COMPASS Simulation for PHEBUS FPT-3 Experiment

Jun Ho Bae [a*], Jongtae Kim [a], Rae-Jun Park [a], Donggun Son [a], Dong Ha Kim [a]
[a] *KAERI, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea*
[*] Corresponding author: bjh@kaeri.re.kr

1. Introduction

COMPASS have been developed as a stand-alone simulation tool which can be run for a variety of prescribed ex-vessel boundary conditions [1]. At the same time, to make up the in-vessel module including the primary loop, the core degradation model in COMPASS have been coupled with the SPACE code [2], which is DBA code developed in Korea. And, it will finally build up the integrated severe accident analysis code, CINEMA, through the coupling with the severe accident ex-vessel module.

The objective of this paper is to assess the core degradation modeling in COMPASS code by simulating the PHEBUS FPT3 experiment. For the comparison purpose, the numerical simulation by using MELCOR 2.1 [3] have also conducted for the FPT3 experiment. Consequently, COMPASS results of PHEBUS FPT3 have been compared with the experimental data and MELCOR results.

2. Methods and Results

2.1 Numerical Simulation Methods

Figure 1 shows the node system used in the calculation of COMPASS. Although it is not shown in this paper, MELCOR has 27 axial nodes and 2 radial nodes to simulate the test section in the experiment. Among the 27 axial nodes, the 21 nodes corresponds to the core region having a fuel assembly. For the comparison purpose, COMPASS have the same axial and radial node number in the core region, which is consisted of 21 axial nodes and 2 radial nodes.

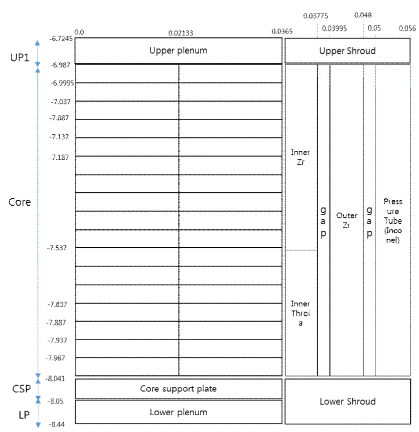

Fig. 1. Node system of COMPASS code

2.2 PHEBUS FPT-3 Experiment

PHEBUS FPT3 experiment has been conducted with the purpose of simulation of severe accident progression. The test section has been inserted into the real PHEBUS core and it is connected to the vertical and horizontal pipes which is modeling a hot leg in RPV and connected to the U-tube which is modeling a steam generator. And it is connected to the horizontal pipe which is modeling a cold leg in RPV and finally connected to the cylindrical tank which is modeling a containment. From the bottom of test section, hot steam of 165 °C is inserted into the test section with a low flow rate of 0.5g/s. The inside of test section is remained at a constant pressure 0.2MPa and the outside of the test section is at a constant pressure of 2.5MPa. Hot water of 165 °C was flowing outside the test section with a high flow rate of 35ton/h, which roles as the heat sink of test section.

Figure 2 shows the cross-sectional view of test section. In the test section, a fuel assembly has been installed, which consist of 18 irradiated fuel rods, 2 fresh fuel rods, 1 control rod and the surrounding shroud tube. Control rod is located at the center of fuel assembly and 20 fuel rods are surrounded by the shroud tube, consist of inner shroud, outer shroud and pressure tube. In a radial direction, these three layers of shroud tube are separated with two vapor gaps.

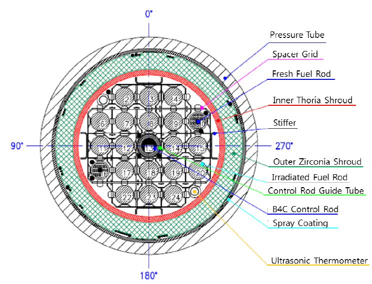

Fig. 2. Cross-sectional view of test bundle

2.3 Numerical Results

In the fuel degradation phase in PHEBUS FPT3 experiment, it is important to analyze the fuel rod heat up, material melting and relocation, hydrogen generation by steam oxidation. Hence, lots of thermocouples are installed in the experiment to analyze the fuel degradation progression. Figure 3 shows the fuel temperature evolutions at the location of 200mm from the bottom of fuel bundle. Black solid line denotes the experimental results and 2 red dashed lines are MELCOR results and 2 blue dotted lines are

COMPASS results. It is shown from the figure that COMPASS and MELCOR codes are well predicting the overall fuel temperature evolution of the experiment. The figure also shows that the fuel temperature rapidly increase by the oxidation reaction around 10,000 for the both of experiment and numerical simulation, although COMPASS are showing a smoother temperature increase compared to the experimental data.

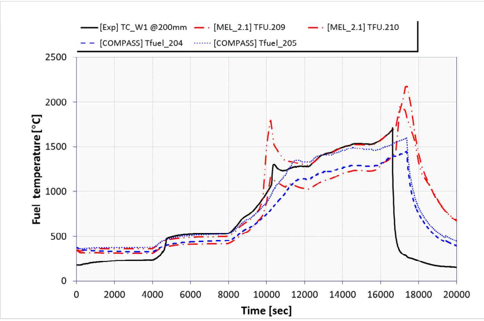

Fig. 3. Fuel temperature evolution

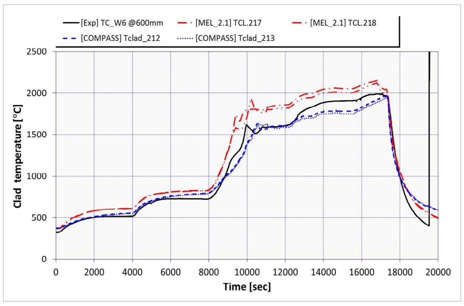

Fig. 4. Clad temperature evolution

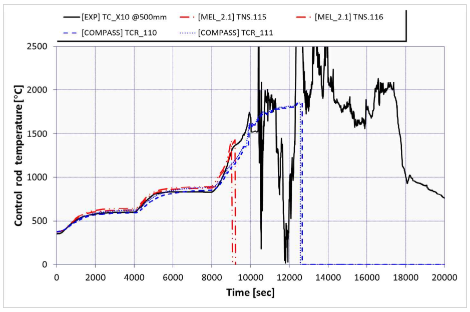

Fig. 5. Control rod temperature evolution

Figure 4 shows the cladding temperature evolution at the 600mm locations from the bottom of fuel bundle. The clad temperature is shown to increase having the similar pattern with the fuel temperature. MELCOR results are showing the earlier temperature increase by the oxidation reaction compared with the experiment and shows a little bit higher temperature after the oxidational reaction. On the other hand, the figure shows that COMPASS are well predicting the cladding temperature of the experimental data.

Figure 5 shows the control rod temperature evolution at the 500mm locations from the bottom of fuel bundle. In the PHEBUS FPT3 experiment, differently with FPT0, FPT1 and FPT2, the control rod is consisted of B4C and Inconel. Since the thermocouples are installed on the control rod guide tube, which is made of Inconel having a low melting temperature, the thermocouple is shown to experience earlier failure rather than the other thermocouples. After the oxidational reaction around 10,000sec, the thermocouples are guessed to experience a failure. It is shown from the figure that COMPASS and MELCOR codes are well predicting the control rod temperature in the experiment.

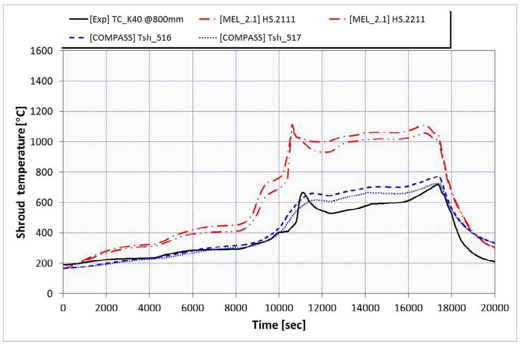

Fig. 6. Shroud temperature evolution

Figure 6 shows the shroud temperature evolution at 800mm from the bottom of fuel bundle. Similarly with the fuel temperature, MELCOR shows the steep temperature increase around 10,000sec by the exothermic oxidation for the case of 200mm location and it has slightly higher temperature rather than experimental data. While, COMPASS shows mild temperature increase around 10,000sec and it has slightly lower temperature compared with the experimental data. For the case of 800mm location, while COMPASS are nearly good agreement with the experimental data, MELCOR are predicting the notable higher value for the shroud temperature.

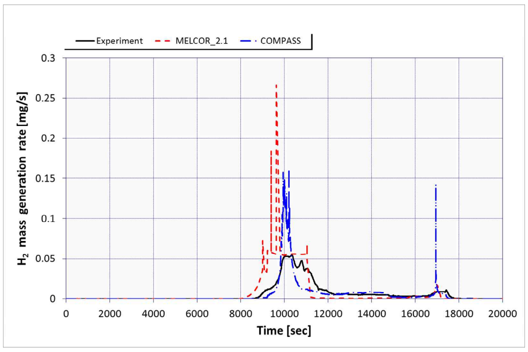

Fig. 7. Hydrogen mass flow rate

As remarked previously, the surrounding structure are consisted of three solid layers and two vapor gaps between the solid layers. MELCOR are modeling the whole surrounding structure as a single heat structure by using HS module. For the case of HS module, although the most outer nodes of heat structure can model the radiation and convection heat transfer, the inner nodes of heat structure can only consider the conduction heat transfer. Hence, in the MELCOR simulation of FPT3 experiment, only the conduction heat transfer can be modeled through a vapor gap. Since the thermal conductivity of vapor is very low compared with solid material, MELCOR are adopting a gap closure model, which are assuming a high thermal conductivity of vapor in a gap for a high temperature condition (over 900K). Although this concept is reasonable and beneficial to reconcile the limitation for the HS module, it has still a limitation for a low temperature condition.

Figure 7 shows the calculated results and the experimental data for the hydrogen generation rate. It is shown from the figure that COMPASS and MELCOR are well predicting the hydrogen generation rate in the experiment, although MELCOR are showing that oxidation reaction is started at a slightly earlier time. The accumulated hydrogen mass calculated COMPASS is slightly lower than the experimental data, while MELCOR are predicting a little bit higher hydrogen mass compared with the experimental data (It is not shown in the paper). However, the increasing slope of accumulated hydrogen mass as well as the final accumulated hydrogen mass still shows a good agreement between the numerical results and experimental data.

3. Conclusions

For the purpose of COMPASS code validation, the numerical simulation for PHEBUS FPT3 experiment has been conducted. The temperature of the main component has been secured by using COMPASS code for a fuel, cladding, control rod and surrounding structure. And they are compared with that of experimental data as well as MELCOR simulation results. Although the MELCOR simulation results are showing a little bit difference with the experimental data, especially for the shroud temperature, it can be concluded that COMPASS and MELCOR codes are well predicting the experimental data. MELCOR are showing that an oxidational reaction starts a little bit earlier time and has the slightly higher value of the accumulated hydrogen mass, while COMPASS code predicts the slightly lower value of the accumulated hydrogen mass.

ACKNOWLEDGEMENTS

This work was supported by the Nuclear and Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by Korea government (No. 20141510101670).

REFERENCES

[1] J. H. Bae, J. T. Kim, D. G. Kim, R. J. Park, D. H. Kim, J. H. Song, Design of Severe Accident Code COMPASS Ver. 2.3. KAERI/TR-6407/2016, 2016.

[2] S. J. Ha, C. E. Park, K. D. Kim, C. H. Ban, Development of the SPACE Code for Nuclear Power Plants, Nuclear Engineering and Technology, Vol.43, p. 45-62, 2011.

[3] R. O. Gaunt, R. K., Cole, C. M. Erickson, MELCOR Computer Code Manuals, NUREG/CR-6119, vol.3, Rev.0, SAND2001-0929P, 2001.