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Cooling Characteristics with Partial Core Blockage during Long Term Cooling Period of Hot-Leg LBLOCA

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1. Introduction

During a loss-of-coolant accident (LOCA), the coolant is recirculated from a containment sump to a reactor coolant system (RCS). The debris, which is mainly composed of fragments of pipe and insulator stripped off at a break location, can be filtered by sump strainer. Some of debris, however, can pass the strainer and it may collect on the surface of the fuel assembly (FA) bottom nozzle or adhere on the cladding. The collected debris leads to a flow resistance which results in decreasing the coolability at the core.

In order to resolve this safety issue, various experimental studies with separate effect test facility [1] and code simulations [2, 3] were performed. The integral effect test data, however, are quite limited. In the present study, a core blockage effect test was performed with a thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation). A long term cooling phase of hot leg large break loss of coolant accident (LOCA) was simulated and the core blockage ratio was increased gradually from 0 to 93.2 %.

2. Experimental Facility

With an aim of simulating a gradual blockage at the bottom of core, a partial blockage module was installed at the flow skirt of ATLAS reactor pressure vessel (RPV) as shown in Fig. 1. Fig. 2 shows a photograph of the core blockage module. The blockage module is composed of three parts – inner, middle, and outer cylinder. Inner cylinder is fixed cylinder which has all flow holes. Middle cylinder has relatively large holes and outer cylinder has smaller holes. The middle cylinder closes the large holes of inner cylinder and the outer cylinder closes the small holes of inner cylinder while they are rotated.

A blockage ratio is controlled by a rotation angle of three parts of blockage module. During the test, it is impossible to directly monitor the blockage ratio. Therefore, a correlation between the blockage ratio and the rotation angle of cylinders was developed by performing a blockage characteristic test before the main test. Based on the correlation, the blockage ratio can be estimated according to the rotational angle of cylinders in the present test.

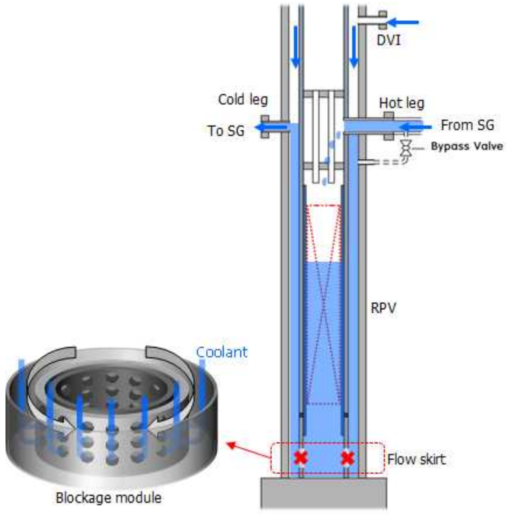

Fig. 1. Location of partial core blockage module

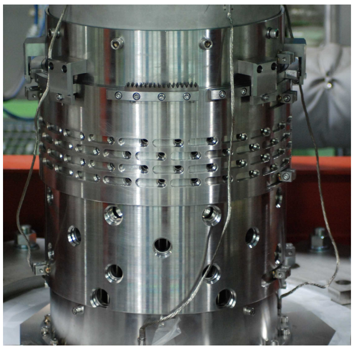

Fig. 2. Photograph of partial core blockage module

3. Experimental Conditions

As a target scenario for the present test, a hot-leg LBLOCA was selected since this transient can be a limiting case of a partial core blockage from a safety point of view. Considering the simulation capability of ATLAS as an integral effect test facility, a long term cooling phase of LBLOCA was only simulated in the present test. Fig. 3 shows a schematic diagram of break location for a hot-leg LBLOCA. According to the previous separate effect test and code analysis results, the debris may reach the sump strainer after 1500 ~ 18000 seconds from a break [4]. So, the initial conditions of present test were determined as pre-defined values based on 1500 seconds after a break. The initial test conditions were obtained from the pre-calculation results by utilizing MARS-KS code [5].

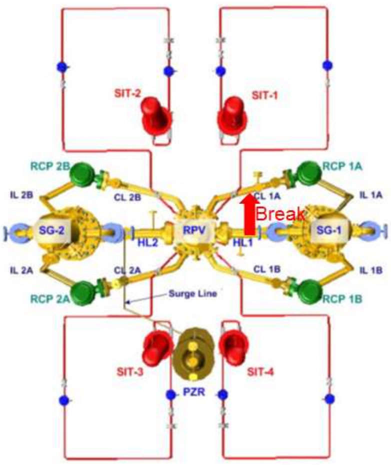

Fig. 3. Schematic diagram of break location

4. Experimental Results

Fig. 4 shows the core power applied in the present test. This curve is based on the 1.2*ANS73 curve after 1060 seconds for ATLAS test (1500 seconds for referenced nuclear power plant).

Fig. 5 is a variation of blockage ratio during the whole test period. The maximum core blockage ratio was 93.2 % in the present test. A complete blockage could not be reached because the blockage module had a problem in smoothly moving at the high pressure and temperature conditions of the present test.

At the beginning of test, the core level was lower than hot leg. After injection of the safety injection water from a safety injection pump (SIP), the core and downcomer levels increased as shown in Fig. 6. After the core level reached the hot leg, the level was maintained because the mass balance between the safety injection and the break was established.

The differential pressure across the blockage module was measured to investigate the pressure drop characteristics induced by core blockage as shown in Fig. 7. During the whole test period, the differential pressure was very low (less than 0.1 kPa) resulting from the very low core flow rate since the target transient was a long term cooling phase of LBLOCA. The differential pressure was not remarkably affected by the core blockage up to 93.2% as shown in Fig. 7.the blockage ratio for 0 ~ 93.2 % blockage condition.

Even though the core inlet was blocked up to 93.2%, any excursion of core surface temperature was not observed as shown in Fig. 8 which indicates an effective cooling despite a highly blocked condition.

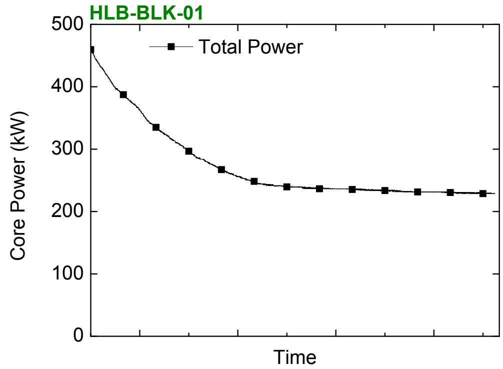

Fig. 4. Variation of core power

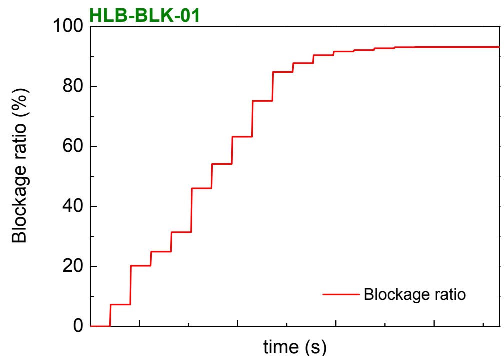

Fig. 5. Variation of blockage ratio

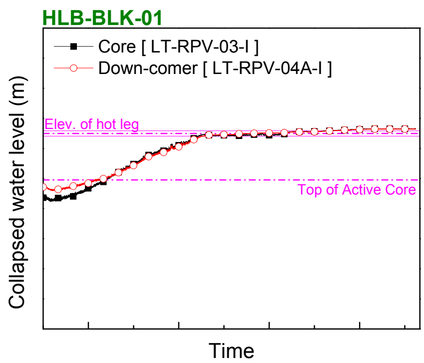

Fig. 6. Core and Down-comer collapsed water levels

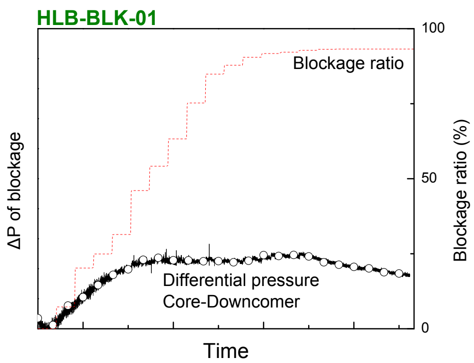

Fig. 7. Differential pressure across the core blockage module

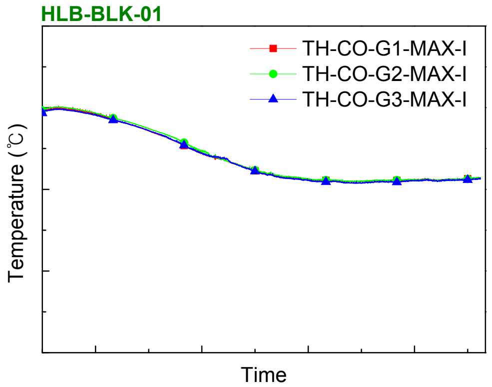

Fig. 8. Variation of the maximum core temperature

5. Conclusions

The effect of core partial blockage in terms of core cooling was synthetically investigated with ATLAS. A long term cooling phase of hot LBLOCA was simulated and the core blockage ratio was increased gradually from 0 to 93.2 % in the present test. It can be concluded from the present test results that even though a core inlet is blocked up to 93.2% the core can be effectively cooled.

Acknowledgement

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