Investigation on Clearance of the Upper Downcomer during ATLAS Test for DVI Line Break

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1. Introduction

According to a risk-informed regulation (RIR), an intermediate-break loss-of-coolant accident (IBLOCA) can reduce unnecessary burden of designing a safety system for the nuclear reactor safety [1]. To validate a safety analysis code for an IBLOCA scenario, a thermal hydraulic integral effect test data is essential to understand two-phase flow phenomena during the transient. Also, extension of the experimental database for various conditions of break position and safety injection is required to address remaining safety issues on an IBLOCA. So that, an international co-operation project OECD-ATLAS2 selected a direct vessel injection (DVI) line break accident as B3.2 test item by utilizing an integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) [2]. This study focuses on a thermal hydraulic transient for the DVI line break scenario in the ATLAS test. In particular, an effect of the clearance of the loop seals and the upper downcomer was analyzed with respect to the nuclear reactor safety.

2. Test Facility and Condition

ATLAS is an integral effect test facility for an advanced light water reactor constructed at KAERI (Korea Atomic Energy Research Institute). The scale of ATLAS is a half-height and 1/288-volume with respect to APR1400 (Advanced Power Reactor 1400 MWe) and ATLAS was designed according to the three-level scaling methodology [3]. Initial steady-state conditions in the B3.2 test of the OECD-ATLAS2 project were based on those of APR1400. Applying the scaling ratio of each operation parameter, the initial and boundary conditions for the present test were obtained.

An overall configuration of the safety injection (SI) and break location in the test is given in Fig. 1, where the DVI-3 was assumed to be broken. To preserve similarity in a double-ended guillotine break of a DVI line of APR1400 (8.5 inch pipe), the inner diameter and the length of the break nozzle were designed to be 15.13 mm and 191.6 mm, respectively. The SI water from the SIP (Safety Injection Pump) and SITs (Safety Injection Tanks) was injected through intact DVI nozzles which are connected to an upper downcomer of reactor pressure vessel (RPV). According to a single failure assumption with more conservative condition, only a single SIP through DVI-1 nozzle was available. For the SIT injection, three SITs of SIT-1, 2, and 4 were used in the test.

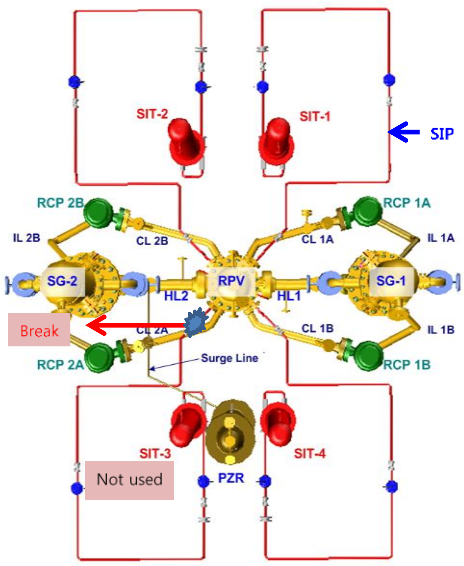


Fig. 1. Break and safety injection system in B3.2 test

3. Test Results

As agreed in the OECD-ATLAS2 project, the test data should be confidential until the year of 2023. So that, all of the test results in this paper including the time frame (t*) were divided by an arbitrary value and plotted on the non-dimensional axis.

Figure 2 shows the primary system pressure of the reactor coolant system in the B3.2 test. After the initiation of the break at t*=0.03, a rapid depressurization of the primary system induced a reactor trip. The primary system pressure showed a plateau around t*=0.04, when the primary and secondary system pressures became a state of nearly equilibrium. Decrease of the coolant level in the downcomer changed the break flow from a liquid-dominant two-phase flow to a vapor-dominant two-phase flow, so that the primary system pressure decreased steeply again after the end of the plateau region.

Maximum heater surface temperature showed an excursion behavior during the early period after the break, where the peak cladding temperature was measured at t*=0.41. Increase of the cladding temperature and the core heat-up were closely related to a behavior of the coolant inventory in the RPV. The maximum cladding temperature of the core heaters was compared to the water level of a reactor core, an upper downcomer, and intermediate legs during the excursion period in Fig. 3. Excursion of the reactor core temperature started according to continuous decrease of the core water level after t*=0.037, while the loop seal and the downcomer were still filled with the water. From t*=0.039, coolant in the loop seals started to be cleared due to a larger buildup of the steam pressure in the core. Even though the loop seal was cleared, a remained coolant in the upper downcomer prohibited an effective release of the steam flow toward the DVI line break. So that, the core water level was maintained low and the cladding temperature kept increasing until the coolant in the upper downcomer was cleared around t*=0.041. This phenomenon of clearing the coolant in the upper downcomer can be regarded as an additional prerequisite for a cool-down of the reactor core during a DVI line break.

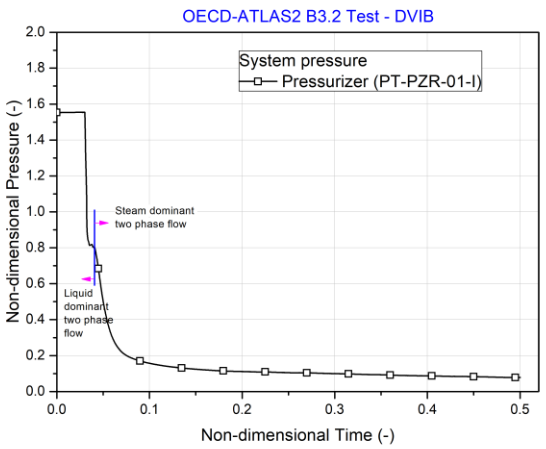


Fig. 2. Pressurizer pressure in ATLAS B3.2 test

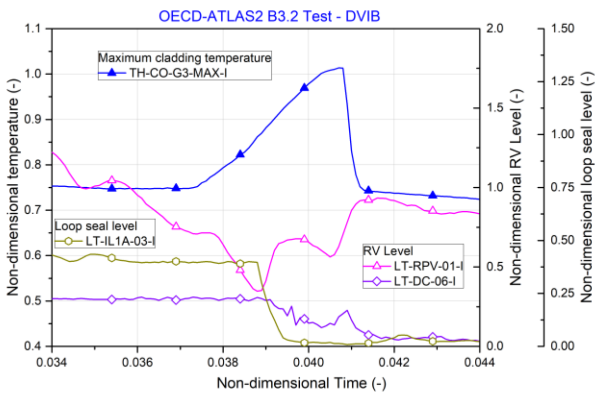
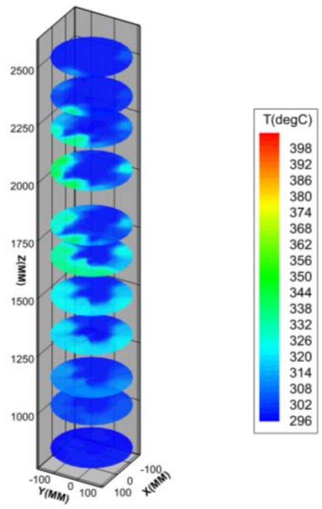
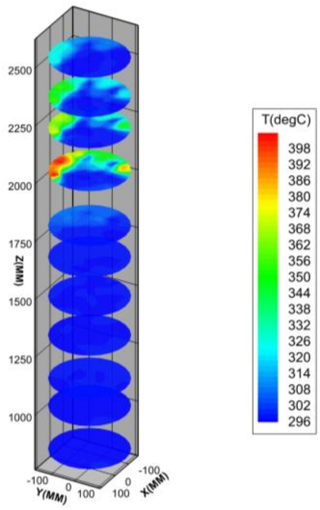


Fig. 3. Coolant level and cladding temperature in ATLAS B3.2 test

A contour of the cladding temperature was plotted in Fig. 4 by interpolating all temperature measurements. For both of the moment at the lowest core water level and the peak cladding temperature, a larger heat-up of the heater was observed around an outside region of core (Group 3). Considering that a uniform power distribution for all heater rods was applied in the reactor core, the higher cladding temperature in Group 3 was attributed to a smaller flow or cooling capability in the outside region.



(a) At the lowest core water level



(b) At the peak cladding temperature

Fig. 4. Maximum cladding temperature in ATLAS B3.2 test

4. Conclusions

The B3.2 test of the OECD-ATLAS2 project was performed to simulate a DVI line break IBLOCA by utilizing the ATLAS facility. An 8.5-inch break of the DVI line was simulated and a single failure of the SIPs was assumed. From the test result, the DVI line break induced a rapid depressurization of the primary system and a blowdown of the coolant of the RPV. It made a steam pressure build-up in the reactor core and an excursion behavior of the cladding temperature. The minimum water level in the reactor core was observed at the moment of the loop seal clearance. Since the break nozzle was located at the DVI line, the clearance of the upper downcomer could make an effective flow path of the steam toward the break and quench the reactor core. The maximum cladding temperature was observed before the clearance of the upper downcomer.

The B3.2 test data can be used to evaluate the capability of thermal hydraulic safety analysis codes in predicting an IBLOCA transient. Also, detailed experiment results with respect to an asymmetric and multi-dimensional thermal-hydraulic phenomenon will be used to validate the code prediction and identify a deficiency in the constitutive models.

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