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Experimental Study on the Prolonged Station Blackout with the Steam Generator Tube Rupture

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1. Introduction

During a long transient of a SBO (Station Blackout), a steam generator tube rupture (SGTR) accident can occur when a steam generator (SG) tube is exposed to a superheated steam flow. Because a SGTR is a safety issue due to the release of fission products to the containment, it is necessary to experimentally investigate the thermal hydraulic behavior of a nuclear power plant (NPP) for a SBO accident combined with a SGTR occurrence. The objective of this study is to perform an integral effect test to evaluate the effect of a SGTR to reactor safety and the natural circulation characteristics during a prolonged SBO condition, with the ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) facility. The present test result can contribute to enhance the physical insights into the system response during a prolonged SBO with a SGTR occurrence and asymmetric secondary cooling.

2. Test Condition

2.1 Test Facility

The ATLAS is an integral test loop to simulate the thermal hydraulic phenomena of a NPP.[1] The reference plant of ATLAS is the APR1400 (Advanced Power Reactor 1400 MWe), which has a rated thermal power of 4000 MW and a loop arrangement of 2 hot legs and 4 cold legs for the reactor coolant system (RCS). ATLAS is a half-height and 1/288-volume scaled test facility with respect to the APR1400 [2]. ATLAS was designed according to the three-level scaling methodology [3,4] to simulate various scenarios as realistically as possible. Figure 1 shows a schematic diagram of the ATLAS facility.

2.2 Test Condition

In the transient simulation of the prolonged SBO with the SGTR occurrence, the SBO transient was initiated by inducing a trip signal of the reactor core and turbine. When the reactor was tripped, both the RCP (Reactor Coolant Pump) and turbine were stopped. Coincidently with the reactor trip, the main feedwater pumps stopped, and a main feedwater isolation signal (MFIS) was generated to close the main feedwater isolation valves (MFIVs). The main steam isolation valves (MSIVs) were also closed at the initiation of the transient.

SGTR is assumed to occur at SG-1 at the moment that the collapsed water level in the core is lower than the top of the heated section. This assumption in the test was based on the possibility of a SGTR by a highly superheated steam flow from the core. A break tube was installed to simulate a single tube rupture with a choking orifice.

The auxiliary feedwater was supplied only to SG-2 through the down-comer nozzle in a periodic manner, depending on the secondary level of SG-2. In general, the turbine-driven auxiliary feedwater was designed to be supplied at a wide-range level of 25% and terminated at a wide-range level of 40%. However, to simulate a delayed supply of the auxiliary feedwater as an accident management measure, the initial auxiliary feedwater was supplied when the excursion of the maximum heater surface temperature was observed in the present test.

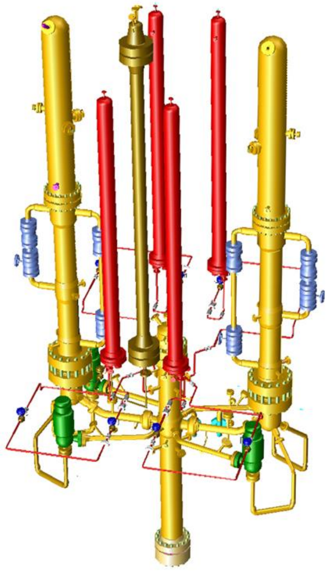

Fig. 1 Bird's eye view of ATLAS [2]

3. Test Result

Figure 2 shows the pressure behavior of the primary and secondary systems in the transient. Because the MFIVs and MSIVs were closed simultaneously with the start of the SBO, the secondary system pressure increased to the set-point that opened a MSSV (Main Steam Safety Valve), and it showed an oscillating behavior according to the opening and closing of the MSSV until dry-out of the SGs. After the secondary side of steam generators dried out by the coolant release through the MSSV, the primary system pressure started to increase due to degradation of the heat removal capacity of the steam generators. The primary system pressure reached the opening set-point of POSRV. During that period, the secondary system pressures of the steam generators decreased slightly due to heat loss to the atmosphere.

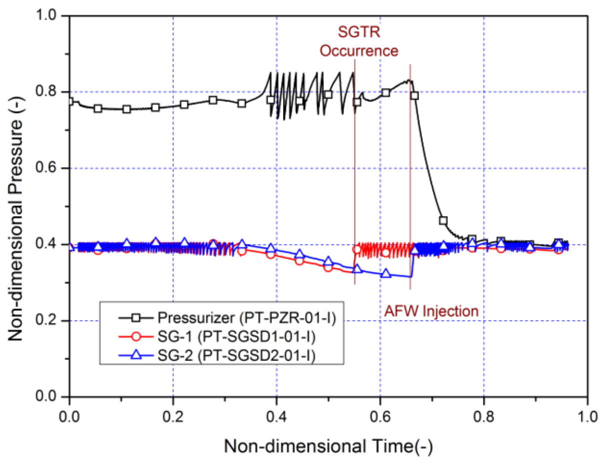

Fig. 2. System pressure during the SBO transient

Figures 3 present the transient behavior of the collapsed water level in the reactor pressure vessel. After the steam generator dry-out, heat-up of the primary system induced an increase in the pressurizer water level. Discharge of the coolant in the primary system through the POSRV decreased the collapsed water level in the core and the downcomer, as revealed in the figure. When coolant inventory in the core was depleted and the active core started to be uncovered, the SGTR occurrence in SG-1 was simulated by opening the valve in the SGTR simulation pipe. Figure 2 shows that the SGTR flow increased the secondary system pressure of SG-1 and that the MSSV started to open and close again. Although the coolant in the primary system was continuously released to SG-1 through the SGTR simulation pipe, the primary system pressure did not decrease. This means that the small area of the SGTR break (simulating a single tube rupture) was not sufficient to depressurize the primary system and that the coolant in the primary system kept a heat-up by the decay heat from the core.

Coolant discharge through the POSRV and SGTR contributed to a decrease in the core water level under the top of the active core; therefore, the surface temperature on the core heaters started to present an excursion behavior as presented in Fig. 4. It induced the auxiliary feedwater injection to SG-2 according to assumption of the test. Supply of the auxiliary feedwater cooled down the primary system effectively, so the system pressure decreased and the core water level was recovered, as shown in Figs. 2 and 3, respectively. The coolant inventory in the core could be recovered by the inflow of the coolant from the pressurizer, that is, the cool-down of the primary system due to the auxiliary feedwater induced a rapid decrease of the pressurizer water level, which led to an increase in the core water level as revealed in Fig. 3. Cool-down by the auxiliary feedwater injection contributed to a decrease in the maximum heater surface temperature, as presented in Fig. 4.

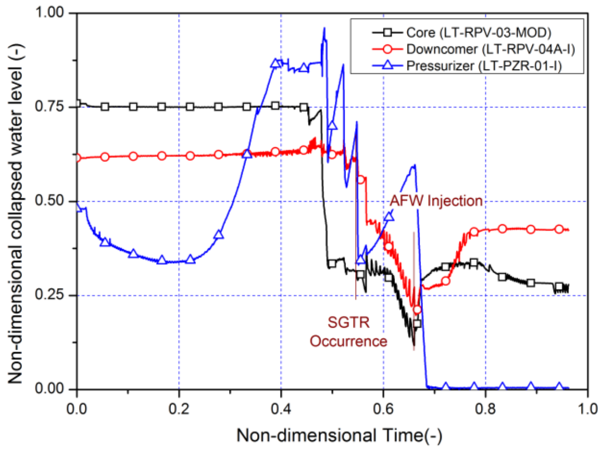

Fig. 3. Primary system coolant level during the SBO transient

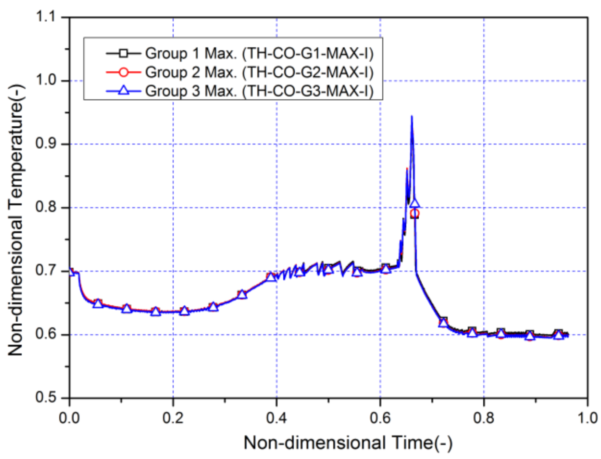

Fig. 4. Maximum heater surface temperature during the SBO transient

4. Conclusions

The integral effect test in the ATLAS test facility was performed to simulate a prolonged SBO with asymmetric secondary cooling and occurrence of a SGTR. The main purpose of this test was to provide physical insight and an experimental database for the system response of the PWR during the scenario of a combined SBO and SGTR. From the transient test result, major thermal-hydraulic parameters such as the system pressures, collapsed water levels, and natural circulation flows in the primary loops were measured and investigated. Periodic discharge of the primary system coolant through the POSRV resulted in core uncovery, so a SGTR was simulated in SG-1. Due to the small size of the tube rupture, the occurrence of the SGTR did not reduce the primary system pressure before the injection of the auxiliary feedwater. Delayed supply of the auxiliary feedwater after an excursion of the heater surface temperature successfully cooled the primary system until the end of the transient. Inflow of the coolant from the pressurizer contributed to recovery of the inventory in the core.

This integral effect test data can be used to evaluate the prediction capability of existing safety analysis codes and identify any code deficiency in predicting an SBO transient with a SGTR occurrence and an asymmetric supply of auxiliary feedwater.

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