Preliminary Analysis of Natural Circulation Flow in the Reactor Cavity under IVR-ERVC for SMART

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1. Introduction

The IVR (In-Vessel corium Retention) through the ERVC (External Reactor Vessel Cooling) is known to be effective means for maintenance of the reactor vessel integrity during a severe accident in a nuclear power plant [1]. This measure is adopted in low-power reactors, such as the AP600, the AP1000, and the Loviisa nuclear power plant as a design feature for severe accident mitigation, and in the high-power reactors of the APR (Advanced Power Reactor) 1400 and the APR+ as an accident management strategy. Also, this is adopted in a small integral reactor of the SMART, as a design feature for severe accident management. Many studies [2] have been performed to evaluate the IVR-ERVC.

Preliminary simulations of two phase natural circulation in the reactor cavity of the SMART have been performed to investigate natural circulation mass flow rate in the annulus between the outer reactor vessel and the insulation by using the RELAP5/MOD3 computer code. The objective of this analysis is to have insight on the design requirement of the reactor vessel insulation for the IVR-ERVC in the SMART. The reactor vessel insulation design of the SMART is not performed yet. For this reason, two cases of natural circulation analysis with and without the water circulation outlet have been performed in this study.

2. Design Characteristics of the SMART

Table I shows the comparison of SMART main design parameters with other plants of the OPR1000 and the APR1400.

Table I: Comparison of SMART main design parameters with other plants

Design Parameters	SMART	OPR 1000	APR 1400
Core Thermal Power (MW)	330	2815	3983
Fuel(UO_2) Mass (ton)	16.8	85.6	120.0
Mass for Active Core Zircaloy-4 (ton)	4.7	23.9	33.6
Bottom Head Inner Diameter (m)	5.3	4.2	4.7
Bottom Head Thickness (cm)	20.0	15.2	16.5
Number of ICI Nozzle in the Lower Head	None	45	61

The SMART has a big size of the reactor vessel compared with others, because the main components of steam generators, pressurizer, and reactor coolant pumps are located inside the reactor vessel. So, it has big size of the lower plenum compared with the thermal power. If all core material is melted and relocated to the lower plenum of the reactor vessel, a corium height is approximately 0.79 m.

3. RELAP5 Input Model

Figure 2 shows a RELAP5/MOD3 input model for the natural circulation analysis in the reactor cavity of the SMART.

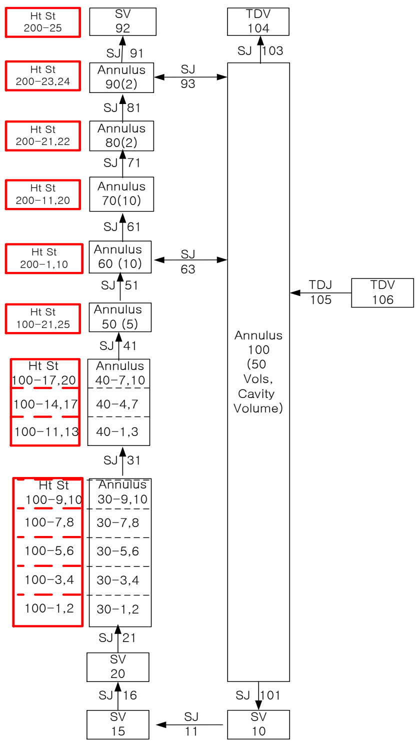

Figure 1. RELAP5 input model for the natural circulation analysis in the reactor cavity of the SMART.

The coolant supplied by the IRWST (In-containment Refueling Water Storage Tank, Time Dependent Volume No. 106) circulates from the cavity water pool (Annulus No. 100) through gap between the outer reactor vessel and the insulation (Annulus No. 30, 40, 50, 60, 70, 80, and 90). The cross flow junctions of No. 63 and 93 are the water circulation outlet and the steam outlet, respectively. The spherical and cylindrical reactor vessels are simulated using heat structures number 100 and 200, respectively. The reactor power is simulated as a boundary condition of the heat flux in the left side of the spherical heat structure number 100. Heat flux supplies from the bottom to 45 degree in the spherical reactor vessel, because the corium is located to this height of the lower plenum. In this analysis, heat flux is 0.2 MW/m^2 from the MELCOR results. The generated steam is vented to the containment atmosphere (Time Dependent Volume No. 104). In all simulation, the initial conditions are assumed to be ambient pressure and no coolant mass flow rate. The coolant level of the reactor cavity maintains constant value by IRWST water. Two simulations with and without the water circulation outlet have been performed.

4. Results and Discussion

Figure 2 shows the RELAP5 results on the water circulation mass flow rate with the water outlet. In this case, the water inlet area, the water outlet area and the steam outlet area were 0.5 m^2, respectively. An oscillatory coolant flow was generated in the water inlet and water outlet. The average natural circulation mass flow rate in the water inlet was approximately 65 kg/s in this case, but it was 0.5 kg/s without the water outlet. In general, an increase in the coolant mass flow rate leads to an increase in the CHF (Critical Hest Flux) on the outer reactor vessel. So, The CHF with the water outlet is bigger than that without the water outlet.

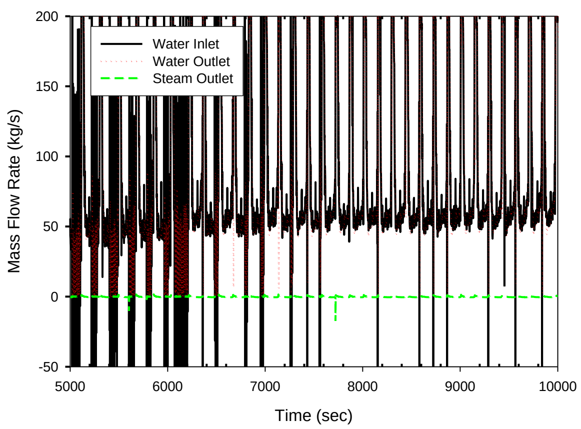

Figure 2. RELAP5 results on the water circulation mass flow rate with water outlet.

Figure 3 shows the pressure distribution as a function of the height from the bottom of the reactor vessel. The pressure difference between the top and bottom with the water outlet is higher than that without the water outlet, which results in an increase of the coolant circulation mass flow rate.

Figure 4 shows the void fraction distribution as a function of the height. The void fraction without the water outlet is higher than that with the water outlet, because of pool boiling condition in no water outlet case.

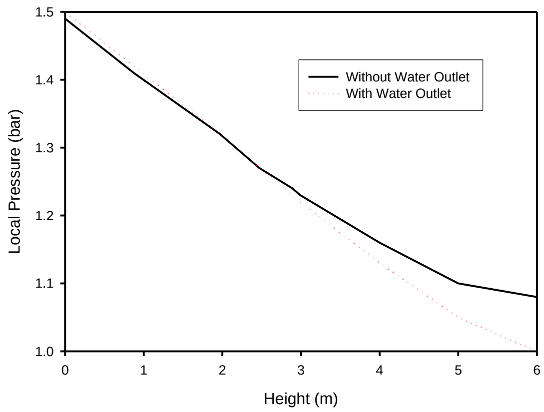

Figure 3. The pressure distribution as a function of the height.

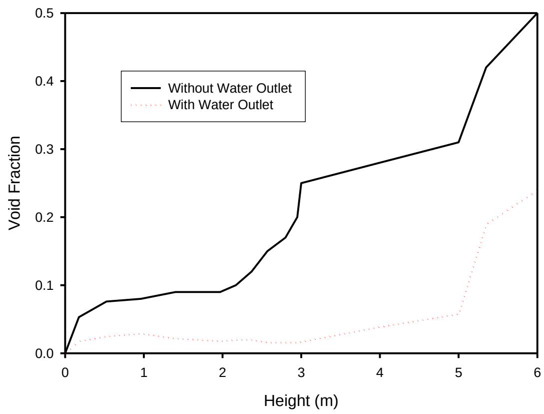

Figure 4. The void fraction distribution as a function of the height.

5. Conclusion

Preliminary simulations of two phase natural circulation in the reactor cavity of the SMART have been performed. The RELAP5/MOD3 results have shown that the water mass flow rate without the water outlet in the water inlet was approximately 0.5 kg/s, which meant pool boiling condition. However, the water circulation mass flow rate with the water outlet was approximately 65 kg/s, which led to increase in the CHF of the outer reactor vessel. More detailed analysis is necessary to suggest an optimal design of the reactor vessel insulation for SMART IVR-ERVC.

ACKNOWLEDGMENTS

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