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Evaluation of Two Phase Natural Circulation Mass Flow Rate in the Reactor Cavity under IVR-ERVC Condition for Different Thermal Power

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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 reactor vessel integrity during a severe accident in a nuclear power plant [1]. This measure is adopted in the AP600, AP1000, and Loviisa nuclear power plants as a design feature for severe accident mitigation, and in the OPR (Optimized Power Reactor)1000, the APR (Advanced Power Reactor)1400 and the APR+ as an accident management strategy. Many studies [2] have been performed to evaluate the IVR-ERVC.

Simulations of two phase natural circulation in the reactor cavity of OPR1000 and APR1400 under IVR-ERVC conditions have been performed to determine the natural circulation mass flow rate in the annulus between the outer reactor vessel and the insulation using the RELAP5/MOD3 computer code. The maximum heat removal rate of the CHF (Critical Heat Flux) on the outer vessel wall depends on the coolant circulation mass flow rate. As shown in Fig.1, an increase in coolant mass flow rate leads to an increase in CHF on the outer reactor vessel.

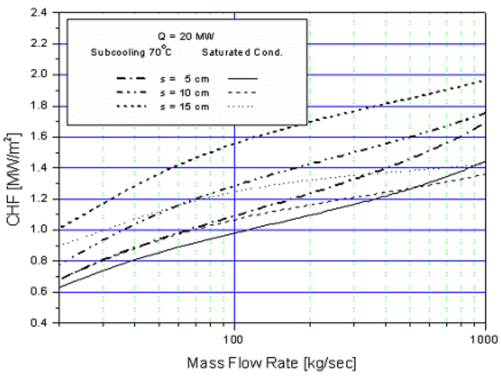

Fig.1. SULTAN results of CHF as a function of coolant mass flow rate.

As shown in Table I, the thermal power of the APR1400 is higher than that of the OPR1000. The present study is focused on the determination of the natural circulation mass flow rate for different thermal power.

2. RELAP5 Input Model

Fig. 2 shows a RELAP5/MOD3 input model for the two phase natural circulation analysis in the reactor cavity under IVR-ERVC condition.

Table I: Comparison of the design parameters

Design Parameters	OPR1000	APR1400
Core Thermal Power (MW)	2815	3983
Fuel(UO_2) Mass (ton)	85.6	120.0
Mass of Core Zircaloy-4 (ton)	23.9	33.6
Bottom Head Inner Dia. (m)	4.2	4.7
Bottom Head Thickness (cm)	15.2	16.5

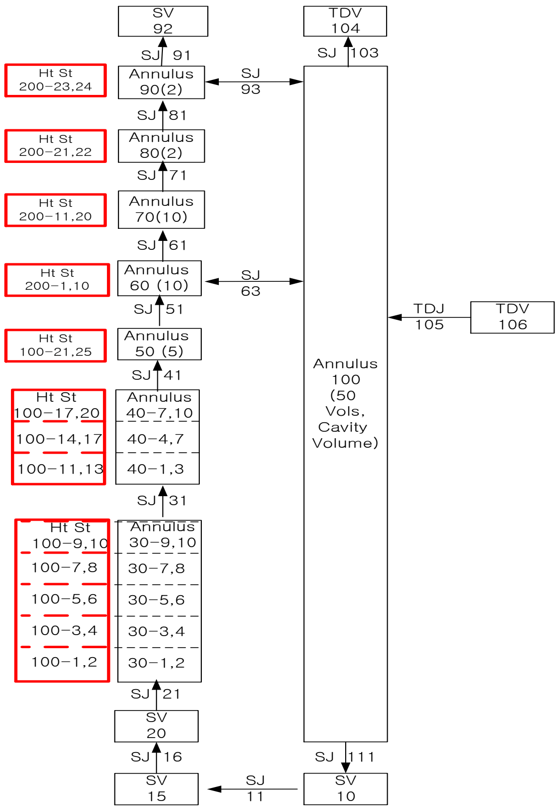

Fig. 2. RELAP5 input model for a natural circulation analysis in the reactor cavity.

The coolant supplied by the RWST (Refueling Water Storage Tank, Time Dependent Volume No. 106) circulates from the cavity water pool (Annulus No. 100) through a gap between the outer reactor vessel and 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 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 at the left side of spherical heat structure number 100, as shown in Fig.3. This is MAAP4 results.

The generated steam is vented to the containment atmosphere (Time Dependent Volume No. 104). In all simulations, the initial conditions are assumed to be ambient pressure with no coolant mass flow rate. The coolant level of the reactor cavity maintains a constant value by RWST water.

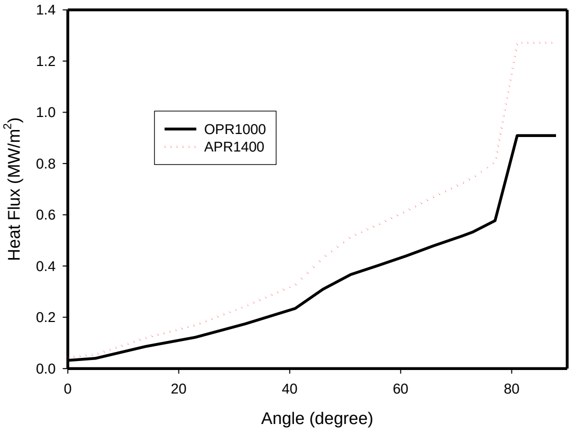

Fig. 3. Heat flux to the coolant as a function of angle.

3. Results and Discussion

Figs. 4 and 5 show the RELAP5 results on the water circulation mass flow rate in the APR1400 and OPR1000, respectively. In these calculations, the water inlet area and steam venting area are the same, but the water circulation outlet area of the APR1400 is bigger than that of the OPR1000. An oscillatory coolant flow was generated in two cases. Table II shows the RELAP5 results on the water circulation mass flow rate as a function of coolant injection temperature from the RWST. The coolant circulation mass flow rate of the APR1400 is higher than that of the OPR1000. An increase in the coolant injection temperature leads to an increase in coolant circulation mass flow rate, which leads to increase in CHF on the outer reactor vessel wall.

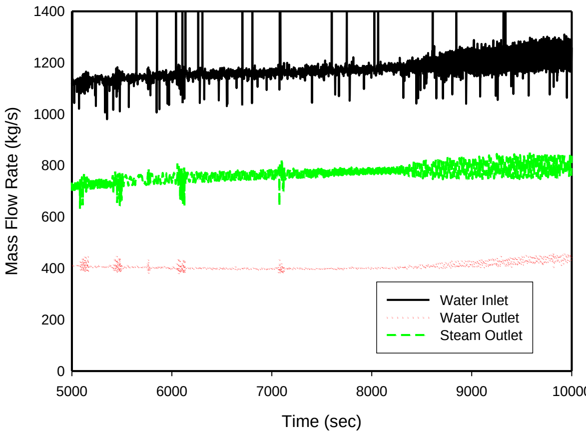

Fig. 4. RELAP5 results on the water circulation mass flow rate in the APR1400.

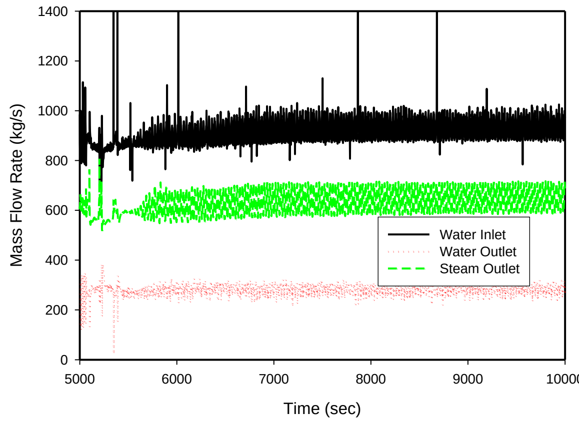

Fig. 5. RELAP5 results on the water circulation mass flow rate in the OPR000.

Table II: RELAP5 results on coolant mass flow rate

Ext. Water Temp.	Reactor Type	Coolant Mass Flow Rate (kg/s)		
		Water Inlet	Water Outlet	Steam Outlet
25 (^{o}C)	APR1400	1237.7	860.9	337.4
	OPR1000	892.2	540.1	352.9
50 (^{o}C)	APR1400	1319.4	981.7	338.0
	OPR1000	962.9	959.2	0.9
80 (^{o}C)	APR1400	1370.8	960.0	408.7
	OPR1000	998.6	998.6	0.2

4. Conclusion

Simulations of two phase natural circulation in the reactor cavity under the IVR-ERVC conditions have been performed for different reactor thermal powers. The RELAP5/MOD3 results have shown that the coolant circulation mass flow rate at high power is higher than that at low power. An increase in coolant injection temperature leads to an increase in coolant circulation mass flow rate, which leads to increase in CHF on the outer reactor vessel wall.

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] 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.