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Validation of SPACE-CAP codes for coupling the RCS and containment systems with OECD-ATLAS3 C1.2 test

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1. Introduction

A containment of a nuclear power plant must maintain its integrity as the final barrier to prevent the release of radioactive fission products into the environment during any anticipated accident. In this regard, the safety analysis of a containment is crucial to ensure the integrity of a nuclear power plant. KAERI (Korea Atomic Energy Research Institute) has performed the integral effect tests simulating multi-dimensional thermal-hydraulic behavior occurring inside a containment using the ATLAS-CUBE (Advanced Thermal-hydraulic Test Loop for Accident Simulation – Containment Utility for Best-estimate Evaluation) facility [1]. The test results can be utilized as a database for evaluating the build-up of pressure and temperature (P/T) in a containment, dependent on the transient variation of the mass and energy (M/E) release from a reactor coolant system (RCS). Given the importance of the interaction between the RCS and the containment, an intermediate-break loss-of-coolant accident (IBLOCA) was simulated in the C1.2 test [2] of the third phase of OECD/NEA ATLAS (hereafter, OECD-ATLAS3) international cooperation project.

In this study, the C1.2 test data was utilized to assess SPACE (Safety and Performance Analysis CodE for nuclear power plant) and CAP (Containment Analysis Package) codes. The SPACE code simulated the RCS of the ATLAS facility, while the containment system of the CUBE facility was modeled by the CAP code calculation [3]. The linked calculation of both codes was performed with considering the M/E transport and the P/T build-up of the containment. 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 compared.

2. Test Condition

2.1 ATLAS-CUBE test facility

ATLAS simulates the thermal-hydraulic transient of a RCS and CUBE simulates the thermal-hydraulic phenomena inside a containment as realistically as possible [4]. ATLAS is a half-height and 1/288-volume scaled test facility with respect to APR1400 (Advanced Power Reactor 1400 MWe) according to the three-level scaling methodology. The CUBE facility 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 including primary shield wall, secondary shield wall, steam generator compartments, pressurizer compartment, pedestal floor, operating floor, in-containment refueling water storage tank, and hold-up volume tank.

2.2 C1.2 test condition

The target scenario for the C1.2 test is an IBLOCA at a cold leg. The steady-state condition was achieved at 1.56 MW of the core power (about 8 % of ideally scaled core power) plus a heat loss compensation. The inner diameter of the break nozzle was 19.0 mm, which corresponded to 12.7 % break of the cold leg flow area. The break flow was discharged from the cold leg 1A of ATLAS to the CUBE containment vessel as shown in Fig. 1.

The safety injection water from the safety injection pump (SIP) was supplied through the direct vessel injection (DVI) nozzles which are connected to an upper down-comer of a reactor pressure vessel. In accordance with a single failure criterion, the operation of SIP through only DVI-1 and -3 nozzles was assumed. For the safety injection from safety injection tank (SIT), initial water level in each SIT was set to be 3.73 m and initial water temperature was set to be 50 ^{o}C. Upper region above the water level of the SIT was filled with nitrogen gas to maintain the initial pressure as 4.3 MPa. The containment spray system was set to operate at a high-high containment pressure (H-HCP) signal to cool the steam-gas mixture within the containment.

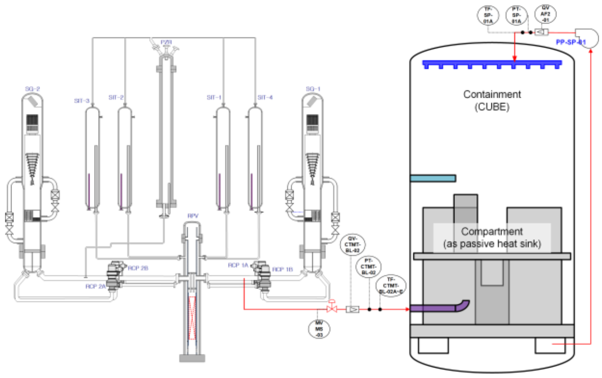

Fig. 1. A schematic diagram for the ATLAS-CUBE test

3. Calculation Result

The C1.2 test was utilized to assess the linked calculation of the SPACE and CAP codes. The nodalization of the SPACE code for the RCS simulation was composed of the one-dimensional components and heat structures, where the M/E from the cold leg was connected to the containment component of the CAP code. The CAP code calculation 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 nodalization for the linked calculation was shown in Fig. 2 for the multi-volume case of the CAP code calculation.

Figure 3 compared the integrated mass of the break flow, which were estimated by a variation of the coolant inventory in the primary system in the C1.2 test, to the SPACE-CAP calculation result. The break flow was over-predicted in the SPACE-CAP calculation, where most of the break flow in the later period was in the liquid flow as found in the calculation result. It affected the slower pressurization of the containment.

Figures 4 and 5 compared the containment pressure and the dome temperature of the CAP code calculation to those of the test result in the C1.2 test. As shown in the figures, the calculation with the multi-volume model predicted a higher containment pressure and temperature than those from the single-volume model. The single-volume model treated the total free volume of the containment simulation vessel with a single temperature, which corresponded to the assumption of the fully mixed steam-gas mixture inside the containment. Unlike the actual phenomena 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 single-volume calculation case included the containment spray injection period, whereas the containment pressure did not reach the set-point of the actuation set-point for the spray injection during the actual C1.2 test result. 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. The further studies are required to estimate the behavior of the spray injection with sensitivity calculation of the various droplet diameter or cooling efficiency.

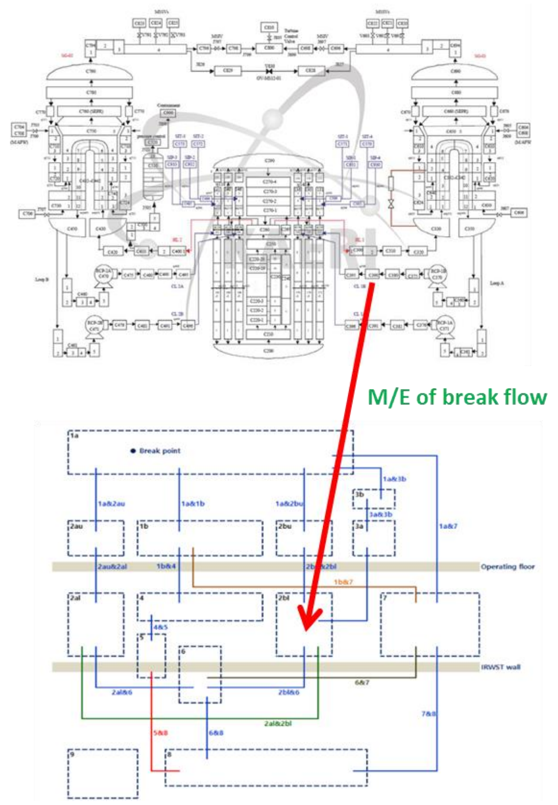

Fig. 2. Nodalization for the SPACE-CAP code calculation

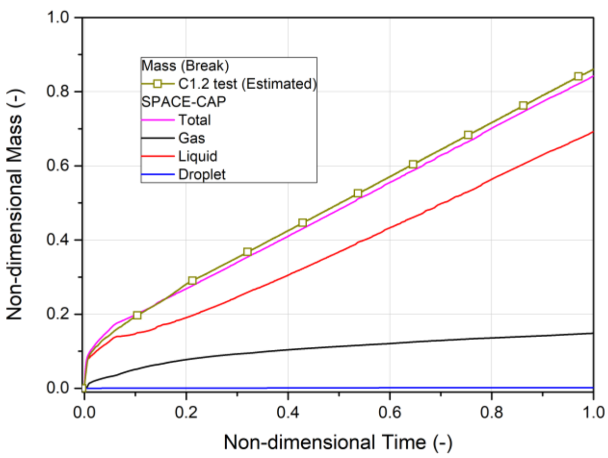

Fig. 3. Integrated mass of the break flow in C1.2 test

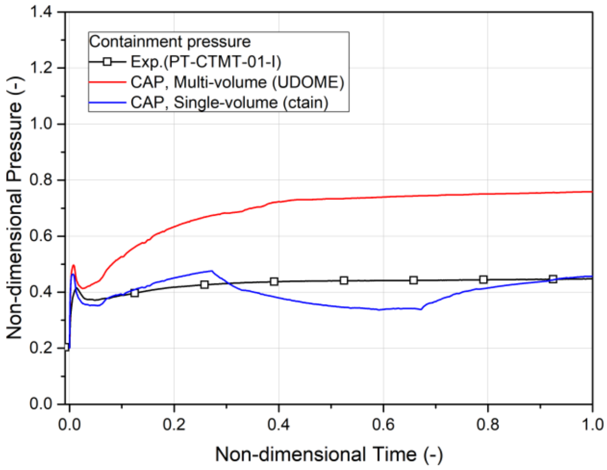

Fig. 4. Containment pressure in the C1.2 test

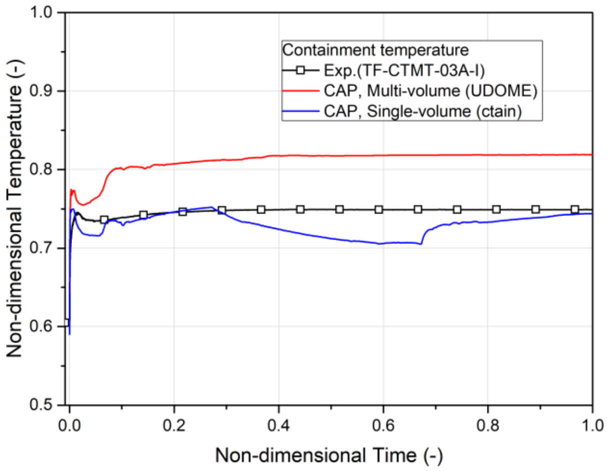

Fig. 5. Containment temperature in the C1.2 test

4. Conclusions

In this study, the SPACE-CAP code was validated with the ATLAS-CUBE test data, focusing on the thermal-hydraulic behaviors in the cold leg break IBLOCA scenario. From comparing the test and calculation result, it was found that a higher pressure and temperature of the containment was predicted in the multi-volume calculation of the containment. 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. Further development and assessment for the SPACE-CAP code are essential to improve the prediction capability for the interactive phenomena in the RCS and the containment.

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REFERENCES

[1] J. B. Lee et al., “Description Report of ATLAS-CUBE Facility and Instrumentation,” KAERI/TR-8614/2021, Korea Atomic Energy Research Institute, 2021.
[2] B. U. Bae, “Quick Look Report on the OECD-ATLAS3 C1.2 Test : Reactor Coolant System (RCS)-Containment integral effect test (IET) for an intermediate-break loss-of-coolant accident (IBLOCA) in the ATLAS-CUBE facility”, OECD-ATLAS3-QLR-23-03, 2023.
[3] Soon Joon Hong et al., “Development of CAP code for nuclear power plant containment : Lumped model”, Nuclear Engineering and Design, vol. 291, pp. 47–63, 2015.
[4] J. B. Lee et al., “Description Report of ATLAS Facility and Instrumentation (Third Revision),” KAERI/TR-8106/2020, Korea Atomic Energy Research Institute, 2020.