Scaling Analysis of the HERMES-HALF Experiment using RELAP5/MOD3

Rae-Joon Park, Kwang-Soon Ha, Young-Ro Cho, Sang-Baik Kim, Hee-Dong Kim
Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong, Daejeon, Korea, rjpark@kaeri.re.kr

1. Introduction

The IVR (In-Vessel corium Retention) through the ERVC (External Reactor Vessel Cooling) is known to be an effective means for maintaining the integrity of the reactor pressure vessel during a severe accident in a nuclear power plant[1]. This measure has been adopted in some low-power reactors such as the AP600 and the Loviisa nuclear power plants, and in the high-power reactor of the APR (Advanced Power Reactor)1400 as an accident management strategy for severe accident mitigation. Many studies[2,3] have been performed to evaluate the IVR. As part of a study on two-phase flow in the reactor cavity under external reactor vessel cooling in the APR1400, HERMES-HALF experiment (Hydraulic Evaluation of Reactor cooling Mechanism by External Self-induced flow-HALF scale)[4] has been performing at KAERI. This large-scale experiment using a half-height and half-sector model of the APR1400 uses the non-heating method of the air injection. For this reason, it is necessary to evaluate the material scaling between air-water and steam-water two phase natural circulation flow, and the geometry scaling between a half-height & sector and a full-height & sector for an application of the experimental results to an actual APR1400. In the material scaling, two cases, such as an air injection and a heat flux input have been performed to compare the air injection experimental results with the real case of the heat flux condition using RELAP5/MOD3 computer code[5]. In the geometry scaling, two cases, such as a half height & sector and a full height & sector, have been performed.

2. RELAP5 Input Models

Figures 1&2 show the RELAP5/MOD3 input models for the HERMES-HALF experiment and the actual heat flux condition. In the RELAP5/MOD3 input model for the HERMES-HALF experiment, the coolant supplied from outer water source flows through the water supply tank and gap between the vessel and the insulation to the outer tank. The air was injected through 9 time-dependent junctions into the gap between the spherical reactor vessel and insulation, and vented to the atmosphere. Coolant inlet and two coolant outlets were simulated using three single junctions. The heat flux from the spherical reactor vessel to the outer coolant was simulated by the air injection mass flow rates. In the RELAP5/MOD3 input model case for the actual heat flux condition, the spherical and cylindrical reactor vessel was simulated using the heat structures. The reactor power was simulated as a boundary condition of the heat flux in the left side of the spherical heat structure number 100. The generated steam was vented to the containment atmosphere. In all the simulations, the initial conditions are assumed to be ambient pressure and no coolant mass flow rate. The coolant level of the water supply tank maintains constant value by outer water source.

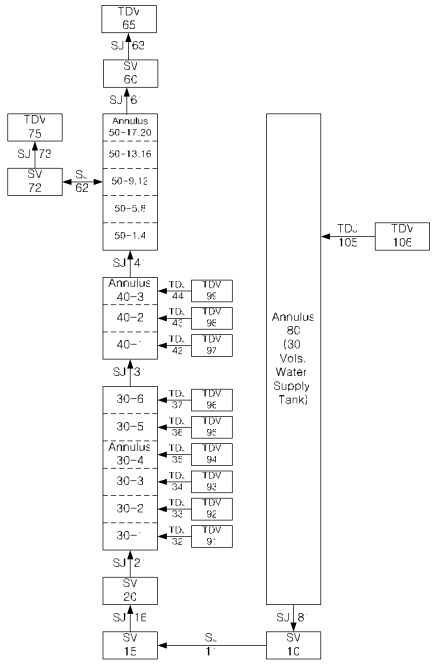

Figure 1. RELAP5 input model for the HERMES-HALF experiment.

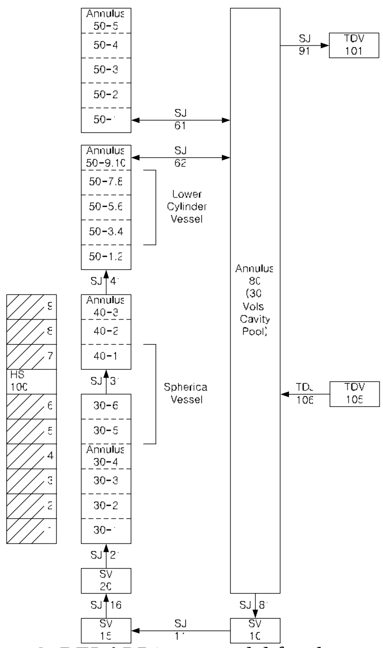

Figure 2. RELAP5 input model for the actual case.

3. Results and Discussion

Table 1 shows the RELAP5/MOD3 results on the water circulation mass flow rate as a boundary condition of the air injection and heat flux condition. The water circulation mass flow rate of the air injection case is eleven times higher than that of the heat flux condition case with the injected water subcooling of 74 ℃, because of steam condensation by the sub-cooled water, inlet momentum of the air, and the density difference between the air and the steam. The density of the air is two times higher than that of the steam. The steam is condensed by supplied sub-cooling water in the heat flux case, but not in the air injection case. The density difference affects the two-phase momentum transfer. A decrease in the water subcooling leads to an increase in the water circulation mass flow rate.

Table 1. Water circulation mass flow rate as a function of the boundary conditions.

Boundary Condition	Water Circulation Mass Flow Rate (kg/s)
Air Injection	331.3 (Subccoling = 74 ℃)
Heat Flux	30.6 (Subccoling = 74 ℃) 95.1 (Subccoling = 10 ℃) 123.1 (Subccoling = 0 ℃)

Table 2 shows the RELAP5/MOD3 results on the water circulation mass flow rate as a geometry change at a full heat flux condition. The water circulation mass flow rate of the full height & half sector case is three times higher than that of the HERMEL-HALF case, because of the height increase. The water circulation mass flow rate of the full height & full sector case is approximately six times higher than that of the HERMEL-HALF case, because of the height and sector increases.

Table 2. Water circulation mass flow rate as a geometry change.

Area (Inlet, Outlet) (m^2)	1/2 Height, 1/2 Sector (kg/s)	Full Height, 1/2 Sector (kg/s)	Full Height, Full Sector (kg/s)
0.15, 0.15	331.3	500.6	754.7
0.6, 0.6	-	1000.0	-
1.2, 1.2	-	-	1826.7

Figure 2 shows the RELAP5/MOD3 results on the water circulation mass flow rate as a function of the water inlet area at a 12.4 % heat flux condition. The RELAP5 results are very similar to the experimental results. An increase in the inlet area leads to an increase in the water circulation mass flow rate. The water circulation mass flow rate of the full height & full sector case is five times higher than that of the HERMEL-HALF case, because of the height increase.

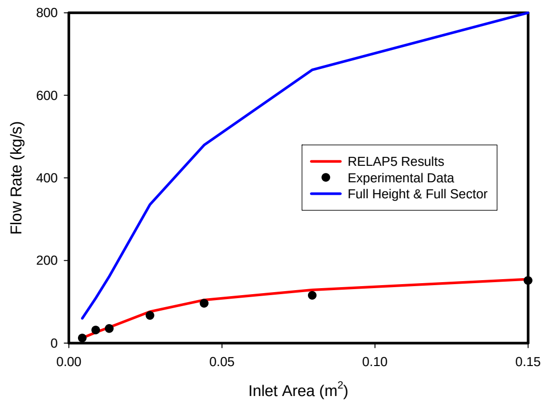

Figure 3. RELAP5 results on the water circulation mass flow rate as a function of the water inlet area.

4. Conclusion

In the material and geometry scaling aspects, the HERMES-HALF experiment has been simulated using the RELAP5/MOD3. The RELAP5 results have shown that the water circulation mass flow rate of the air injection case is eleven times higher than that of the heat flux condition case with the injected water subcooling of 74 ℃. A decrease in the water subcooling leads to an increase in the water circulation mass flow rate.The water circulation mass flow rate of the full height & full sector case is approximately six times higher than that of the HERMEL-HALF case, because of the height and sector increases. The RELAP5 results are very similar to the experimental results. An increase in the water inlet area leads to an increase in the water circulation rate.

ACKNOWLEDGMENTS

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REFERENCES

[1] T. G. Theofanous, C. Liu, S. Addition, S. Angelini, O. Kymalainen, and T. Salimassi, In-Vessel Coolability and Retention of a Core Melt, Nuclear Engineering & Design, 169, 1, 1997.

[2] O. Kymalainean, H. Tuomisto, T. G. Theofanous, In-Vessel Retention of Corium at the Loviisa Plant, Nuclear Engineering & Design, 169, 1, 1997.

[4] S. H. Yang , W. P. Baek, and S. H. Chang, An Experimental Study of Pool-Boiling CHF on Downward Facing Plates, J. of KNS, V. 26 (4) , 1994.

[4] K. S. Ha, R. J. Park, S. B. Kim, H. D. Kim, A Study on the Two-Phase Natural Circulation Flow under ERVC, KNS Autumn Meeting, 2004.

[5] The RELAP5 Development Team, RELAP5/MOD3 Code Manual, NUREG/CR-5535, INEL95/0174, 1995.