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Validation of CAP Code for Containment Steam Injection Test in ATLAS-CUBE Facility

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1. Introduction

Safety analysis of a reactor containment is essential to evaluate the integrity of a nuclear power plant during an accident. The thermal hydraulic behavior in a containment has been intensively investigated within various areas including the experimental or analytical studies. In the field of experimental study to incorporate both systems of a reactor coolant system (RCS) and a containment, the ATLAS-CUBE (Advanced Thermal-hydraulic Test Loop for Accident Simulation – Containment Utility for Best-estimate Evaluation) test facility was constructed in KAERI (Korea Atomic Energy Research Institute) [1]. With an aim of analytical investigation to validate the integrated analysis platform for the containment safety, the CAP (Containment Analysis Package) code was developed for a lumped analysis of the containment [2].

The objective of this study is to validate the CAP code with the ATLAS-CUBE test data, focusing on the steam injection tests with well-quantified boundary conditions. The single and multi-volume models for the CAP code were used and the transient of the pressure and the temperature in the containment simulation vessel was investigated.

2. Test Condition

2.1 ATLAS-CUBE test facility

A thermal-hydraulic integral effect test facility, ATLAS, has been constructed to simulate various scenarios in the RCS as realistically as possible [3]. The CUBE facility was designed to simulate the thermal hydraulic phenomena inside a containment and connected to the RCS of the ATLAS facility. It is composed of a containment simulation vessel, a compartment structure, and a containment safety system. The volume of the containment vessel in CUBE is maintained to 1/288 of the APR1400 reactor containment, which is equivalent to the volume ratio between APR1400 and ATLAS. CUBE is composed of geometrically simplified compartments with APR1400, including primary shield wall, secondary shield wall, steam generator compartments, pressurizer compartment, pedestal floor, operating floor, in-containment refueling water storage tank, hold-up volume tank, etc.

2.2 ST2 test condition

This study utilized the ST2 test series of the ATLAS-CUBE facility [4]. In the ST2 tests, the ATLAS RCS only served to supply the superheated steam to CUBE. The thermal power was applied to the ATLAS core simulator. The feedwater as the target steam supply mass flow rate of 0.2 kg/s was supplied to the secondary side of steam generators through the auxiliary feedwater line. Figure 1 shows the main piping connections and instruments involved in supplying steam from the ATLAS steam generators to CUBE. In the present study, the test results of ST2-CT-01 (upward), -02 (downward), and -03 (horizontal) were analyzed according to the steam supply direction in the containment simulation vessel. The steam was supplied with a flow rate of ~0.2 kg/s. In the case of the ST2-CT-03 test, the cooling performance of the containment spray system was examined.

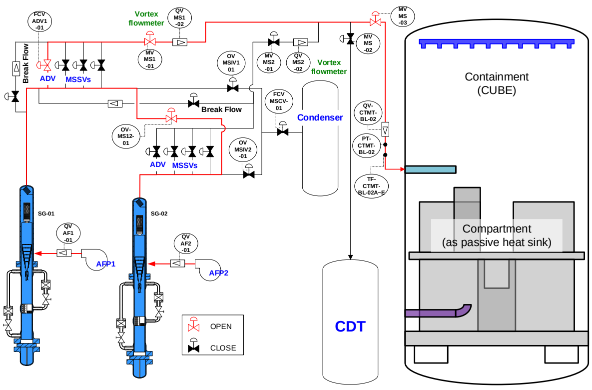

Fig. 1. A schematic diagram for the ATLAS-CUBE steam injection test

3. Calculation Result

The steam injection test result in the ST2 tests was utilized to assess thermal hydraulic analysis codes for the containment. The CAP code calculation with version 2.3 was performed with a single-volume model and a multi-volume model. The single-volume model simulated the free volume of the steam-gas mixture inside the containment simulation vessel with a single volume, whereas the multi-volume model divided the free volume into several compartment rooms with the connecting flow path. The spray injection was not simulated in the calculation case with the multi-volume model, since a droplet field cannot be transported across a junction in the CAP code.

Figures 2 and 3 compared the containment pressure and the dome temperature of the CAP code calculation to those of the test result in the ST2 test series. The experimental results showed a dependency on the steam injection direction. That is, the steam injection in the upward direction presented the higher increasing rate of the pressure or temperature, whereas the test result with the downward injection showed the lower pressurization rate. Thermal stratification inside the reactor containment became more significant in the upward direction case, so that a relatively cold steam-gas mixture around the lower region of the containment affected to the degradation of the condensation heat transfer at the surface of the compartment structures or the containment simulation vessel.

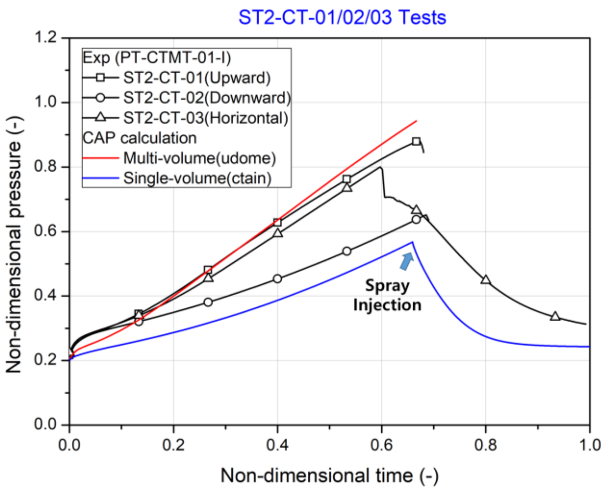

Fig. 2. Containment pressure of ATLAS-CUBE ST2 test series

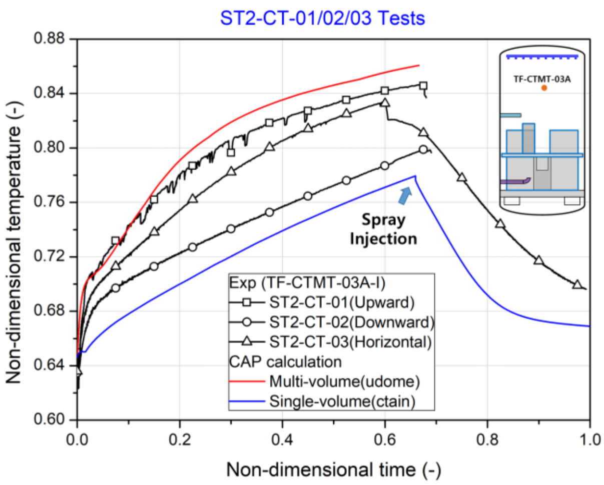

Fig. 3. Containment temperature of ATLAS-CUBE ST2 test series

In case of the CAP code calculation, the containment pressure and temperature with the single-volume model were underestimated. The calculation with the multi-volume model predicted a higher containment pressure and temperature than those from the single-volume model, which were close to the result of the ST2-CT-01 test with the upward steam injection. The single-volume model treated the total free volume of the containment simulation vessel with a single temperature, so that it corresponds to the assumption of the fully mixed steam-gas mixture inside the containment. Unlike the actual phenomenon observed in the thermal stratification in the ATLAS-CUBE tests, the uniform temperature inside the containment in the single-volume case could overestimate the heat transfer at the passive heat sink and it affected a slower increase of the pressure and temperature of the containment.

The ST2-CT-03 test included the containment spray injection period after the termination of the steam injection. Since the multi-volume model of the CAP code cannot simulate the droplet transport through the volumes, the calculation result with the single-volume model could be compared to the pressure and temperature inside the containment as shown in Figs. 2 and 3. The cooling capability of the spray system could be interpreted from the decreasing rate of the pressure or temperature, which indicated that the cooling behavior was similarly captured in the CAP code calculation with a higher cooling rate.

4. Conclusions

In this study, the CAP code was validated with the ATLAS-CUBE test data, focusing on the thermal-hydraulic behaviors related with the steam supply and the containment spray injection. The CAP code calculation result with the single-volume model underestimated the containment pressure and temperature, while the multi-volume model predicted a higher containment pressure and temperature. The uniform temperature inside the containment in the single-volume case could overestimate the heat transfer at the passive heat sink and it affected a slower increase of the pressure and temperature of the containment. The cooling behavior by the actuation of containment spray system was similarly captured in the CAP code calculation with a higher cooling rate.

The further studies are required to estimate the behavior of the spray injection with sensitivity calculation of the various droplet diameter or cooling efficiency in the CAP code. Also, the integral effect tests for the RCS and the containment in the ATLAS-CUBE facility will be assessed with the linked calculation of the SPACE and the CAP code.

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