Experimental Results of A1.1 Test for OECD-ATLAS Project

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1. Introduction

After the Fukushima accident, design extension conditions (DECs) such as an SBO and a total loss of feed water (TLOFW) attracted wide international attention in that such high-risk multiple failure accidents should be revisited from the viewpoint of the reinforcement of the "defense in depth" concept. In particular, an SBO is one of the most important DECs because a total loss of heat sink can lead to a core melt-down scenario under high pressure without any proper operator action.

KAERI (Korea Atomic Energy Research Institute) is operating an OECD/NEA project (hereafter, OECD-ATLAS project) by utilizing a thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) [1]. Considering the importance of the SBO scenario and the related accident mitigation measures, a prolonged SBO scenario was selected as the first test subject worthy of investigation in the OECD-ATLAS project as summarized in Table 1. As for a prolonged SBO transient of the OECD-ATLAS project, two tests, named A1.1 and A1.2, were determined to be performed.

Table I: Test Matrix for the OECD-ATLAS Project

Topics	Tests	Remarks
A1-Prolonged SBO		
- Asymmetric 2nd cooling	1	Asymmetric FW supply and additional failure
- Asymmetric passive 2nd cooling	1	Asymmetric passive FW supply (ex. PAFS)
A2-SBLOCA during SBO		
- SBO+RCP seal failure	1	Effects of leakage flow rate
- SBO+SGTR	1	TISGTR
A3-TLOFW		
- 1ry & 2nd bleed + 1ry feed	1	With additional failure such as stuck open POSRV, ATWS, and a SGTR
A4-MBLOCA		
- PZR surge line break (10-inch)	1	Safety injection through cold leg (or DVI)
A5-Open items	2	Counterpart test for addressing scaling issues
Total	**8**	

In most nuclear power plants (NPPs), a turbine-driven auxiliary feedwater system was designed to remove the decay heat during the early period of an SBO transient. From a conservative point of view, however, it is necessary to investigate the thermal-hydraulic behaviors of the NPP when a turbine-driven auxiliary feedwater supply is not available during the initial period of an SBO transient and moreover a mobile pump-driven auxiliary feedwater supply can only become realized in the later period of the scenario. In particular, asymmetric heat removal characteristic through the supply of auxiliary feedwater only to one steam generator has its own peculiar importance in terms of safety analysis code validation. With an aim of considering these safety importance, in the A1.1 test, a prolonged SBO transient was simulated with two temporal phases: Phase (I) for a conservative SBO transient without the supply of active auxiliary feedwater, and Phase (II) for asymmetric cooling through the supply of active auxiliary feedwater only to one steam generator. To investigate the effects of the delayed supply of auxiliary feedwater as an accident management measure, the auxiliary feedwater was supplied when the maximum heater surface temperature in the core reached 450 ^{o}C.

2. Description of the A1.1 Test

The target scenario for the A1.1 test is a prolonged SBO with asymmetric secondary cooling through the delayed supply of active auxiliary feedwater only to SG-2. In the A1.1 test, any active component such as a safety injection pump (SIP) is unavailable. However, passive components such as a pilot-operated safety relief valve (POSRV) and a main steam safety valve (MSSV) are assumed to be available. Coincidently with the reactor trip, 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.

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 be terminated at a wide-range level of 40%. However, to simulate the delayed supply of auxiliary feedwater as an accident management measure, the auxiliary feedwater was started to be supplied when the maximum heater surface temperature in the core reached 450 ^{o}C in the A1.1 test.

The decay heat was simulated to be 1.2-times that of the ANS-73 decay curve from a conservative point of view. The initial heater power was controlled to be maintained at about 1.643 MW, which was equal to the sum of the scaled-down core power (1.565 MW) and the heat loss rate of the primary system (about 80 kW). The heater power was then controlled to follow the specified decay curve after 12.07 seconds from the reactor trip.

3. Experimental Results

3.1 Overall Thermal-Hydraulic Behaviors

Overall system behaviors observed in the A1.1 test is shown in Fig. 1. With the start of the SBO, the reactor, all four RCPs, turbine, MFIV, and MSIV were tripped simultaneously. The failure of the main feedwater supply and MSIV closure led to an increase of the secondary system pressure until the set point of the opening of a MSSV. The secondary side inventory of steam generators were discharged into the condensation tank through MSSVs, and the secondary side became dried out in both steam generators. A collapsed water level in SG-2 was recovered after the supply of auxiliary feedwater.

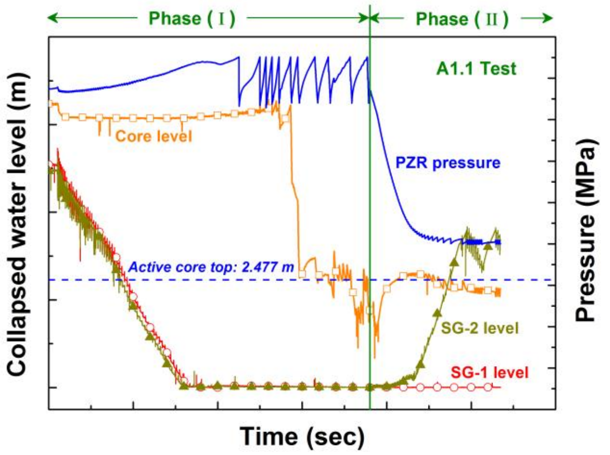

Fig. 1. Overall system behaviors observed in the A1.1 test

After the secondary side of steam generators became dried out, the primary system pressure started to increase due to degradation of the heat removal capacity of the steam generators. A periodic discharge of the primary inventory through the POSRV resulted in a core uncovery and finally the core wall temperature started to increase. In the A1.1 test, the auxiliary feedwater was supplied when the maximum heater surface temperature reached 450 ^{o}C. Supply of the auxiliary feedwater led to the recovery of the core level and cool-down of the core.

3.2 Effect of Delayed Asymmetric Secondary Cooling

Natural circulation flow was established after the RCP trip, and a single-phase natural circulation flow was maintained until the steam generators became dry-out. Voiding at the top of the U-tube interrupted the single-phase natural circulation flow and then the two-phase natural circulation flow continued until the upper plenum of the core became empty. After the primary inventory loss through the POSRV began, the natural circulation flow became degraded, as shown in Fig. 2. Depending on the heat removal capacity of the steam generators, the natural circulation flow characteristics showed different trends in the primary loops. Contrary to the loop-1 where the auxiliary feedwater was not supplied, the natural circulation flow started to recover in the loop-2 after the supply of the auxiliary feedwater was initiated.

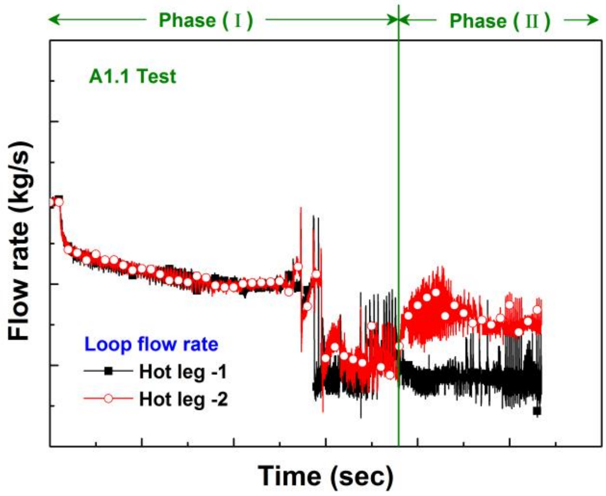

Fig. 2. Flow rates in the hot legs

4. Conclusions

As the first test of the OECD-ATLAS project, the A1.1 test was performed to simulate a prolonged SBO with asymmetric secondary cooling through the delayed supply of auxiliary feedwater only to SG-2. In the A1.1 test, after the primary inventory loss started through the POSRV, the natural circulation flow became degraded. Depending on the heat removal capacity of the steam generators, the natural circulation flow characteristics showed different trends in the primary loops. An asymmetric cooling pattern was clearly observed during the period when the auxiliary feedwater was supplied.

This integral effect test data of the A1.1 test can be used to evaluate the prediction capability of the current safety analysis codes and to identify any code deficiency for an SBO simulation especially focused on the effect of an asymmetric supply of the auxiliary feedwater.

Acknowledgements

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[1] C.-H. Song et al., "ATLAS Program for Advanced Thermal-Hydraulic Safety Research", Accepted to *NED Special Issue* (IW-NRTHS, Mumbai, India, Jan. 13-15, 2014), 2015.