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Simulation of transient behavior of corium pool in the lower plenum of RPV using COMPASS

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1. Introduction

Development of an integrated severe accident analysis code has been started by the collaboration of three institutes in Korea. KAERI (Korea Atomic Energy Research Institute) is responsible for developing modules related to the in-vessel phenomena, including the corium behavior in the lower plenum of RPV.

We developed computational software called COMPASS (COre Meltdown Progression Accident Simulation Software) [1]. As a module of the COMPASS, a computational code called SIMPLE (Severe In-vessel Melt Progression in Lower plenum Environment) was developed to analyze transient behavior of molten corium in the lower plenum, interaction between corium and coolant, and heat-up and ablation of reactor vessel wall [2]. In the present study, we simulated typical LOCA scenario of APR1400 by using COMPASS + SIMPLE.

2. Methods and Results

To calculate transient behavior of corium pool in the lower plenum, we use COMPASS and SIMPLE simultaneously.

2.1 Governing equations

We solve mass and energy equation in time at the active core region (COMPASS) and lower plenum (SIMPLE). Fuel (UO_2), Clad (Zr, ZrO_2), supporting structures (Stainless Steel), and control rods (Inconel, B4C) are considered. These materials are classified into two groups: oxidic (UO_2, ZrO_2) and metallic (Zr, SS, INC, B4C) materials. Coolant is modeled as two-fluid model. In the lower plenum, two-layer model (bottom oxidic and top metallic) is used and there are solidified core materials (particulate debris).

2.2 Boundary conditions

We set flow into the cold leg is given in time. Flow out of RPV (hot leg flow) is the same as flow into the cold leg. Computational domain is RPV (including active core, upper plenum, lower plenum, surrounding structures, etc.). To connect COMPASS and SIMPLE, corium mass flow rate and thermo-hydraulic conditions to the lower plenum are given to the SIMPLE, and the SIMPLE calculates total heat to the coolant and surrounding structures.

2.3 LOCA results

Fig. 1 shows changing masses in the lower plenum. Relocation starts to the lower plenum around 3700 second from the start of the simulation. In the beginning of the relocation from the core support plate, there is mainly particulate debris in the lower plenum with the corium-water interaction during the relocation. Composition of that particle debris are mainly stainless steel and Inconel. Their melting temperatures are 1673 and 1623 Kelvin. After then, metallic and oxidic molten pools are formed in the lower plenum.

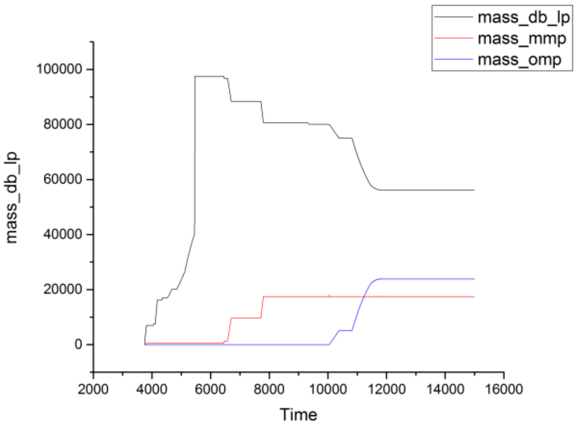

Fig. 1. Time trace of masses (particulate debris, metallic molten pool, oxidic molten pool, respectively) in the lower plenum.

Fig. 2 shows solidified crust thickness of the oxidic molten pool. Number 1 indicates the bottom point of the lower plenum. Increasing the number, the location where the oxidic pool contacts with RPV wall is elevated. Because we used ACOPO correlation, the heat flux to the RPV wall is increasing at the upper location of oxidic pool. As a result, crust thickness is thick at the bottom, thin at the upper positions. No corium contacts with upper most node, so the crust thickness of #4 shows zero throughout the simulation. Black line shows crust at the upper surface of oxidic pool. It is thin and nearly eliminated after the oxidic materials are relocated.

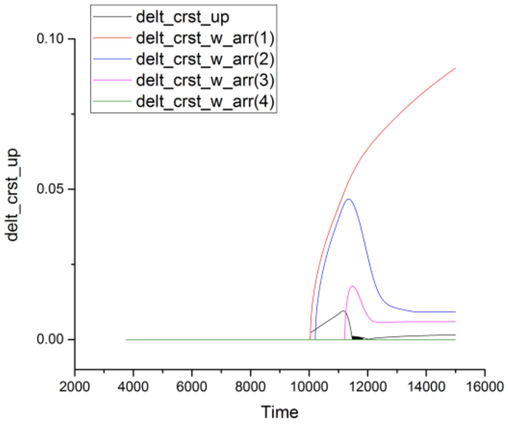

Fig. 2. Solidified crust thickness of oxidic molten pool at different locations.

Fig. 3 shows RPV wall thickness at different location. Initial thickness of the RPV wall is 16.5cm. Vessel wall melting is started at 12100 seconds, at 3rd computational node. Remaining RPV wall thickness is about 9cm. At the 2nd node, wall ablation starts at 13500 seconds, because the wall interface temperature is slowly increased than that of 3rd node of RPV. Ablation rate is increasing at upper nodes.

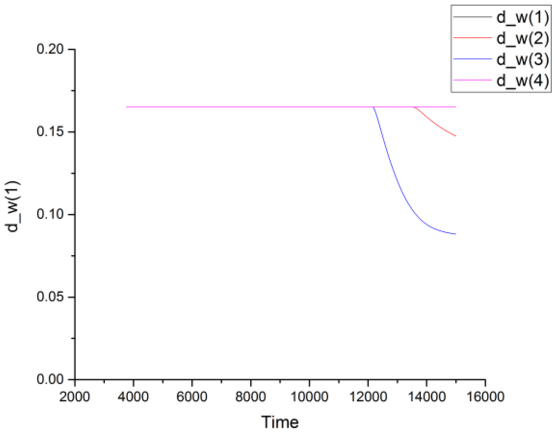

Fig. 3. RPV wall thickness.

3. Conclusions

Transient behavior of the molten corium in the lower plenum was simulated with COMPASS + SIMPLE. SIMPLE module was created with the mass and energy equations of particulate debris bed, metallic molten pool, oxidic molten pool. It receives thermo-hydraulic conditions of the lower plenum, then returns total heat to the coolant and surrounding structures. After relocation of the corium to the lower plenum, most of them were remain particulate debris bed. RPV wall ablation starts after the oxidic materials were relocated, and there is solidified crust where the oxidic pool contact with RPV wall.

REFERENCES

[1] Development of PWR Core Degradation Model: Core Meltdown Progression Accident Simulation Software (COMPASS), KAERI, 2014.
[2] Development of Analysis Module for the RPV Lower Plenum Molten Pool Behavior, KAERI, 2014.