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Thermal-hydraulic Analysis of SGTR for Supporting PSA in APR+

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1. Introduction

The Advanced Power Reactor Plus (APR+) is being developed in Korea. To enhance the safety of the APR+, a passive auxiliary feedwater system (PAFS) has been adopted in the APR+. The PAFS completely replaces the conventional active auxiliary feedwater system (AFWS). It is operated by a natural driving force mechanism when demanding auxiliary feedwater. It could maintain the system function of cooling the primary side and remove the decay heat while operated PAFS. For estimating the safety of APR+ design, the probabilistic safety assessment (PSA) of APR+ is performed. As the PAFS replaces the conventional AFWS, it is required to verify the cooling capacity of PAFS for the accurate evaluation. For this reason, this paper discusses the cooling performance of the PAFS while transient accidents.

2. Concept and basic design of PAFS

The PAFS consists of a heat exchanger, a passive condensation cooling water tank (PCCT), check valves, isolation valves powered by a battery (Class 1E), piping, instrumentation and control systems. PAFS is composed of two independent trains; each train covers 100% of capacity. Fig.1 shows a outline of the PAFS in the APR+. The steam feed line of the PAFS starts from the main steam line upstream of the main steam isolation valves (MSIVs). The steam is condensed in the heat exchanger. The condensed water goes through the return line and finally merges into an economizer line. Isolation valves and check valves are installed to ensure PAFS isolation from the main feedwater system during normal operation.

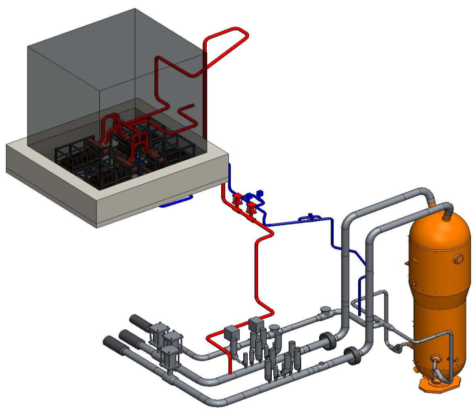

Fig 1. Outline of PAFS in APR+ (3-D)

3. Performance analysis

3.1 Transient scenarios

As the PAFS completely replaces the conventional active auxiliary feedwater system (AFWS), the sensitivity test is performed for evaluating the CDF effect by the PAFS. According to the result, the important transient accident and test scenarios were selected. When the safety injection is failed during steam generator tube rupture event, it could be prevented the core damage if the temperature and pressure of the primary side will be decreased by using steam generator secondary side and coolant is injected into the primary side by shutdown cooling pump. For verifying the scenarios, it should be confirmed the cooldown performance of the PAFS during transient accident through thermal-hydraulic analysis. In this case, the secondary side should cool down the primary side because all of the decay heat of reactor core is not removed by break flow from broken part.

. For SGTR analysis, the transient scenarios and assumptions are described as follows:

1. Break
   - 1 double-ended tube rupture in 9.5m point from steam generator tube sheet
2. System conditions
   - 4 HPSI are unavailable and 4 SIT, 1 SC pump and 2 PAFS are available.
3. Assumption
   - Aggressive cooldown is available by using PAFS.
   - Stuck open of the main steam line safety valves is not occurred during SGTR

3.2 RELAP model for APR+

For the analysis, APR+ is modeled by using the best estimate thermal-hydraulic code, RELAP5/MOD3.3. Fig. 2 shows the noding diagrams of the APR+ and the PAFS. The model is developed in accordance with the design data and system configuration of the APR+ and the PAFS and the PAFS model is attached to the APR+ model. The PCCT in the PAFS model is divided into six volumes to simulate natural convection in the PCCT. The heat exchanger is divided into 70 volumes to analyze in detail the condensation inside the heat exchanger tube. It was assumed that primary heat load is transferred to the secondary side. A steady-state analysis is successfully performed by using the APR+ conditions

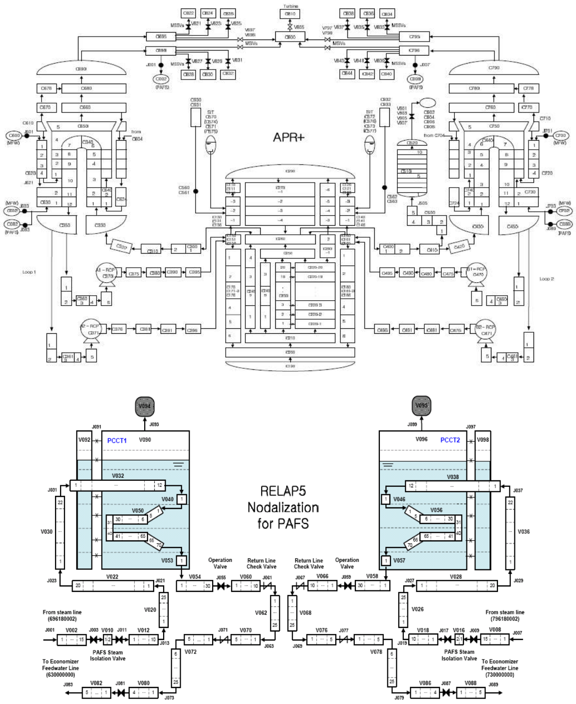

Fig. 2. Noding diagrams of APR+ and PAFS

3.3 Results

3.3.1 Thermal-hydraulic analysis during SGTR

Analyses were performed for 1 double-ended tube rupture. The behavior of pressurizer and steam generator pressure and core exit temperature following SGTR event is presented in Figure 3. Two trains of PAFS are actuated and the water of SITs is discharged following the depressurization of pressurizer. During the SGTR transient, the Pressurizer and Steam generator pressure and core exit temperature continues to drop and the plant parameters are stabilized by cooldown using PAFS.

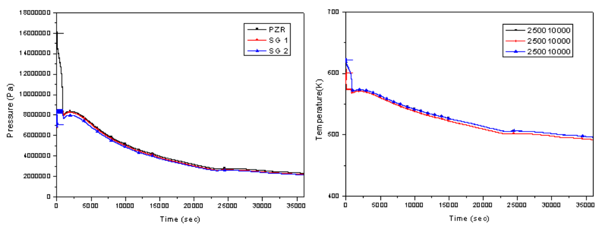

Fig 3. Pressurizer and steam generator pressure & core exit temperature (SGTR)

3.3.2 Sensitivity analysis

Through the thermal-hydraulic analysis, it is verified that plant was cooled down by using PAFS and the core damage is not occurred when the safety injection was failed during SGTR. According to this result, the sensitivity analysis of CDF in APR+ was performed and table 1 shows sensitivity analysis results of CDF. Since the core damage is not occurred in case of sequence 1, CDF is deleted after thermal-hydraulic analysis. And CDF is decreased in sequence 2 because it doesn't need to discharge from SIT.

TABLE I.

Sensitivity analysis results of core damage frequency

Details of event	After thermal-hydraulic analysis (A)	Before thermal-hydraulic analysis (B)	CDF difference (A-B)
Sequence 1. (SGTR) (SI fail) (SCS injection Fail)	-	4.43E-07	-4.43E-07
Sequence 2. (SGTR) (SI fail) (ASC fail)	2.58E-09	1.01E-07	-9.87E-08

3. Conclusions

To improve the safety of APR+, the PAFS has been adopted instead of the AFWS. In this study, RELAP calculation results under SGTR prove that the PAFS provides the sufficient performance to cool down the primary side and removes the decay heat generated in the core. The results were used for the sensitivity analysis of PSA and CDF was decreased after thermal-hydraulic analysis. Also the results show that PAFS contributes to the safety improvement of APR+. It is expected that the results can be used for a more realistic and accurate safety evaluation.

ACKNOWLEDGMENTS

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