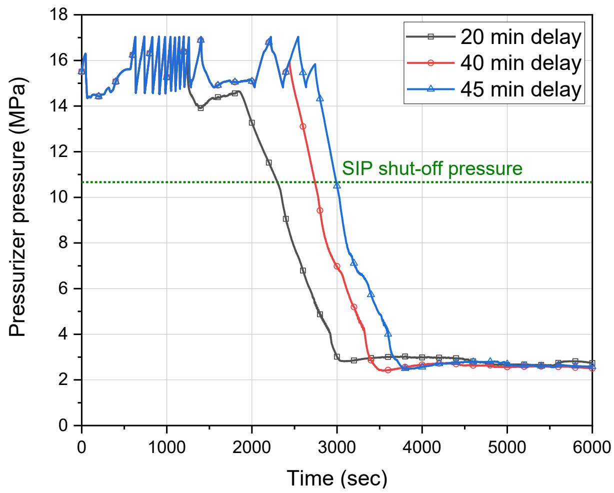

Fig. 3. Pressurizer pressure according to POSRV opening time in TLOFW

Fig. 4 shows the PCT results performed in the TLOFW sensitivity analysis. PCT in Fig. 4 did not show a significant change until about 2100 seconds. After that, however, PCT started to increase rapidly as the feed-and-bleed operation was delayed due to delayed POSRV manual opening. In the results of manual opening of the POSRVs at 40 minutes after reactor trip, the PCT did not exceed 1204 ℃ through feed-and-bleed operation. However, if the POSRV opening was performed after that, the PCT exceeded 1204 ℃, and there was concern about core damage.

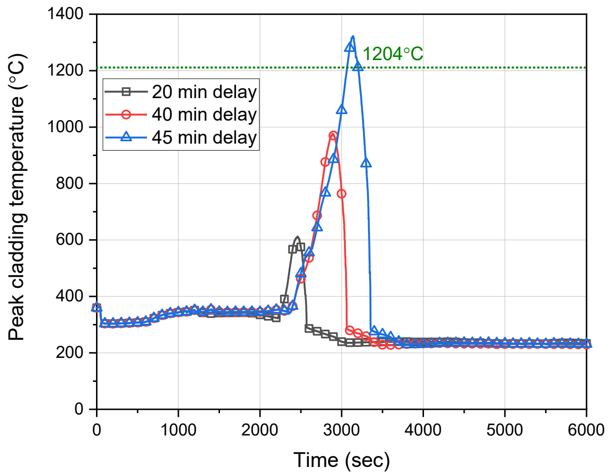

Fig. 4. Peak cladding temperature according to POSRV opening time in TLOFW

4. Conclusions

In this study, sensitivity analysis was performed according to mitigation action time in the extended SBLOCA and TLOFW. Through this analysis, it was identified how the mitigation action time affects the RCS temperature, pressure and PCTs. These results could be used to evaluate the maximum allowable operator action time and time margin. However, since the analysis result may vary depending on the assumptions and modeling applied to this analysis, a careful reexamination on them is required before applying to actual regulator review.

REFERENCES

[1] Korea Institute of Nuclear Safety, Safety Review Guideline for Accident management Program (Rev.3), 2021
[2] Korea Hydro & Nuclear Power Co., Ltd. (KHNP), Final Safety Analysis Report (FSAR) of. Shin-Hanul Units 1&2.