Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Experimental Investigation on the Core Quench Phenomenon under a Low Reflooding Rate Condition using the ATLAS

Hyun-Sik Park, Ki-Yong Choi, Seok Cho, Kyoung-Ho Kang, Dae-Hun Kim,
Byong-Jo Yun, Tae-Soon Kwon, Won-Pil Baek and Yeon-Sik Kim
Thermal Hydraulics Safety Research Division, Korea Atomic Energy Research Institute
1045 Daedeokdaero, Yuseong, Daejeon, 305-600, Korea
**Corresponding author: hspark@kaeri.re.kr*

1. Introduction

Recently KAERI has performed a set of reflood tests [1, 2] by using the ATLAS facility (Advanced Thermal-Hydraulic Test Loop for Accident Simulation) [3] which is a thermal-hydraulic integral effect test facility for the pressurized water reactors of APR1400 and OPR1000. The reflood tests include both Phase-I and Phase-II tests. Phase-I tests are parametric effect tests for a reactor vessel downcomer boiling during the LBLOCA late reflood period and Phase-II tests are integral effect tests for the thermal-hydraulic phenomena in the downcomer and the core during the LBLOCA reflood period to provide the peak cladding temperature data for an evaluation of the safety analysis code and the corresponding licensing methodology. However, both the Phase-I and Phase-II tests are not easily simulated by the existing codes such as the RELAP5/MOD3 and there is a need from the industry to perform a separate effect test under a low reflooding rate condition using the ATLAS to help validate the RELAP5 reflood models. The present paper provides the experimental results for the separate effect test by using the ATLAS.

2. Test Conditions

The experimental conditions were decided based on the discussion between KHNP, KNFC, and KAERI researchers. The present separate effect test could provide a data peculiar to the APR1400, which includes the thermal-hydraulic phenomena of the direct vessel injection (DVI), reverse heat transfer from the steam generator and steam binding effect throughout the primary loop.

First of all, the existing KAERI reflood test results with single and 6-by-6 bundle tests were analyzed to show that the core heater was always cooled by droplets for the various ranges of reflooding rates. A sensitivity analysis of the 6-by-6 bundle tests were also performed to investigate the effect of the reflooding velocity, initial heater surface temperature and heater power by using the MARS code. It showed that the heater rods were rapidly quenched with the increase of the reflooding rate.

In the present test the ECC water from a safety injection pump was supplied through four SI lines, instead of two which has the assumption of a single failure, to reduce the pressure at the pump discharge line. The opening degrees of the flow control valves were adjusted to give a pre-determined flow rate of 0.3 kg/s each. In the ATLAS facility the ECC water was supplied from the RWT and the temperature of 50^{o}C was kept the same as that of APR1400. The containment simulator pressure was fixed at around 0.10 Mpa and the initial outer wall temperature was determined to be 150^{o}C when the downcomer boiling is negligible. The intial heater surface temperature was set to be 300^{o}C to prevent high temperature trip. The initial heater power was fixed to the scaled-down power of 490.5 kW which is corresponding to the downcomer wall temperature and it decayed down following the 102% of ANS-79 decay curve during the test. The power distribution was uniform along a radial direction. The secondary pressure was set to be around 5.0 MPa to consider the effects of a reverse heat transfer and steam binding.

3. Test Procedure

When the water level in the core region reached a specified level and all the other initial conditions of the test were stabilized, the test condition was considered to have reached an initial condition of the reflood test. After this, the core power was inserted to increase linearly from 0 to a specified initial heater power and to maintain the core power until the maximum heater rod surface temperature reached a specified surface temperature of 300^{o}C, which generated a SI pump injection signal. It was assumed that the reflood started about 2 seconds after the SI pump injection signal. With the start of the reflood, the heater power is triggered to follow the specified decay heat, which is 1.02 times that of the ANS-79 decay curve. The SI pump was operated to obtain a flow rate of 0.30 kg/s through four DVI lines. The temperature rises of the heater rods, the dowmcomer wall temperature and the void fractions of the core and downcomer regions were monitored during the test. Generated steam and entrained water flowed via broken and intact loops into two separating vessels of the containment simulator. The steam was vented to the atmosphere to maintain a constant pressure in the containment simulator and its flow rate was measured with a turbine flowmeter.

4. Test Results and Discussion

A separate effect test with a low reflooding rate was performed to provide the typical thermal-hydraulic data to assess the reflood models of the safety analysis code. Figure 1 shows the variation of the pressures in the RPV and the temperatures in the downcomer. The overall pressure trend showed the test procedure of a steady state condition, trip, vent, drain, break initiation, and SI pump injection. While the pressure in the primary system decreased to 0.1 MPa, the fluid wall temperature in the downcomer region also decreased. The fluid temperature decreased rapidly after the water inventory began to be drained and the wall temperature decreased rapidly after the ECC water from the SI pump was injected into the reactor pressure vessel. After the SI pump flow rate and the core power were introduced, the reflood test started at 1244 seconds from the beginning of the DAS and its averaged wall temperature was 174°C, which is higher than the target value of 150°C. It is because the wall temperature decreases slower than expected due to the uncovery of the downcomer wall surface.

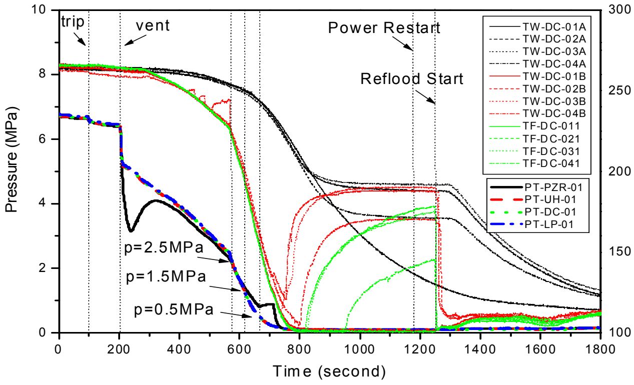

Figure 1 Variation of the pressures in the RPV and temperatures in the downcomer

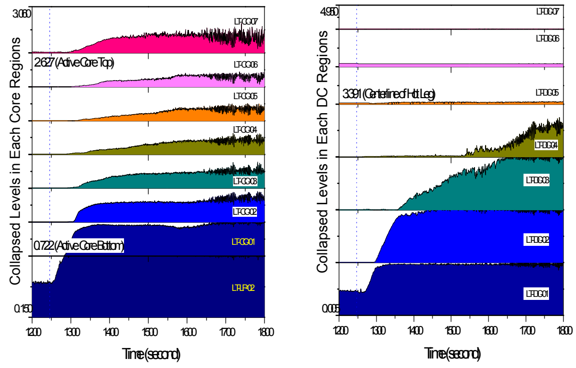

Figure 2 Variation of the sectional water levels in the downcomer and core

Figure 2 shows the sectional water level variations of the reactor pressure vessel both in the core and downcomer regions. When the reflood test started with the initiation of the core power and SI pump flow rate, the sectional water levels of both in the core and downcomer regions increased from the lower part gradually as the downcomer wall cooled down. The cooling capacity of the SI water overcomes the decay heat from the core and the stored energy from the reactor pressure vessel.

Figure 3 shows the maximum surface temperature variations of the core heater rods during the test. The maximum surface temperature of the heater rod was about 584°C. The entire rewetting process was finished by about 306 seconds after the reflood start time.

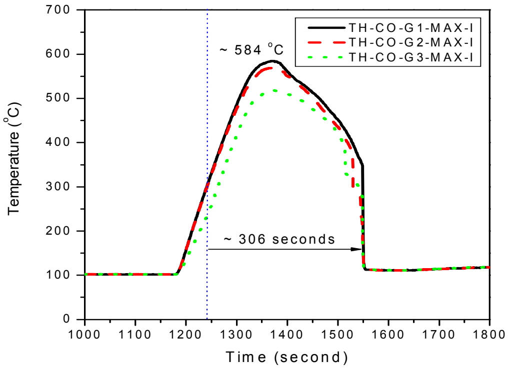

Figure 3 Variation of the maximum heater rod surface temperatures

5. Conclusion

A separate effect test was performed under a low reflooding rate condition by using the ATLAS, which is a thermal-hydraulic integral effect test facility constructed and operated by KAERI. The experimental results showed a gradual reflooding in the core and a cooling of the core heater rods and the reactor pressure downcomer. The experimental data could be used to evaluate and revise the reflood models of safety analysis codes such as RELAP5/MOD3.

REFERENCES

[1] Park, H.S., Choi, K.Y., Cho, S., et al., "Recent ATLAS Test Results on the Late Reflood Period of the Large-Break LOCA for APR1400," IAEA Topical Meeting on Advanced Safety Assessment Methods for Nuclear Reactors, Daejeon, Korea, Oct. 30-Nov.1 (2007).

[2] Park, H.S., Choi, K.Y., Cho, S., et al., "An Integral Effect Test on the Reflood Period of a Large-Break LOCA for the APR1400 Using the ATLAS," Proceedings of ICAPP '08, Anaheim, CA USA, June 8-12 (2008).

[3] Baek, W. P., Song, C.H., Yun, B.J., et al., "KAERI Integral Effect Test Program and the ATLAS Design," Nuclear Technology 152, 183 (2005).