Study on Main Steam Line Break Induced Steam Generator Tube Rupture Accident using SPACE code

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1. Introduction

After the Fukushima nuclear accident, beyond design basis conditions has played an important role for developing the reactor coolant system (RCS) cooldown strategy and recovery action. Additional failures of the safety components are also considered in terms of sufficient safety margin with application of proper emergency operating procedures.

The revision of the nuclear safety act in June, 2015 required all nuclear power plants in Korea to submit Accident Management Plan (AMP) [1] that covers design basis accidents, multiple failure accidents and severe accidents. The AMP contains nine multiple failure accidents such as Station Black Out (SBO), Multiple Steam Generator Tube Rupture (MSGTR) and so on. KHNP applied for a license for AMP in 2019. Since then, questions on various fields have been received from regulatory agencies and an answer to those questions has been submitted to regulatory agencies. In addition to the nine previously submitted multiple fault incidents within AMP, the regulatory body has requested that analysis of "Main steam line break (MSLB) and induced steam generator tube ruptures (SGTR)" accidents be performed.

In this paper, we conducted an additional analysis of the "MSLB and induced SGTR" accident required by the regulatory body for APR1400 nuclear power plants and reviewed the results.

2. Analysis Results

2.1 Sequence of Event

For APR1400, leak before break (LBB) concept is applied to main stream line from steam generator (SG) outlet to main steam isolation valve (MSIV). Therefore the break location for MSLB is downstream of MSIV. In addition, one steam generator tube was ruptured in LOOP A. Conservatively, we assumed that the MSLB and the SGTR were occurred at the same time.

The reactor trip signal is generated by a variable overpower trip (VOPT). Because the coolant flow out through the ruptured tube, the pressure of primary system decreases. The pressure of the primary system decrease to the set point of the safety injection.

When the steam discharged from the broken steam line, a low SG pressure signal was generated. In this case, main steam isolation system (MSIS) is operated by low SG pressure. The MSIV was closed to prevent excessive cooling of the primary system by steam discharge and to avoid leakage of radioactive materials through the broken steam line. The sequence of the MSLB and induced SGTR is shown in Table I. LOOP A was assumed as the affected part both of steam line and steam generator as shown in Fig. 1.

Table I: Sequence of event

Time (s)	Event
0.0	MSLB and induced SGTR occur
6.6	Reactor trip by VOPT
15.1	MSIV closed by SG low pressure
333.4	HPSI injection
703.4	MSSV open/close

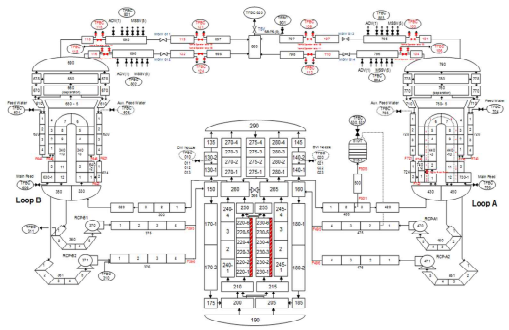

Fig. 1. Nodalization diagram of SPACE code for APR1400.

2.2 Analysis

The SPACE code [2] is used to analyze the thermal hydraulic behavior of the MSLB and induced SGTR event in transient period. The SPACE is developed by the Korea Hydro & Nuclear Power Co. through collaborative works with other Korean nuclear industries and research institutes. It is a best-estimate two-fluid, three-field analysis code used to analyze the safety and performance of PWR.

Figures 2 to 6 present the result of main parameter of thermal hydraulic behavior. Figure 2 shows the pressures of the primary and secondary systems. The pressure of the SG decreased sharply at the beginning of the accident due to the release of steam through the broken main steam line, but the pressure was raised again by the operation of MSIS. When MSIS signal was activated, the MSIV was closed. After that, the pressure of the SG increased due to the outflow of coolant through the ruptured SG tube, and the increased pressure reaches the MSSV set point, and the MSSV is

repeatedly opened and closed as shown in Fig. 3. Figure 4 shows core collapsed level. Although the collapsed level of the core is slightly lower than before the accident occurred, it sufficiently exceeded the top of the active core after the safety injection was supplied to the core.

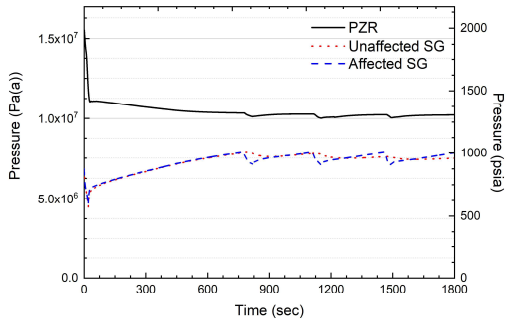

Fig. 2. PZR and SG pressure

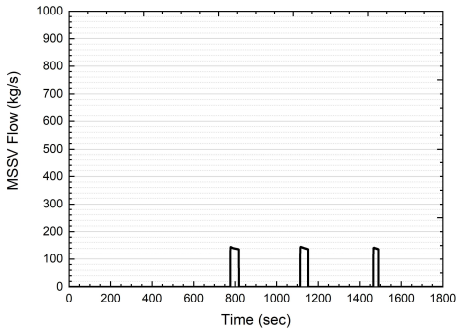

Fig. 3. MSSV flow

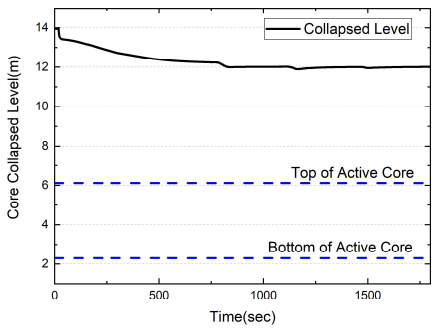

Fig. 4. Core collapsed level

Figure 5 and 6 show the flow rate through the affected SG tube and steam line. At the start of accident, the discharge flow rate through the damaged part increased rapidly. As the reactor trip signal occurred, the coolant flow rate through the affected part decreased. However, due to the pressure difference between the primary and secondary system, the flow rate through the affected part increased again. When the MSIV was closed, the flow rate of affected SG tube gradually decreased. The flow of broken steam line was almost zero after than MSIV closed. When MSIV was closed, discharge flow of steam line was not released through the broken steam line. As a result, the SPACE code has been predicted the thermal hydraulic behavior of the MSLB and induced SGTR event reasonably well.

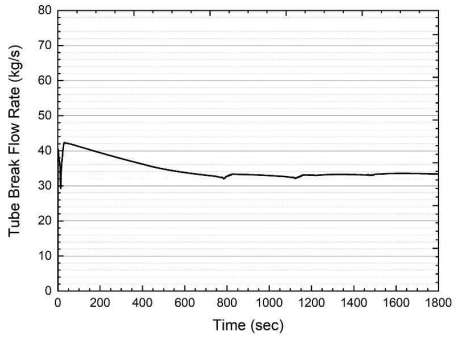

Fig. 5.SG tube break flow

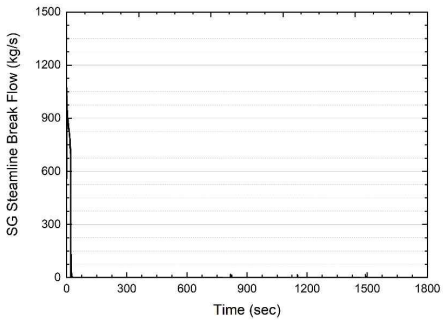

Fig. 6. Steam line break flow

3. Conclusions

This study shows the result of thermal hydraulic behavior on the MSLB and induced SGTR event using SPACE codes. Because the APR1400 nuclear power plant applied the LBB concept, the MSLB and induced SGTR event was considered at downstream break of MSIV. The MSIV closing time and steam line break flow are the important factors because radioactive material can be released to outside of containment vessel through broken steam line. When MSIV was closed, radioactive material was not released through the broken steam line. Also, we verified the radiological effect of this event using a RADTRAD code used to calculate radiation dose in the AMP. We confirmed that dose result was well below the limit.

REFERENCES

[1] KHNP, Accident Management Plan for Shin-Kori Units 3&4, 2020.
[2] KHNP, SPACE code manual, 2017.