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Performance analysis of a Passive Auxiliary Feedwater System in APR+

Sang Hee Kang*, Jong Cheon, 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 in the APR+. The PAFS replaces the conventional active auxiliary feedwater system (AFWS) by introducing a natural driving force mechanism while maintaining the system function of cooling the primary side and removing the decay heat. The purpose of this paper is to evaluate the performance of the PAFS under design basis events using best-estimated thermal-hydraulic codes.

2. Concept and basic design

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. A schematic diagram of the PAFS in the APR+ is given in Fig. 1. PAFS is composed of two independent trains; each train covers 100% of capacity. 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.

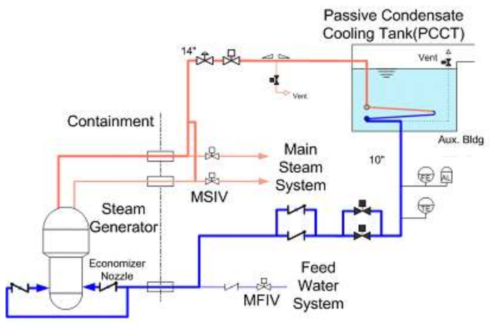
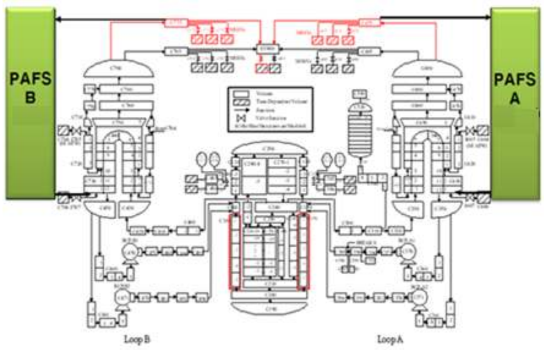


Fig. 1. Schematic Diagram of PAFS in APR+

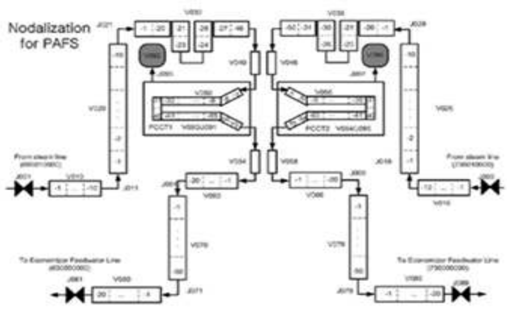
3. Performance analysis

3.1 Methods

For the preliminary analysis, the RELAP5/Mod3.3 code is used. Fig. 2 shows the noding diagrams of the APR1400 and the PAFS. The PAFS model is attached to the APR1400 model. The APR1400 model is used for the preliminary PAFS analysis because the APR+ is now under development. For the final analysis, the system model will be replaced with the APR+ specific data. 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 in order to analyze in detail the condensation inside the heat exchanger tube. Two design basis events, loss of condenser vacuum accident (LOCV) and feedwater line break (FLB) are selected as base analysis cases because LOCV and FLB are known to be limiting event for the PAFS. During LOCV, the two trains of the PAFS are operated and during FLB, only one train of PAFS attached to the intact SG side is available.



(a) APR1400



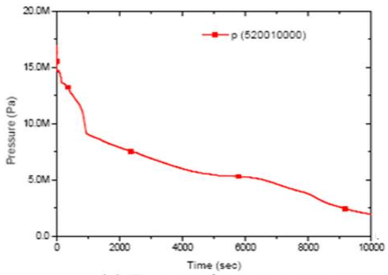
(b) PAFS

Fig. 2. Noding diagrams of APR1400 and PAFS

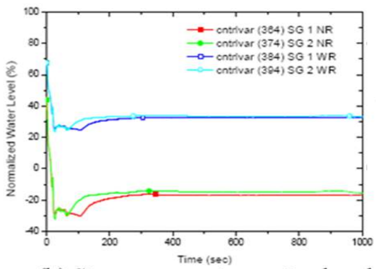
3.2 Results

3.2.1 Loss of condenser vacuum accident

A LOCV may occur due to the failure of the circulating water system to supply cooling water, the failure of the main condenser vacuum system to remove non-condensable gases, or excessive in-leakage of air through a turbine gland. Following the occurrence of an LOCV, the main feedwater pumps, reactor coolant pumps and the turbine are immediately stopped due to the loss of off-site power; a reactor trip occurs on the high pressurizer pressure. The pressure of the pressurizer under the LOCV is given in Fig. 3(a). As illustrated in the figure, the pressure decreases continuously after reactor shutdown. The results show that the cooling performance of the PAFS is sufficient to remove the decay heat of the reactor core. As illustrated in Fig. 3(b), the steam generator (SG) secondary water level decreases continuously after the reactor trip and the PAFS is actuated when the SG water level is reached to the PAFS actuation level. During this period, the heat generated in the reactor core is vented through the main steam safety valve (MSSV) by vaporization of the SG secondary water. After PAFS is actuated, the SG water level is maintained at a constant level.



(a) Pressurizer pressure

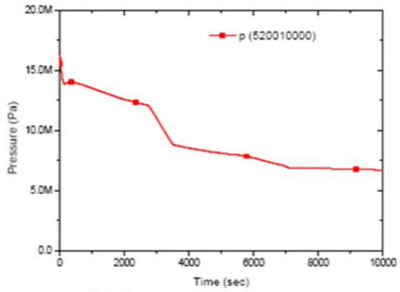


(b) Steam generator water level

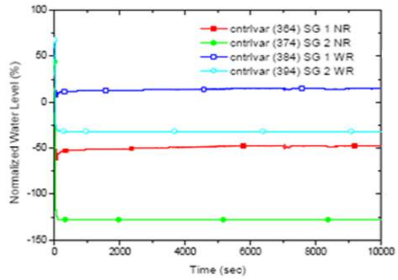
Fig. 3. Pressurizer pressure and Steam generator Water level for the case of LOCV

3.2.2 Feedwater line break

A FLB is initiated by a break in the main feedwater system piping. Depending on the break size and location, the effects of a break can vary. For a conservative analysis, the break location is postulated as being in a feedwater line between the check valve and the SG. The fluid of the affected SG is discharged through the break. The FLB causes an instant reduction in feedwater flow and a reactor trip under high pressurizer pressure. The pressure of the pressurizer for the FLB is given in Fig. 4(a); this graph shows that the single PAFS under FLB has enough cooling performance to accomplish decay heat removal. After the reactor trip, the pressure is continuously decreased and the SG secondary water level is continuously decreased. When the water level of the intact SG side gets to the PAFS actuation level, the PAFS begins to work. As shown in Fig. 4(b), the SG water level is maintained at a constant level while the PAFS is operating.



(a) Pressurizer pressure



(b) Steam generator water level

Fig. 4. Pressurizer pressure and Steam generator Water level for the case of FLB

3. Conclusions

To improve the safety of APR+, the PAFS has been adopted instead of AFWS. In this study, RELAP calculation results under LOCV and FLB prove that the PAFS provides sufficient performance to cool down the primary side and remove the decay heat. A system analysis code such as RELAP has limitations in simulating physical phenomena such as flow instability and oscillations of the PAFS. Consequently, separate effect tests and integral effect tests will be done and those experimental results will be used for the validation of the system analysis code and the evaluation of the feasibility of the performance analysis.

ACKNOWLEDGMENTS

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