Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Integral effect test on operational performance of the PAFS (Passive Auxiliary Feedwater System) for a FLB (Feedwater Line Break) accident

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1. Introduction

PAFS (Passive Auxiliary Feedwater System) is one of the advanced safety features adopted in the APR+, which is intended to completely replace a conventional active auxiliary feedwater system [1]. It cools down the steam generator secondary side and eventually removes the decay heat from the reactor core by adopting a natural convection mechanism; i.e., condensing steam in the PCHX (Passive Condensation Heat Exchanger) submerged inside the PCCT (Passive Condensate Cooling Tank). The test facility, ATLAS-PAFS, was constructed to experimentally investigate the thermal hydraulic behavior in the primary and secondary systems of the APR+ during the transient when the PAFS is actuated [2]. Among the anticipated accidents with the PAFS actuation, the FLB (Feedwater Line Break) was considered as the most important accident in evaluating the cooling capability of the PAFS, during the development of PIRT (Phenomena Identification and Ranking Table) of the PAFS [3]. In this study, the PAFS-FLB-EC-01 test was performed to simulate a break on the pipe connected to the SG-1 economizer, which was analyzed as the most severe case in the APR+ SSAR (Standard Safety Analysis Report). The main objectives of this test were not only to provide physical insight into the system response of the APR+ during the FLB accident but also to produce an integral effect test data to validate a thermal hydraulic safety analysis code.

2. Test Facility

ATLAS is the integral test facility to simulate the various accident scenarios in the APR1400 according to the three-level scaling methodology. In this study, the test condition was determined to simulate the FLB transient of the APR+. Since the break nozzle is placed on the feedwater line of the SG-1 (Steam Generator 1), the PAFS was connected to the SG-2 of the ATLAS as shown in Fig. 1. The PCHX has three tubes which conserves the heat transfer rate at the surface according to the scaling methodology. A reduced diameter of the tube enabled the heat removal rate to be conserved in the facility. The tubes have the same material and the thickness to preserve the heat flux and the wall temperature. PCCT was designed as a rectangular pool, which has a half-height scale and a reduced area according to the global scaling ratio of the ATLAS. The PCCT is placed at the elevation of 17.3 m above the ground in order to conserve the level difference between the PCHX and the coolant surface in the SG-2. The steam-supply and the return-water line connect the PCHX to the steam generator of the ATLAS. In order to preserve a pressure drop of the facility to a half of the prototype, the pipe size was determined to be 1-1/2" for the steam-supply line, and 1-1/4" for the return-water line.

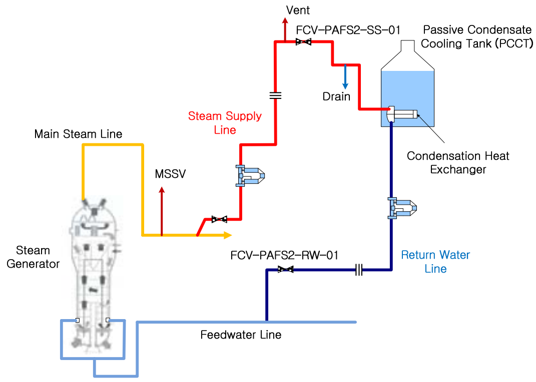

Fig. 1 Configuration the ATLAS-PAFS

3. Experimental Result

Figure 2 show a pressure trend of the pressurizer and the steam generators. Coincidently with the break at 403 seconds, main feedwater pump stopped and main feedwater was isolated. Due to a loss of the heat removal capacity by the secondary system, the pressure of the primary system increased during the initial period. It should be noted that the ATLAS has a low core power of 8% against 100% of rated power. That contributed to a relatively small increase of the primary system pressure before the reactor trip. While the reactor trip occurred by the HPP (High Pressurizer Pressure) signal in the prototype, the reactor was tripped at 628 seconds due to the LSGP (Low Steam Generator Pressure) signal from the affected SG in the present test. The collapsed water level in the affected steam generator (SG-1) showed a sharp decrease by the break flow as shown in Fig. 3. LSGP signal at the SG-1 occurred at 628 seconds. It closed the MSIV (Main Steam Isolation Valve) of the SG-1 and generated a reactor trip signal. When the reactor trip occurred, the RCP trip and the turbine trip were occurred coincidently. Turbine trip means that the SG-2 was also isolated. The pressure increase to 8.1 MPa in the SG-2 made the MSSV (Main Steam Safety Valve) open to mitigate the pressure increase by releasing the steam to the atmosphere. And the decrease of the pressure to 7.7 MPa resulted in the closure of the MSSV and the pressure increased again. This procedure made a fluctuating behavior of the steam pressure of the SG-2 as shown in Fig. 2.

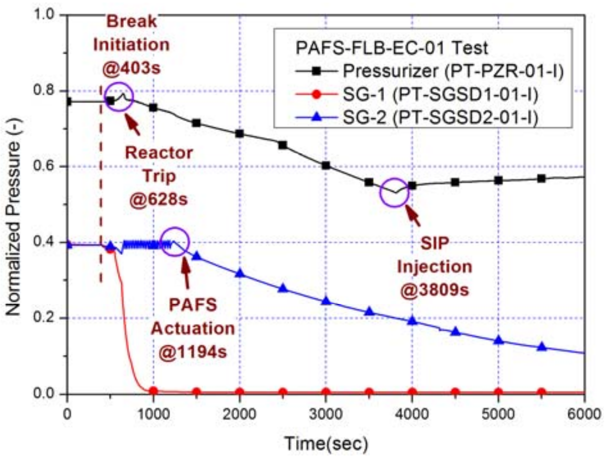

Fig. 2 Primary and secondary pressures

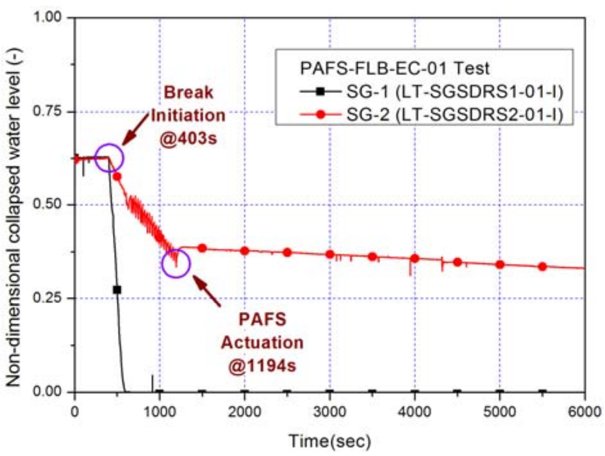

Fig. 3 Collapsed water level of SG

From the release of the steam by opening of the MSSV, the collapsed water level in the SG-2 decreased to 2.78m (set-point of the PAFS actuation) at 1194 seconds as shown in Fig. 3. It made a PAFAS (Passive Auxiliary Feedwater Actuation Signal) to activate the PAFS for cooling down the decay heat. PAFAS opened the PAFS actuation valve (FCV-PAFS2-RW-01) to make a closed loop as shown in Fig. 1. When the valve was open, the water in the return-water line and the PCHX drained to the SG-2 through the economizer nozzle, so that the mass flow rate measured by a flow meter at the return-water line (QM-PAFS2-RW-02) showed a peak value of 0.775 kg/s at 1205 seconds as shown in Fig. 4 and the collapsed water level of the SG-2 increased to 3.1 m as presented in Fig. 3.

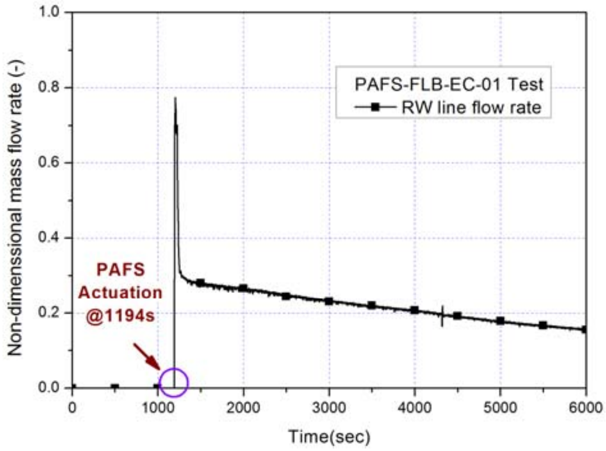

Fig. 4 Mass flow rate of the return-water line

4. Conclusions

The PAFS-FLB-EC-01 test was performed at the ATLAS-PAFS facility to simulate a break on the pipe connected to the steam generator economizer in the APR+. The pressure and the temperature of the primary system continuously decreased during the heat removal by the PAFS operation. From the present experimental result, it could be concluded that the APR+ has the capability of coping with the hypothetical FLB scenario with adopting the PAFS and proper set-points of its operation. This integral effect test data will be used to evaluate the prediction capability of safety analysis codes and to identify any code deficiency for a FLB simulation with an operation of the PAFS.

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