Numerical Study of the Multi-Dimensional Thermal-Hydraulic Behavior in Containment using CUPID

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1. Introduction

After the Fukushima accident, the importance of the containment integrity as the final barrier to prevent radioactive materials from escaping to the environment has been emerged. In this circumstance, a lot of experimental and numerical studies have been performed to evaluate the thermal hydraulic behavior in the containment under accident conditions. For instance, PANDA facility at PSI, THAI facility at BT, MISTRA facility at CEA, and CIGMA facility at JAEA have been utilized to evaluate the behavior of steam and non-condensable gases such as hydrogen or helium in containments. In addition, the test data from these facilities were used for validations of CFD codes through an international or domestic benchmark problems [1, 2].

However, the conventional experimental facilities for the containment test have the common limitation; they cannot simulate the interaction between RCS (Reactor Cooling System) and containment because the broken flow was treated as the boundary condition without a realistic RCS connection.

Korea Atomic Energy Research Institute (KAERI) constructed the containment test facility by connecting it to the ATLAS facility. In this paper, a preliminary calculation using the CUPID code [3] was performed to investigate the distribution of injected steam, heat removal capacity, locations where the wall condensation occurs, and so on.

2. Experiment

KAERI constructed an integral test facility named ATLAS-CUBE. The purpose of the ATLAS-CUBE is to simulate the realistic mass and energy transfer between the RCS and containment, and to analyze the pressure and temperature transient behavior in a containment under accident conditions. In addition, the test data will be provided for the validation of CFD codes.

2.1 Specification of ATLAS-CUBE

ATLAS-CUBE has 1 to 6.6 of linear scaling ratio, and the prototype is APR1400. The diameter, height, and volume of the scaled-down containment are 6m, 12m, and 340m^3, respectively.

The heat capacity of the passive heat structures is the most importance factor in the scaling of the ATLAS-CUBE. The soil was used to preserve the heat capacity instead of the concrete while the scaling distortion on the heat transfer area is allowed. Fig. 1 shows the bird-eyes view of ATLAS-CUBE. The primary and secondary shield walls, steam generator and pressurizer compartments walls, operating floor, reactor cavity wall, corium chamber room wall, and hold-up volume tank are modeled.

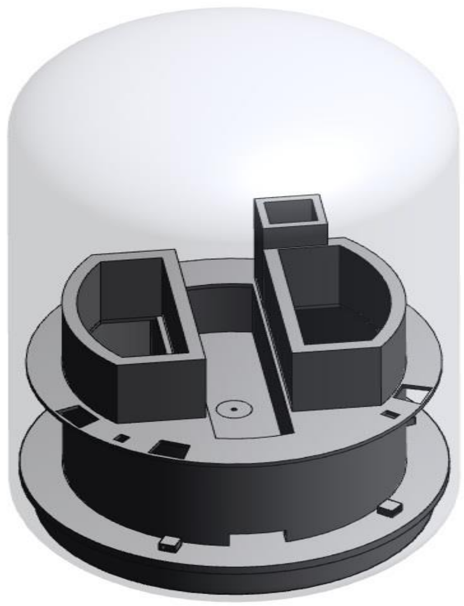

Fig. 1 3D schematics of ATLAS-CUBE

2.2 Measurement and Test Condition

The flow rate and its pressure and temperature of the broken flow from the RCS are measured. The gas temperature profile in the containment and the solid temperature profile of the passive heat structures are also measured. The heat removal rate by the heat structure are calculated by using these temperature profiles.

Two injection pipes are installed in the containment: one is installed at the top region of the steam generator compartment to simulate the Steam Line Break (SLB) accident, and the other is installed at bottom region around the location of the cold leg to simulate the LOss of Coolant Accident (LOCA).

3. CUPID Analysis

3.1 Grid Generation

A hybrid grid of tetrahedrons, hexahedrons, and pyramid cells are generated by using the SALOME software as shown in Fig. 2. The total number of cells is 425,000. The grids in compartment walls are not modeled. Instead, the temperature boundary condition was imposed on the compartment walls.

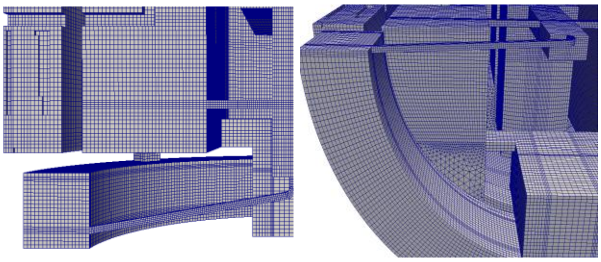

Fig. 2 Hybrid grid for ATLAS-CUBE

3.2 Calculation Setup and Physical Models

The SLB accident is assumed. The broken flow and its TH condition are decided by referring the system code calculation result. The initial and boundary conditions are as below.

- Initial containment pressure: 1 bar
- Initial containment gas temperature: 301. 1 K
- Non-condensable gas quality in containment: 1.0
- Steam injection velocity: 4.8 m/s
- Steam pressure: 2.588 bar
- Steam temperature: 402.9 K
- Compartment wall temperature: 301.1 K

The standard *k-ε* turbulence model is used and the buoyancy effect is directly calculated from the density differences without the Boussinesque approximation. In addition, Uchida wall condensation model is applied to simulate the steam condensation on the compartment wall.

3.3 Calculation Result

As the superheat steam is injected, it goes upward because of the buoyancy effect as shown in Fig. 3. The steam jet firstly impinges on the upper wall of the containment even though the steam velocity in x-direction is 4.8 m/s.

Fig. 4 shows the gas temperature transient at five elevations along the center line (*x=y=0* m). The temperature at 10m height increases firstly because the injection pipe is located at 9m height and the injected steam passes the 10m point at first in 10 s. Then, the steam is accumulated from the top of the containment as a result of thermal stratification.

As shown in Fig. 3 and Fig. 4, the steam jet does not contact the compartment walls in the early phase of the SLB, which means that there is no chance for the wall condensation and the function of passive heat structure as a heat sink is negligible. In addition, the bulk condensation of steam occurs because the initial temperature of the air is 301 K, but its amount is negligible.

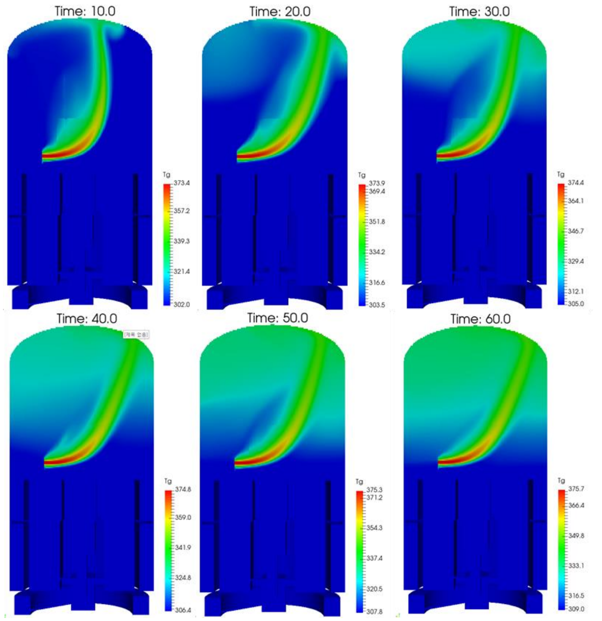

Fig. 3 Gas temperature contour

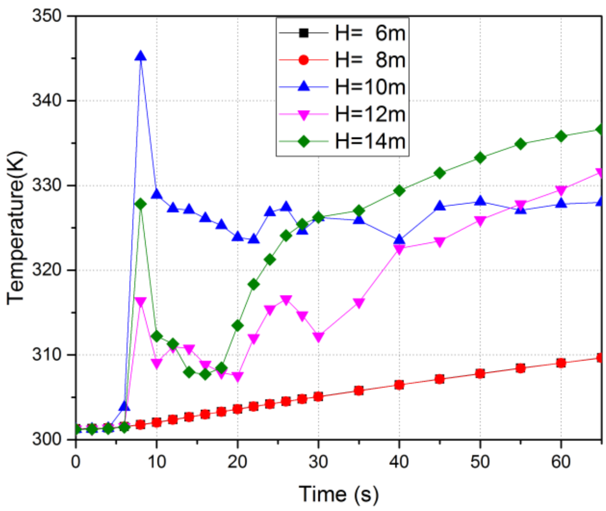

Fig. 4 Transient of gas temperature along height

4. Conclusions

A preliminary calculation for the ATLAS-CUBE test was performed using the CUPID code. The calculation result of the SLB accident condition showed that the thermal stratification occurred and the passive heat structure was not involved in the early phase of the scenario. Thus, the detailed information on the axial gas temperature distribution in the upper region of the containment and wall temperature distribution of the cap of the containment wall will be needed for this phase.

In the future, a long transient calculation and comparison with test data will be performed.

ACKNOWLEDGMENTS

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