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Integral Effect Test of Steam Line Break Accident using ATLAS-CUBE (Containment Utility for Best-estimate Evaluation) Facility

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1. Introduction

Safety analysis of a nuclear reactor containment is essential to evaluate the integrity of the containment during an anticipated accident in a nuclear power plant. In particular, Fukushima accident showed an importance of the containment safety even in a design extension condition (DEC). Major thermal hydraulic phenomena in the containment are dependent on the amount of the mass and energy (M/E) supply from a reactor coolant system (RCS), while the condition of the reactor containment such as a pressure and temperature (P/T) can also affect the transient behavior of the RCS during the accident.

In this study, an experimental investigation on the interaction between the RCS and containment was performed with construction of an integral effect test facility, ATLAS-CUBE. ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) has simulated the thermal hydraulic transient of the RCS and a containment simulation vessel including compartment structure, connection pipe, and spray system was designed and constructed, which was named as CUBE (Containment Utility for Best-estimate Evaluation). Considering the importance of interaction between the RCS and the containment, a steam line break (SLB) scenario was simulated in the facility.

2. Test Facility

ATLAS is an integral effect test facility for simulating a thermal hydraulic transient in the RCS of a pressurized water reactor.[1] According to the three-level scaling methodology[2], it has a scale of a half-height and 1/288-volume with respect to APR1400 (Advanced Power Reactor 1400 MWe)[3]. The containment simulation vessel in the ATLAS-CUBE facility was designed to conserve the equivalent volume ratio to the ATLAS. The design specification of the containment simulation vessel was summarized in Table I and the arrangement of the ATLAS-CUBE facility was shown in Fig. 1.

Table I : Design of containment vessel in the ATLAS-CUBE facility

Parameter	Design value
Inner diameter	6.0 m
Cylinder height	10.03 m
Dome height	1.5 m
Total free volume	340 m^3

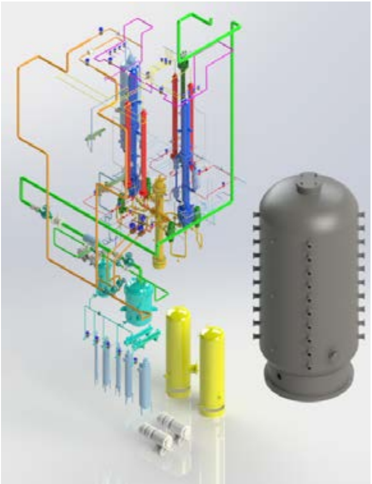

Fig. 1 Arrangement of ATLAS-CUBE facility

The containment simulation vessel of the ATLAS-CUBE test facility incorporated compartment structures, which could play a role of a passive heat sink during the accident transient. Major components of the compartment structures such as a primary shield wall (PSW), a secondary shield wall (SSW), steam generator (SG) compartment walls, a pressurizer (PZR) wall, a pedestal floor (PF), and an in-vessel refueling water storage tank (IRWST) wall were considered as shown in Fig. 2. In order to conserve the scale of the passive heat sink, CT-140 (a refractory) was selected as a material of the compartment structures due to a high heat capacity and a low thermal conductivity. The facility also included a spray system to cool down the steam-air mixture in the containment and a pipe connection system to supply the M/E from the ATLAS RCS. Instrument system of the facility was constructed to measure a multi-dimensional thermal hydraulic behavior inside the containment, including the pressure, temperature, and flow rates. Figure 3 shows the distribution of the fluid temperature measurements.

Fig. 2 Internal structure of the containment simulation vessel

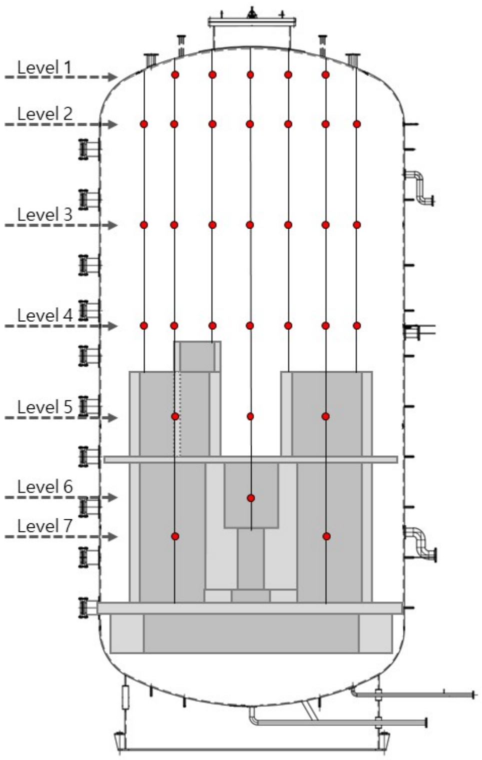

Fig. 3 Temperature measurement of the containment simulation vessel

3. Test Results

The ATLAS-CUBE test facility was utilized to perform an integral effect test for the SLB transient (SLB-CT-01), for investigating interaction behavior of the RCS and the containment. After achieving a steady state condition in the ATLAS according to a normal operation of the APR1400, the SLB was simulated on the SG-1 steam line. Auxiliary feedwater was assumed to be available, so that it could supply the coolant after the secondary system inventory was depleted. Safety injection pump (SIP) was activated according to a decrease of the primary system with a single failure assumption, and a spray system in the containment was operated at a high pressure signal of the containment.

Figure 4 shows the system pressure of the reactor containment in the SLB test. After the initiation of the break at t*=0.03, a rapid build-up of the containment pressure was observed due to a large amount of the M/E supply from the break. The pressure was decreased due to the heat transfer with the passive heat sink in the containment until t*=0.08, then showed an increasing behavior again until the activation of the spray system at t*=0.37. The result pointed out that the design of the spray system had a sufficient capability to cool down the containment and prevent a further pressure build-up.

The steam-air mixture temperature inside the containment was plotted in Fig. 5, which compared an axial distribution at the center of the vessel. The mixture temperature above the SLB simulation level in the containment (Level 01 ~ 04) presented a similar behavior to the containment system pressure. However, the mixture around the compartment structures (Level 05 and 06) was maintained with a lower temperature, since a high-temperature steam injection could not sufficiently mix the fluid inside the containment. This result pointed out that a multi-dimensional distribution of the fluid temperature around the passive heat sink should be considered to realistically estimate a build-up behavior of the P/T in the containment.

Figure 6 compares a surface temperature of the compartment structures in the containment. As the steam injection pipe is located above the SG compartment wall, most of the compartment maintained a low temperature compared to the steam-air mixture temperature except the SG compartment wall and the pressurizer compartment wall. After activation of the spray system, the compartment wall temperature was well mixed to show a nearly uniform distribution. Since the coolant in the spray system was circulated from the IRWST, the temperature of the fluid or the compartment wall inside the containment kept increasing until the end of the test.

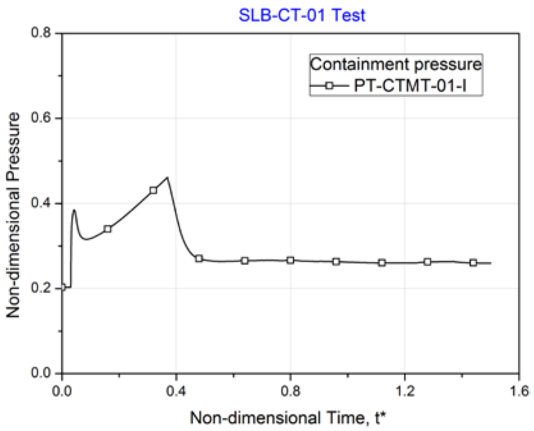

Fig. 4. Containment pressure in SLB-CT-01 test

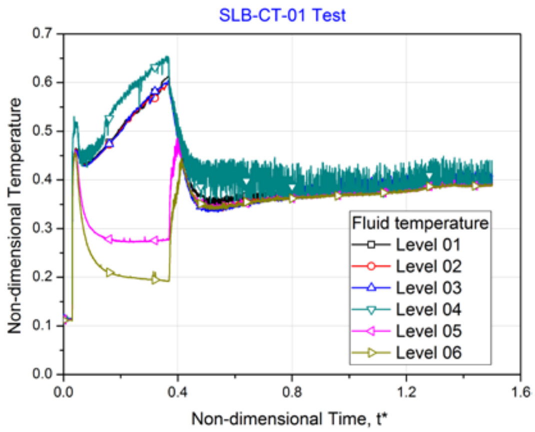

Fig. 5. Steam-air mixture temperature in SLB-CT-01 test

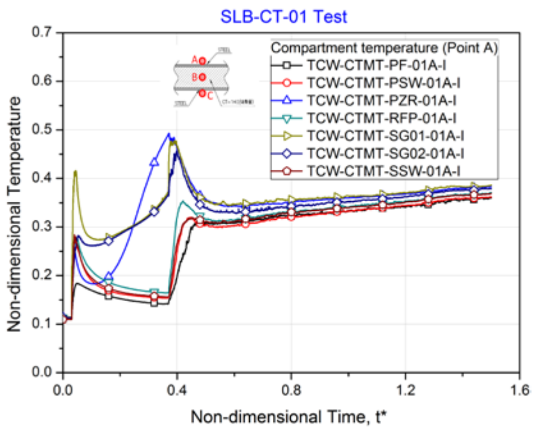

Fig. 6. Compartment wall temperature in SLB-CT-01 test

4. Conclusions

ATALS-CUBE test facility has been designed and constructed to investigate the interactive behavior of the RCS and containment, so that the integral effect test could be performed to extend a scope of the analysis to the containment. The containment simulation vessel preserved the volumetric scale to that of the RCS and the compartment structures inside the containment were designed to play a role of the passive heat sink.

As the first integral effect test after the construction of the facility, the SLB transient was simulated by injecting a break flow from the steam line into the containment. Since the steam injection was located above the compartment structures and a high-temperature steam was accumulated in the upper part of the vessel, a stratified behavior of the fluid and wall temperature was observed in the containment. This pointed out that a multi-dimensional approach in analysis of the P/T in the containment would be essential to realistically reflect the heat transfer of the passive heat sinks. After activation of the spray system, the steam-air mixture and the compartment wall temperature showed a sufficiently mixed distribution.

The integral effect test data performed in the ATLAS-CUBE test facility will be able to contribute to validate the evaluation methodology for M/E and P/T transient of the containment.

ACKNOWLEDGMENTS

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