Performance Analysis of APR+ PAFS for CDF evaluation

Sang Hee Kang* and Han Gon Kim
Korea Hydro & Nuclear Power Co., Ltd. & Korea, 508 Kumbyung-Ro, Yuseong-Gu, Daejeon, Korea, 305-343
**Corresponding author: kshee@khnp.co.kr*

1. Introduction

The Advanced Power Reactor Plus (APR+), which is a GEN III+ reactor based on the APR1400, is being developed in Korea. In order to enhance the safety of the APR+, a passive auxiliary feedwater system (PAFS) has been adopted. The PAFS replaces the conventional active auxiliary feedwater system (AFWS) by introducing a natural driving force mechanism while maintaining the system functions of cooling the primary side and removing the decay heat. As the PAFS completely replaces the conventional active auxiliary feedwater system (AFWS), it is necessary to verify its cooling capacity for the core damage frequency (CDF) evaluation. This paper discusses the cooling performance of the PAFS in 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. It is composed of two independent trains; each train covers 100% of capacity. The PAFS in the APR+ is illustrated in Fig. 1. 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.

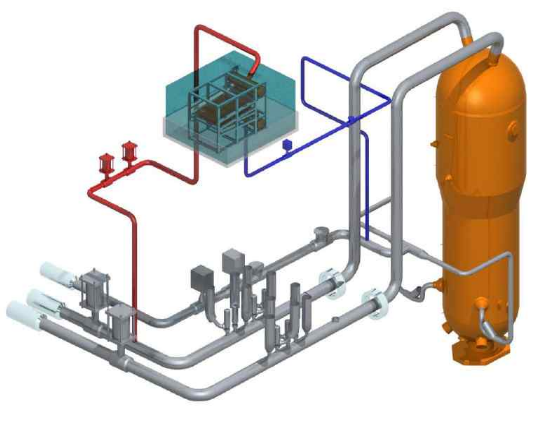


Fig 1. Outline of PAFS in APR+ (3-D)

3. Performance analysis

3.1 Transient scenarios

To verify that the PAFS provides aggressive cooldown performance, a small break LOCA and SGTR event were selected as transient scenarios for simulation as they are limiting events in terms of the CDF.

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

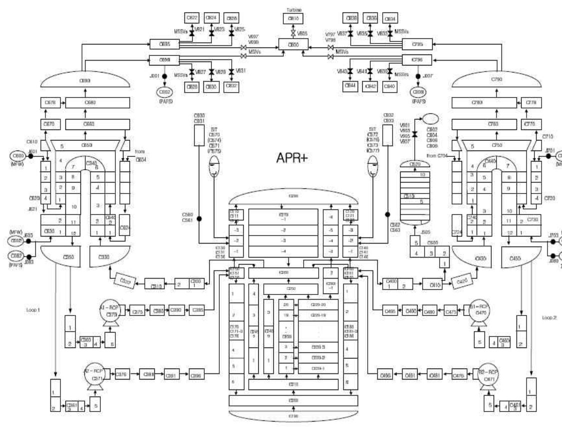
1. Break : 0.38, 1.0, 1.5 and 1.91 inches of the cold leg break
2. System condition: 4 SI are unavailable and 4 SIT, 1 SC pump, and 2 PAFS are available.
3. No operator action during the accident
4. Loss of Offsite Power

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

1. Break: 1 and 5 double-ended tube rupture at 9.5m from the steam generator tube sheet
2. System conditions: 4 SI are unavailable and 4 SIT, 1 SC pump, and 2 PAFS are available.
3. Operator action: Affected SG is isolated 30 minutes after initiation of the event.

3.2 RELAP model for APR+

For the analysis, the RELAP5/Mod3.3 code is used. Fig. 1 shows the noding diagrams of the APR+ and the PAFS. The PAFS model is attached to the APR+ model. The PCCT in the PAFS model is divided into six volumes to simulate a natural convection in the PCCT. The heat exchanger is divided into 70 volumes in order to analyze in detail the condensation inside the heat exchanger tube.



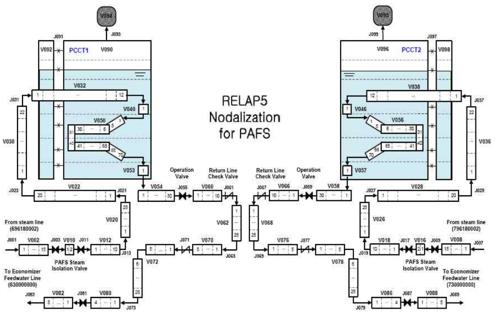


Fig. 2. Noding diagrams of APR1400 and PAFS

3.3 Results

3.3.1 Small break loss of coolant accident (SBLOCA)

The SBLOCA analysis was performed for breaks of 0.38, 1.0, 1.5 and 1.91 inches of the cold leg. The break size of 1.91 inches is the most limiting case among the 4 break sizes. Figure 3 shows the transient behavior of the RCS pressure and core exit temperature for the 1.9 inch break. Following reactor trip, the MSSVs are opened to control the main steam system pressure but are not opened after PAFS actuation. Two trains of PAFS are actuated and the water of the SITs is discharged following depressurization of the pressurizer. For the SBLOCA, the RCS pressure decreases continuously and the condition of RCS reaches the entry conditions of the shutdown cooling (400psia and 350°F) by cooldown using the PAFS. Also, the core is cooled down gradually to a sufficient subcooled state.

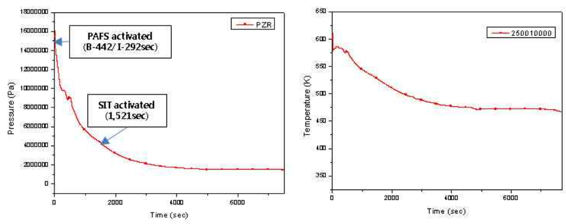


Fig 3. RCS pressure and core exit temperature
(1.91inches, SBLOCA)

3.3.2 Steam generator tube rupture (SGTR)

Analyses were performed for 1 and 5 double-ended tube ruptures. The 5 tube rupture is the limiting case in terms of SGTR. The behavior of RCS pressure and core exit temperature following the 5 tube rupture is presented in Figure 4. Two trains of PAFS are actuated, but one PAFS of the affected SG is isolated 30 minutes after initiation of the event. The water of the SITs is discharged following depressurization of the pressurizer. During the SGTR transient, the RCS pressure and the core exit temperature continue to drop and the plant parameters are stabilized by cooldown using the PAFS.

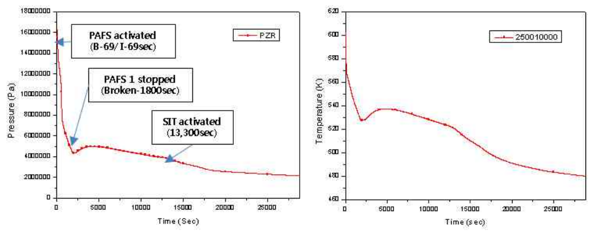


Fig. 4. RCS pressure and core exit temperature
(5 double-ended tube rupture, SBLOCA)

4. Conclusions

To improve the safety of APR+, the PAFS has been adopted instead of the AFWS. In this study, RELAP calculation results obtained under a SBLOCA and SGTR verify that the PAFS provides sufficient performance to cool down the primary side and removes the decay heat generated in the core. The results also show that the plant maintains a stable state without core damage by the aggressive cooldown using the PAFS. It is expected that the results can be used for more realistic and accurate safety evaluations.

ACKNOWLEDGMENTS

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