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Evaluation of Effect of N_2 Gas on the Cooling Capability of Passive Auxiliary Feedwater System (PAFS) in APR+

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1. Introduction

In Korea, Advanced Power Reactor Plus (APR+) has being developed by adding passive safety features to Advanced Power Reactor 1400MWe (APR1400). Passive Auxiliary Feedwater System (PAFS) is one of passive system adopted in the APR+ to replace the conventional active auxiliary feedwater system. Because PAFS removes decay heat from the reactor core, it is required to verify the performance of PAFS in postulated accidents cases. In addition, an effect of non-condensable gas on the heat removal capability of PAFS should be evaluated since the non-condensable gas may deteriorate a condensation heat transfer through the condensation heat exchanger in PAFS. In this study, the effect of N_2 gas was evaluated using MARS.

2. Analysis for N_2 Effect

2.1. Design and Operating Condition of PAFS

PAFS is designed to be separately installed in two loops of the secondary side instead of a conventional active auxiliary feedwater system. PAFS consists of the steam supply line, the condensation heat exchanger, and return water line, and passively removes decay heats by a natural circulation. The condensation heat exchanger submerged in Passive Condensate Cooling Tank (PCCT) consists of 4 tube bundles wit 240 horizontal condensate tubes. The condensation tubes are designed to have an inclination of 3 degrees for prevention of a water hammer effect. Furthermore, the flow regimes in the condensate tubes are restricted to a horizontal stratified flow and an annular-mist flow [1].

2.2. Development of MARS Model

As shown in Fig. 1, the APR1400 model is developed. Although the PAFS was designed for the APR+, the APR1400 model was used because the design of the APR+ is not completed yet. Instead, the number of condensation tube in the PAFS was reduced in the MARS calculation to compensate the difference of thermal power between the APR+ and the APR1400. PAFS is modeled by connecting the inlet and the outlet of PAFS to the main steam line and economizer nozzle, respectively as shown in Fig. 2. For a steady state calculation, a main feedwater flow, turbines, and condenser are modeled as a boundary condition.

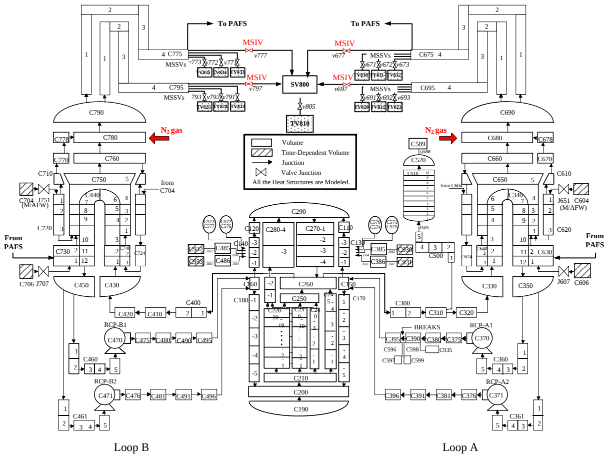

Fig. 1. MARS model for APR1400

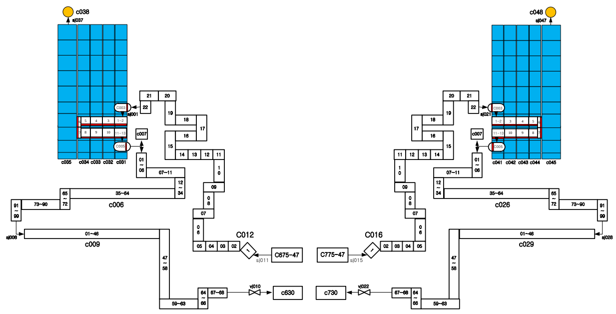

Fig. 2. MARS model for PAFS

2.3. Analysis Cases

In order to evaluate the effect of N_2 gas, a LOss of Condenser Vacuum (LOCV) accident is simulated. The N_2, gas was assumed to be generated in the total volume of feedwater in steam generators, main steam line, and other pipe lines in PAFS. Therefore, the generated mass of N_2 gas can be calculated by multiplying the solubility of N_2 gas to total mass of feedwater. For a conservative estimation, the solubility of N_2 gas is calculated at a room temperature.

N_2 gas generated from feedwater in steam generator s(SGs) and PAFS is injected to a steam dome in SG during steady state calculation (S.S. injection case). In addition, a comparative case is simulated by injecting N_2 gas into the steam dome after close of main steam safety valves (MSSVs) and turbine stop valve (TSV) (Delayed injection case). The reference case is also compared by calculating the identical accident scenario without N_2 injection (No injection case).

3. Analysis Result

Figure 3 shows the total mass of N_2 gas accumulated in the PAFS of one secondary loop and other components such as the SG, main steam line, and so on, respectively. Because the N_2 gas accumulated in the secondary loop is released through the MSSVs and the TSV in an early phase of the accident, the N_2 mass is larger in the delayed injection case than the S.S. injection case.

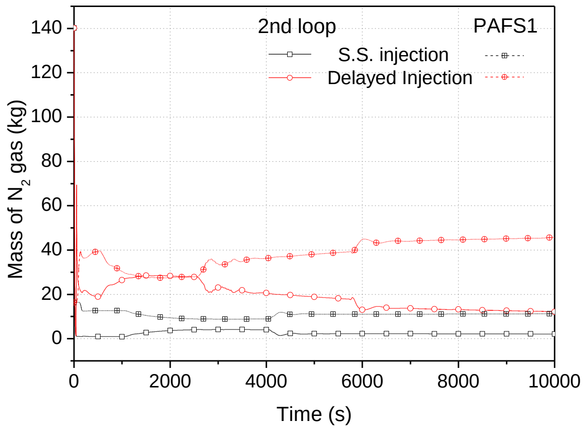

Fig. 3. Comparison of N_2 gas distribution

As the sequence progresses, the N_2 gas is accumulated in the PAFS rather than other components. In particular, the N_2 gas is accumulated at the outlet region of the condensate tube and the return water line according to the transient time. Therefore, the deterioration of the HTC in the outlet of the condensation tube increases with time as shown in Fig. 4. Figure 4 shows the condensation heat transfer coefficients (HTCs) at the inlet, the center, and the outlet of the condensation tube. In the delayed injection case, the HTC at all locations in the condensation tube is significantly deteriorated compared to the delayed injection case.

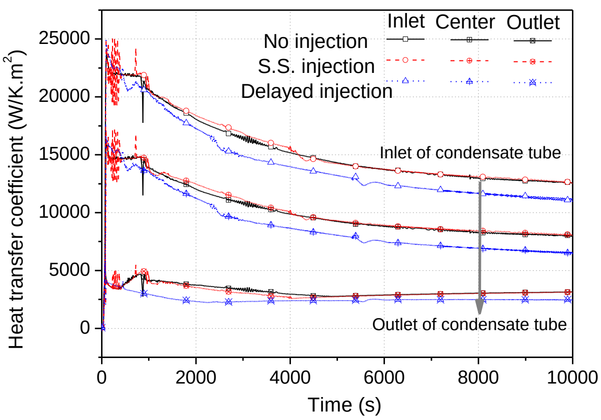

Fig. 4. Comparison of heat transfer coefficient

Pressures in a pressurizer (PZR) and a SG in one secondary loop are compared in Fig. 5. The result of S.S. injection case shows almost similar value with the no injection case because of the early release of N_2 gas. On the other hand, the pressures in the PZR and the SG increase when the N_2 gas is injected after the closure of the MSSVs and the TSV. The pressures of PZR are 6.04 MPa and 7.47 MPa at 10,000 seconds in the no injection case and the delayed injection case, respectively.

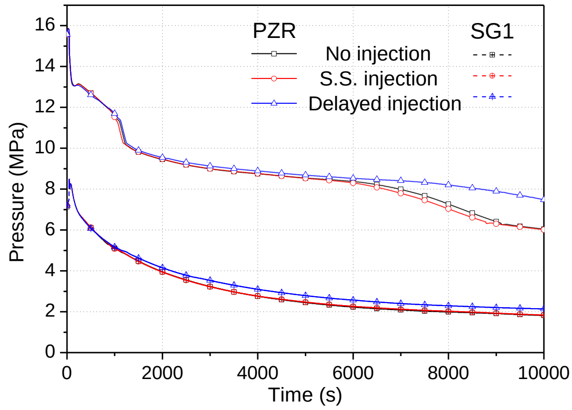

Fig. 5. Comparison of pressures in a PZR and a SG

4. Conclusions

In this paper, the effect of N_2 gas on the heat removal capability of the PAFS was evaluated for LOCV accident case by using the MARS code. The analysis result showed that the condensation heat transfer coefficient deteriorates as the N_2 gas is accumulated in the condensation tube. Consequently, the system pressure increases in order to remove the decay heat by increase of steam temperature at the inlet of condensate tube.

However, the system pressure was not increased in the case where the conservative assumption on the N_2 injection was not applied because the N_2 gas is releases through the MSSVs and TSVs before their closure. In addition, the conventional nuclear power plants control the non-condensable gas in the feedwater so that the possibility of existence of non-condensable gas is very low. Therefore, it is necessary to evaluate the realistic assumption on the mass of non-condensable gas that may be generated in SGs and PAFS.

ACKNOWLEDGEMENT

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[1] K. Y. Choi, Evaluation of conceptual design of a condensing heat exchanger for passive auxiliary feedwater system, Korea Atomic Energy Research Institute, KAERI/CM-1318/2010, 2010.